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Brain Activity Related with Mathematics Anxiety

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For the purpose of determining neurophysiological mechanism of math anxiety, we conducted an EEG measurement for 22 sixth grade elementary students including 11 students with high math anxiety (HMA group), and 11 students with low math anxiety (LMA group). We found that in HMA group, delta wave was significantly generated from the right frontal lobe, and in LMA group, four paths are clearly connected while they perform math tasks (right inferior occipital gyrus ↔ left superior parietal lobule /left middle frontal gyrus ↔ left inferior parietal lobule /left middle frontal gyrus ↔ right inferior parietal lobule /right middle frontal gyrus ↔ right inferior parietal lobule). According to the above results we suggest that math anxiety is related to emotions associated with pain, reduces working memory and has a negative effect on math performance

Keywords: mathematics anxiety, EEG, delta wave, brain connectivity, working memory
MESC Classification: C80
MSC2010 Classification: 97C30

1. INTRODUCTION

Anxiety refers to general feelings of uneasiness and distress about unspecified, uncertain, and often formless form of threat or danger (Zeidner & Matthews, 2011). The word anxiety probably derives from the Indo-germanic root “angh” which means to constrict, or to press shut (Tyrer, 1999). Anxiety is regarded as one of fundamental negative feelings along with anger, sadness, and hatred. When anxiety is associated with math performance, it is called “math anxiety”. Math anxiety is a negative emotional reaction to situations involving mathematical problem solving (Christina, Sarah & Menon, 2012).

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Math anxiety were first defined by Gough (1954) who created the term “math phobia” which means fear of mathematics that usually stems from unpleasant experiences in mathematics. While in psychology, anxiety is usually distinguished from fear which is focused on an immediate danger (Zeidner & Matthews, 2011), many studies have used the two terms interchangeably, and a study suggested that fear and anxiety have many similarities (Ohman, 2008). The Thesaurus of Educational Resources Information Center considers math anxiety, math fear, and math avoidance as synonyms.

Such anxiety is not necessarily detrimental. Sometimes, it can even be helpful because it can make a person to quickly respond to potential dangers. It is a so common feeling that if someone does not experience it, that can be rather a maladjustment (Andrew, 2003). Beck & Emery (1985), however, identified “anxiety paradox” that the same cognitive-motivational systems that evolved to protect the individual from getting into harm’s way may become twisted and misdirected so as to work against the person. While in most cases, appropriate level of anxiety can lead to an action to solve a problem; excessive anxiety can lead to deterioration of the problem (Choi, 2012).

As for math anxiety, it undermines performance on math tests by disrupting the processes involved in developing problem solving strategies to apply to math problem (Ashcraft, 2002). We also know that in a calculation test, high level of math anxiety lowers the level of working memory, disrupting various processes including storing information in long-term memory and retrieving it, as well as evaluating and judging stimulus (Ashcraft & Kirk, 2001). In addition, math anxiety can often hinder the successful completion of tasks involving manipulation of numerical information, and is a prominent cause of problem-solving difficulties across the all mathematics-related fields. (Ashcraft & Krause, 2007; Suinn, Taylor & Edwards, 1988; Wigfield & Meece, 1988).

It was found out that math anxiety is widely experienced by the first grade elementary students (Ramirez & Beilock, 2011), and the detrimental effect of math anxiety on mathematical development is lifelong (Bynner & Parson, 1997; Rubinsten & Tannock, 2010). Considering these findings and brain plasticity, it is important to conduct studies on math anxiety in young students. Even behavioral studies of adults reported that math anxiety has a negative effect on performance of basic numerical operations such as counting, addition, and subtraction (Ashcraft & Ridely, 2005; Maloney, Risko, Ansari & Fugelsang, 2010). It was also found that math anxiety hinder the successful performance of numerical comparison task (Maloney, Risko, Ansari & Fugelsang, 2010) and of addition task involving the carrying operation (Ashcraft & Kirk, 2001), as well as of multi-phase arithmetic calculation (Mattarella-Micke, Mateo, Kozak, Foster & Beilock, 2011). Furthermore, a research reported that math anxiety has a negative effect on mathematical skills, which leads to adverse effects on career choice, employment, and professional success (Ma, 1999). Like this, math anxiety is regarded as a widespread phenomenon affecting student math performance across the globe (Jain & Dowson, 2009; Lee, 2009), but its precise developmental origins are not known (Rubinstein & Tannock, 2010).

In one of the many studies to identify the mechanism of math anxiety which has a negative effect on mathematical performance, Ashcraft & Kirk (2001) found that math anxiety is not associated with individual mathematical functions but with working memory. In other words, anxiety reduces the working memory capacity, causing a poor math performance. According to a study by Vukovic, Kiffer, Bailey & Harari (2013), math anxiety may affect how some children use working memory resources to learn mathematical applications. In addition, Ramirez, Gunderson, Levine & Beilock (2013) found a negative relation between math anxiety and working memory and argued that early identification and treatment of math anxieties is important because early anxieties may eventually lead students with a high potential working memory to avoid mathematics.

Studies on math anxiety can be expanded like this mainly because with a recent advancement of cognitive science, various brain imaging techniques were introduced, and such cognitive neuroscience techniques allowed quantitative and positive analysis which makes up for the weakness of cognitive psychology researches (Hansen & Monk, 2002). Some researches on math anxiety using cognitive neuroscience techniques reported that children with high math anxiety would show decreased engagement of the intraparietal sulcus and dorsolateral prefrontal cortex [DL-PFC] regions typically associated with mathematical cognition in children (Ansari, 2008; Rivera, Reiss, Eckert & Menon, 2005), and Suarez-Pellicioni, Nunez-Pena & Colome (2013) found, using EEG, that math-anxious individuals experience difficulties in controlling the expansion of information unrelated to problem-solving.

At the early stage of brain study, researchers on cognitive functions using brain imaging equipment such as EEG, fMRI, and PET were mainly based on functional specialization principle (Price & Friston, 1997), and recently they have been developed toward functional integration principle to identify how regions are connected (Lee & Kwon, 2011).

A recent study by Young, Wu & Menon (2012) tried to identify the neurobiological mechanisms underlying math anxiety for the first time, using the effective connectivity analysis based on functional integration principle. This study found that math anxiety was associated with hyperactivity of right amygdala regions that are important for processing negative emotions, as well as with reduced activity of posterior parietal and dorsolateral prefrontal cortex (DL-PFC) involved in mathematical reasoning. Furthermore, effective connectivity between amygdala and ventromedial prefrontal cortex regions that regulate negative emotions was elevated in children with high math anxiety. Another functional MRI study using effective connectivity analysis suggested that math anxiety cause a response in the brain similar to physical pain (Lyons & Beilock, 2012a; 2012b). This study examined connectivity between brain regions, and found that dorso-posterior insula (INSp) and mid-cingulate cortex (MCC) were activated in HMA individuals before solving difficult mathematics problems, and that the higher the math anxiety was, the more activated these regions were. Dorso-posterior insula controls emotions associated with pain (such as uneasiness) and identifies location and intensity of pain (Decety, 2011), and a part of mid-cingulate cortex is known to be functionally and anatomically connected to posterior insula (Taylor, Seminowicz & Davis, 2009). Given that these areas are activated when people feel hurt due to social rejection (Kross, Berman, Smith & Wager, 2011), we can assume that individuals with high math anxiety can feel pain and uneasiness with just anticipation of solving a math problem even before actually solving it. Another study identified two emotional impediments to mathematical achievement, namely math anxiety and stereotype, and suggested that they shared a common underlying mechanism (Maloney, Schaeffer & Beilock, 2013).

Based on these existing studies which tried to identify neurobiological mechanisms and causes underlying math anxiety, this study aims to find additional neurobiological mechanisms by examining what difference in brain wave activity are shown between HMA and LMA individuals.

Considering young ages of subjects, non-invasive EEG was used which measures brain behaviors relatively directly, and has high temporal resolution (Baars & Gage, 2007). Data obtained through EEG measurement were analyzed with cross spectrum method to see how different the brain-activation patterns are between the two groups. In addition, lagged coherence was used to see functional connectivity among brain areas in the low math anxiety group.

2. METHODS

This study was undertaken after its ethical and scientific feasibility was deliberated and approved by the Institutional Review Board of Korea National University of Education on October 21, 2013 (Industry-Academic Cooperation Foundation of KNUE-3240).

2.1. Subjects

For the purpose of selecting subjects, math anxiety tests were carried out for 114 sixth grade students from one selected class for each of G, D, Y, and L elementary schools located in D Metropolitan City who had normal eyesight in both eyes without history of mental disorder and brain-related disease. As a tool for the test, this study use ANX-MAT Scale which was developed by Choi (1988) by adapting math anxiety rating scales

(MARS) developed by Aiken (1976), and Richardson & Suinn (1972) to Korean culture and language. Its Cronbach's alpha coefficient is .951 for math content and .894 for math evaluation. This scale was composed of total 20 items including 14 ones to measure Learning Math Anxiety associated with math content (e.g. I feel anxiety when see graphs and charts on the math textbook; I feel anxiety when I see new math formula or signs, etc.), and six ones to measure Math Evaluation Anxiety associated with math evaluation (e.g. I feel anxiety when my math teacher gives math questions; I feel anxiety when I prepare for a math exam, etc.).

In addition, in order to control difference in functions of cerebral hemispheres depending on gender and handedness (Kim, Kim & Kwon, 2005) and difference in brain activation (Hamann & Canli, 2004), Edinburgh Handedness Test (Oldfield, 1971) was conducted and thus 93 right-handed students (34 males/59 females) who accounted for highest proportion were selected.

Sufficient explanation was provided for them about principles of EEG measurement, and purpose of this study, as well as potential benefits and risks of the participation in the study. Out of 22 students who expressed willingness to participate in the study, 11 students with math anxiety score of 60 and over were assigned to High-Math-Anxiety (HMA) group and remaining 11 students with math anxiety score of less than 60 to Low-Math-Anxiety (LMA) group. Mean age of the selected subjects was 12 years (0.2), and HMA group was composed of 6 male and 5 female students, while LMA group consisted of 7 male and 4 female students.

Since the study participants were sampled from different populations, t-test for Two Independent samples was conducted to compare averages of the two samples (Seong, 2007), and SPSS 12.0 program was used for data analysis. The Levene's Test for Equality of Variances between HMA ($n = 11$, $m = 93.36$, $sd = 3.529$, standard error of mean = 1.064) and LMA ($n = 11$, $m = 29.64$, $sd = 3.075$, standard error of mean = .927) yielded a significance probability of .372, which does not refuse null hypothesis that population variances of two groups are equal, and thus equal variance assumption of HMA and LMA was met. In addition, T-test for Equality of Means yielded a significant difference of 63.727 ($t = 45.155$, $df = 20$, standard error of difference = 1.411) in average values between HMA and LMA groups. Therefore, HMA and LMA were proved as heterogeneous groups which had a statistically significant difference for $p < .001$.

After the completion of math anxiety test, sufficient explanation was provided for the 22 subjects about principles of EEG measurement, and purpose of this study, as well as potential benefits and risks of the participation in the study, in order to select subjects who would agree to participate in the EEG measurement. All of the 22 subjects expressed their voluntary willingness to participate in the study, and signed the study participation agreement.

2.2. Tasks

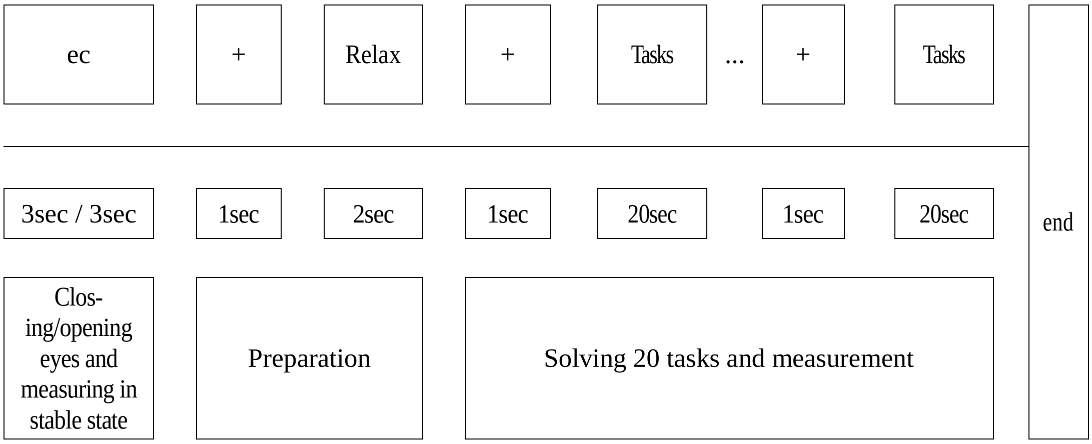
For the purpose of selecting questions for task paradigm development, a preliminary question development team was organized of total 5 members including 2 elementary math education experts and 3 EEG experts. The team selected the first questions thorough 4 rounds of discussions. In selecting and organizing questions, all numerical areas including natural, decimal, fractional numbers, as well as the four fundamental arithmetic operations were included because if they were confined to a specific part of "number" area, that would cause difficulty in generalizing the study findings as well as in excluding task-specific phenomena.

Preliminary tests were conducted for the sixth grade students from Y elementary school in Gyeonggi Province in order to measure reaction time to selected questions and check whether the questions are appropriate for EEG measurement. The results of preliminary test were discussed by the expert council of 6 members including 5 preliminary question developers and one university professor of mathematics, and as a result of the discussion, ultimately total 20 questions were selected (2 questions for addition of natural numbers, 2 questions for subtraction of natural numbers, 1 question for mixed calculation of natural numbers, 1 question for addition of fractions with the same denominator, 1 question for subtraction of fractions with the same denominator, 1 question for addition of fractions with different denominator, and 1 question for subtraction of fractions with different denominator, 1 question for addition of decimals, 1 question for subtraction of decimals, and 1 question for multiplication of decimals, 1 question for division of decimals, 1 question for mixed calculation of decimals, 2 questions for multiplication of fractions, 3 questions for division of fractions, and 1 question for mixed calculation of fractions (e.g. 86–14–4–9–10–6 =).

Task paradigm used for this study was developed using a block design. Measurement procedures are as follows:

- After the start of the measurement, subjects keep their eyes closed for 3 seconds and their brain waves are measured in the stable state;
- A blank screen is displayed for one second. Then, subjects stare at the instructions on the screen and relax again for 2 seconds.
- A blank screen is displayed for one second, and then arithmetic questions are presented on the screen. Twenty seconds are given to solve each question.

Therefore, a question takes total 21 seconds including 1 second for relaxing time, and 20 seconds of problem solving time. Because total 20 questions are presented, it takes 420 seconds to solve all of them during which data on subjects' brain activation is recorded. Therefore, total measurement time is 429 seconds including 3 seconds for measuring brain waves in the stable state, 3 seconds for pre-measurement preparation, and 420 seconds for solving 20 questions. Task paradigm for problem solving of this study is shown in Figure 1.



- Total time required: 429 seconds

Figure 1. Task Paradigm

2.3. Methods

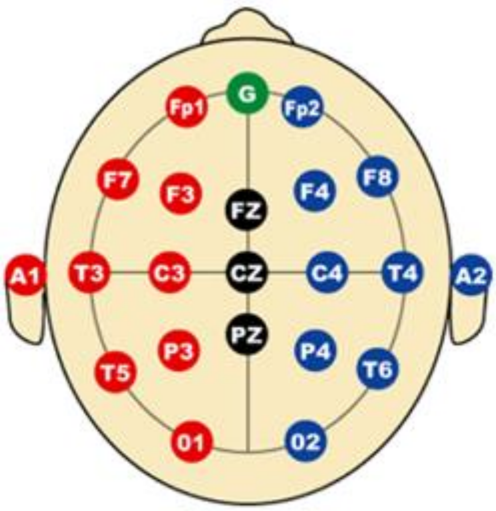
Considering young ages of subjects, non-invasive EEG was used which measures brain behaviors relatively directly, and has high temporal resolution (Barrs & Gage, 2007). Developed task paradigm for arithmetic questions was presented using the stream DX program. The process of collecting brain wave data was attended by the present researcher and two other colleague researchers, who played a role in recording singularities when subjects carry out tasks, and recording task progression in the computer where brain waves are recorded respectively.

For this study, twenty one Ag/AgCL electrodes including 19-channel BioSEMI EEG electrode sets (Ag/AgCI) and 2 reference electrodes were used. Measurement data were collected at the Korea Research Institute of Standards and Science (KRISS) and in order to secure accurate measurement, brain waves were measured in a shield room. As a prior preparation for the measurement, a non-magnetic junction box was installed to connect the electrode input box outside the shield room and EEG electrodes inside it. For the purpose of preventing high-frequency environmental noises from incoming from the amplifier to EEG electrodes, EEG wires were covered with shielding mash, and grounded on the magnetic shield room.

Before the measurement, skins of subjects were cleansed with Skin Pure, skin preparation gel to remove sweat and skin oil. After the measurement, the EEG electrodes were cleaned with ethanol and lukewarm water so as to maintain reliability of measurement and cleanliness.

As a brain waves collecting software, KRISSMEG AG152V2K reader was used. The equipment measures weak electrical signals from brains in the form of analog data and then converts them into digital data, enabling various analyses through computers and various software.

As for measurement location, electrodes were attached as shown in Figure 2, according to Ten-twenty electrode system, international electrode system (Klem, Luders, Jasper & Elger, 1999). Nineteen channels which are used as actual data and reference electrodes A1 and A2 to correct deviation of both cerebral hemispheres were deployed. Since measurement was conducted in a shield room within KRISS, ground electrodes were not used.



Channels	Number
Fp1	1
Fp2	2
F3	3
F4	4
C3	5
C4	6
P3	7
P4	8
O1	9
O2	10
F7	11
F8	12
T3	13
T4	14
T5	15
T6	16
Fz	17
Cz	18
Pz	19

Figure 2. Ten-twenty electrode system (Klem et al., 1999)

Disk-shaped electrodes with a hole at the center were attached on the scalps of subjects, and Elefix electrode paste from Nihon-Kohdon was used. Impedance between electrodes and scalps were kept 10kO and less, and alcohol or dedicated cleanser for EEG was used to lower the impedance when attaching electrodes.

When measuring brain waves, the sampling rate was set to 256 Hz, high pass filter at 0.1 Hz, and low pass filter at 70 Hz, and the measured data were collected across the entire range of brain waves. In order to eliminate 60 Hz noises induced by alternate current, 60 Hz notch filter was used.

Before actual measurement, after all electrodes were attached, subjects were provided with sufficient explanation about the entire process of EEG measurement through preliminary tasks, along with request to minimize movement which can affect brain waves while carrying out the tasks. Before the brain wave measurement during which subjects carry out tasks, their brain waves were measured in the stable state for 3 seconds with eyes closed, and stored as a basic brain waves. And then their brain waves were measured during solving arithmetic tasks. For one second immediately after each task was present, corresponding EEG data of 256 points were collected.

Using tKRISSMEG AG152V2K reader, out of the collected brain wave data, data in the 1-50 Hz range were selected through Band Pass FFT-filtering. It is a method to filter frequencies over 50 Hz so as to eliminate white noises and measurement noises, and find brain activation patterns during solving arithmetic tasks across the entire frequency band.

KRISSMEG AG152V2K reader was also used for preprocessing EEG data. Selective averaging by task was conducted to obtain frequency averages for all tasks with event selection. After frequency filtering, filtered signals are analyzed into power spectrums of brain wave through Fast Fourier Transform (FFT). This study conducted FFT through "Power Spectrum Estimation by FFT" provided by BrainMap-3D program. In addition, Independent Component Analysis (ICA) was conducted to remove noises such as eye-blinking, ECG etc. Each recording unit was stored separately for HMA and LMA groups.

For the purpose of analyzing difference in brain activation between HMA and LMA groups while the subjects solved the arithmetic problems, relative power spectrum analysis was conducted for delta band (1.0~3.9Hz), theta band (4.0~7.9Hz), alpha-1 band (8.0~9.9Hz), alpha-2 band (10~11.9Hz), betta-1 band (12.0~17.9Hz), betta-2 band (18.0~20.9Hz), betta-3 band (21.0~29.9Hz), and gamma band (30.0~50Hz) respectively, and then cross-spectrums were analyzed to obtain standard low resolution brain electromagnetic tomography (sLORETA) images.

Significance testing within and between HMA and LMA groups was conducted to compute statistical non-parametric maps (SnPM) with 5000 randomization on a voxel-by-voxel basis for all frequency bands.

So the null hypothesis "difference in brain activation between HMA and LMA groups does not exist for any part" would be refused if even one t value exceeds the threshold value for $p < .01$ determined by 5,000 runs of random sampling. In other words, voxels in Talairach space having a t-value exceeding the threshold value for $p < .01$ can be regarded as sources of current signals with statistically significant difference.

For this study, significance testing was conducted for all comparison pairs through random sampling process. In other words, statistical analysis was carried out to test significance within and between HMA and LMA groups for all frequency bands, and voxels with significant difference ($p < .01$) were represented as Talairach coordinates.

Statistical difference analysis was conducted using sLORETA in order to see what regions of the brain in particular are connected in the course of solving arithmetic problems. Before selecting regions of interest (ROI) for this purpose, seed points were selected based on the fMRI findings on arithmetic problem solving and activated brain regions.

A study was conducted by some researchers to see what areas of the brain are activated when abacus experts mentally calculate numbers rapidly and accurately. It showed that bilateral superior parietal lobule (BA 7) and bilateral middle frontal gyru (BA 6) were most predominantly activated while the abacus experts performed the 4-digit and 8-digit mental addition tasks (Yixuan, Bo, Wenjing, Mark & Yong-Di, 2012). Another study was conducted to see brain activation during addition and subtraction tasks in quiet and noisy backgrounds (Aini, Ahmad, Siti & Mazlyfarina, 2011). The study showed that attention and working memory were promoted when performing addition rather than subtraction tasks in noisy condition, and during the operations, bilateral inferior parietal lobule and left middle temporal gyrus were activated. Another study found that inferior parietal lobe was activated during numerical operations (Marie & Margot, 2010). Considering existing fMRI findings and the fact that tasks are displayed on the screen during the measurement, inferior occipital gyri associated with visual function were added, and thus ultimately eleven seed points were selected as shown in Table 1.

Table 1. Talairach coordinates for seed points

No.	Brain regions	Hemi-sphere	x	y	z
1	Superior parietal lobule	L	–26	–60	46
2	Superior parietal lobule	R	30	–62	44
3	Inferior parietal lobule	L	–44	–40	42
4	Inferior parietal lobule	R	38	–46	42
5	Inferior parietal lobule	R	46	–34	46
6	Middle frontal gyrus	L	–44	32	28
7	Middle frontal gyrus	R	40	34	22
8	Middle frontal gyrus	R	42	46	26
9	Inferior occipital gyrus	L	–28	–90	–10
10	Inferior occipital gyrus	L	–40	–74	–6
11	Inferior occipital gyrus	R	32	–88	–6

ROIs were determined around seed points and then lagged coherence analysis was conducted to see brain connectivity in LMA, using sLOREAT program.

3. RESULTS

The purpose of this study is to examine difference in brain activation patterns between

HMA and LMA groups during arithmetic tasks, and see functional connectivity between brain areas in particular while subjects in LMA perform arithmetic tasks. Thus, cross spectra analysis was conducted to see the difference in brain activation patterns between HMA and LMA groups, and lagged coherence analysis was carried out using sLORETA program to see functional brain connectivity in LMA, yielding following results.

3.1. Cross spectrum results

This study applied one-tailed test (A>B) in order to see brain activation patterns in HMA and LMA groups while performing arithmetic tasks (Extreme P=0.0156).

Table 2. Threshold value

Hypothesis Test \ P value	t(0.01)	t(0.05)	t(0.10)	Extreme P
One-Tailed (A>B)	14.477	11.316	9.882	0.01560
One-Tailed (A<B)	–13.747	–11.502	–9.921	0.29560
Two-Tailed (A<>B)	15.476	12.526	11.400	0.02920

In the table above, threshold values are 14.477 for t(0.01) and 11.316 for t(0.05) respectively. If you see the exceedance proportion tests in Table 3 for more precise examination, you can find out that threshold value is 13.145629 for the lowest p value (0.015400) of One-Tailed (A>B) (shaded sections in Table 3).

Table 3. Exceedence proportion tests

Thrsh. (1Tailed > 0)	Prob. (1Tailed > 0)	Thrsh. (1Tailed < 0)	Prob. (1Tailed < 0)	Thrsh. (2Tailed)	Prob. (2Tailed)
1.314563	0.029200	–0.719615	0.019600	1.314563	0.031000
2.629126	0.044400	–1.439229	0.078000	2.629126	0.046800
3.943689	0.046400	–2.158844	0.052400	3.943689	0.072800
5.258252	0.044200	–2.878458	0.092600	5.258252	0.076000
6.572814	0.051400	–3.598073	0.148600	6.572814	0.094400
7.887377	0.034200	–4.317688	0.206000	7.887377	0.071000
9.201941	0.043200	–5.037302	0.262200	9.201941	0.087400
10.516503	0.035600	–5.756917	0.278400	10.516503	0.071200
11.831066	0.023000	–6.476531	0.288800	11.831066	0.045200
13.145629	0.015400	–7.196146	0.295600	13.145629	0.029000

Based on the statistical data abo–e, if significant range is set approximately from p = 0.0154 (13.145629) to p = 0.0514,

p = 0.05 range can be found in the threshold values of roughly 7 and above (boxed sections in Table 3).

Table 4 shows normal-MaxStatistics data to see the difference in brain wave activation between HMA and LMA groups for each frequency band.

Table 4. Normal-MaxStatistics data

Frequencies		normal-MaxStatistics
Delta	1.5 ~ 6Hz	7.683750E+0000
Theta	6.5 ~ 8Hz	2.676836E+0000
Alpha 1	8.5 ~ 10Hz	5.150557E-0001
Alpha 2	10.5 ~ 12Hz	–1.245118E+0000
Beta 1	12.5 ~ 18Hz	–7.092664E-0001
Beta 2	18.5 ~ 21Hz	–1.195535E-0001
Beta 3	21.5 ~ 30Hz	–5.058988E-0001
Omega (all)	1.5 ~ 30Hz	1.314562E+0001

Analysis based on statistical data above reveals that for the delta frequency band (1.5 ~ 6Hz), normal-MaxStatistics value is 7.683750E+0000, indicating significant difference because it is above the threshold of 7. That indicates that more delta wave is generated in HMA group than in LMA group. On the other hand, in theta, alpha, beta bands, no statistically significant difference was not observed. In the all frequency bands ranging from 1.5 to 30Hz, significant difference of 1.314562E+0001 was observed solely due to delta wave generation.

In order to trace the location of delta wave signal sources, sLORETA program was used to analyze signals across the all frequency bands ranging from 0.1 to 50Hz (Value= 1.31E+1), using MNI codes. As shown in Figure 3, a lot of delta wave was generated at the point where X coordinate is 10, Y coordinate is 65, and Z coordinate is 20X.

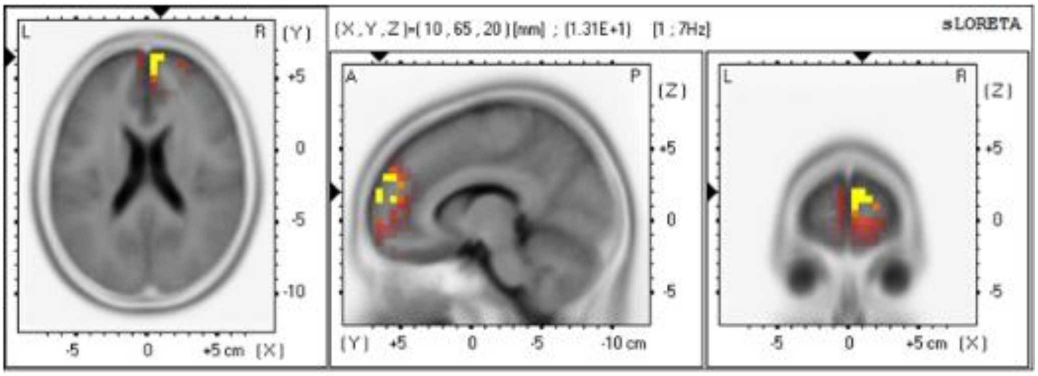


Figure 3. Area where HMA and LMA groups show significantly different activation for delta wave band.

As shown in the Figure 4, the location of signal sources was found using MNI codes around the area much more activated for the delta band in HMA groups than in LMA.

Right Frontal Lobe
BA 10 and 11

Figure 4. Location of signal source where significantly activated frequencies were generated for delta band in HMA

In other words, in right frontal lobe (BA 10 and 11), delta wave is more predominant in HMA group than LMA group. This region is located in front of the frontal lobe and thus also known as prefrontal lobe, along with BA 9. It is the most lately developed cortex associated with motion which controls behavior and motion based on higher mental functions such as judgment and prediction (Baars & Gage, 2007). Figure 5 shows the locations viewed from above, behind, the left, below, front, and the right.

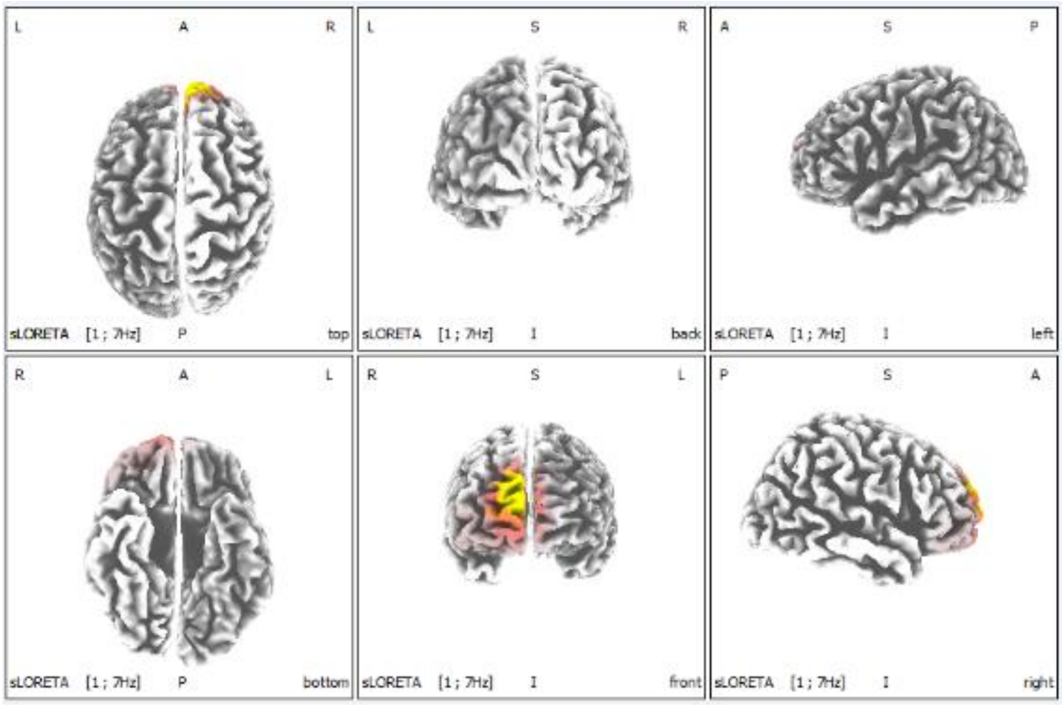


Figure 5. Locations of Delta wave signal sources viewed from six directions.

3.2. Lagged coherence results

Lagged coherence analysis to see connectivity between selected ROIs around seed points yielded results as shown in Table 5, and identified connectivity among 7 points in LMA.

Table 5. Connectivity paths among brain regions in LMA

Division	Connectivity paths among brain regions	
Connectivity 1	No. 11: R-inferior occipital gyrus (32, –88, -6)	No. 1: L-superior parietal lobule (–26, -60, 46)
Connectivity 2	No. 6: L-middle frontal gyrus (–44, 32, 28)	No. 3 : L-Inferior parietal lobule (–44, –40, 42)
Connectivity 3	No. 6: L-middle frontal gyrus (–44, 32, 28)	No. 5 : R-inferior parietal lobule (46, –34, 46)
Connectivity 4	No. 8 : R-middle frontal gyrus (42, 46, 26)	No. 4 : R-inferior parietal lobule (38, –46, 42)

Using sLOPRETA program, data in <Table 5> can be represented as in Figure 6 which shows brain connectivity of 7 points across the all frequency bands (0.1~50 Hz) while subjects performed arithmetic tasks. We can know that middle frontal gyrus in the left hemisphere is connected to inferior parietal lobules in both hemisphere.

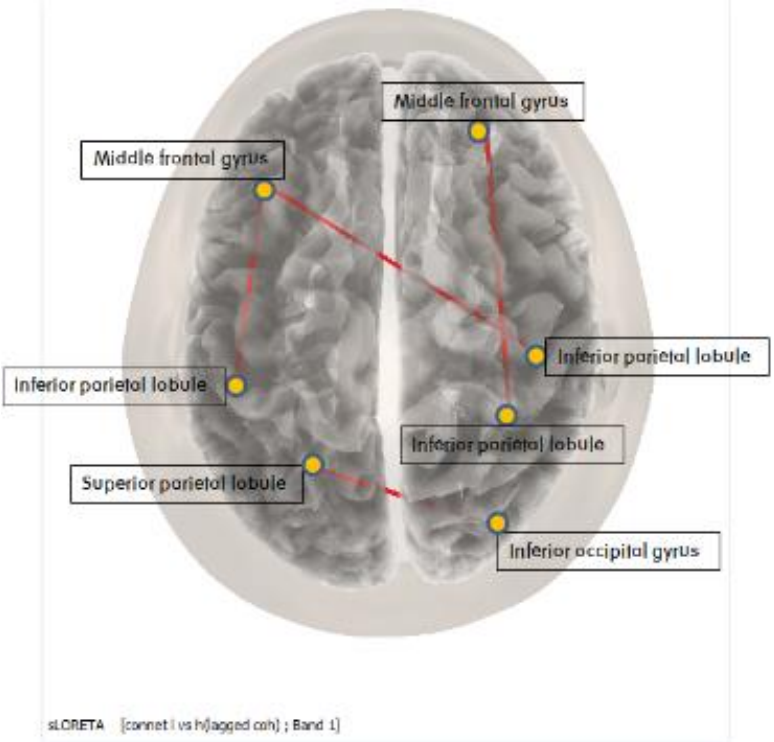


Figure 6. Brain connectivity in LMA

4. DISCUSSION

This study found that more delta wave was generated at the right frontal lobe in the HMA group, compared to LMA group, while they perform arithmetic tasks. In the case of LMA group, brain connectivity was identified among 7 points along 4 paths (R-inferior occipital gyrus ↔ L-superior parietal lobule /L-middle frontal gyrus ↔ L-Inferior parietal lobule /L-middle frontal gyrus ↔ R-inferior parietal lobule /R-middle frontal gyrus ↔ R-inferior parietal lobule). The points of discussion in this study are as follows.

4.1. Brain activation patterns of HMA and LMA groups

First, as for the alpha wave, both HMA and LMA groups show no significant difference, and they are prominently lowered in both groups while they performed math tasks. This observation is consistent with the report by Gevin (1997) that alpha wave was a stable wave generated mainly in relaxed mental states, and cognitive performance causes alpha blocking. Therefore, we can know that there is no difference in brain wave activation associated with cognitive performance between two groups.

Second, both HMA and LMA groups show no significant difference in beta wave as well. Relative power of the beta wave increased similarly during problem-solving in both groups, showing no significant difference between them. Such increase in relative power of beta wave (a fast wave) when subjects performed tasks indicates that large amount of nerve cells are activated during the time. It may be because, as potentials generated from each nerve cell are offset asynchronously, fast waves with lower amplitude and higher oscillation frequency are generated (Lee, Sin, Choi, Park & Kwon, 2004). It is consistent with the study findings by Fairclough, Venables & Tattersall, (2005) that beta wave increases when individuals perform tasks requiring attention than in stable states.

Third, this study found that across the all frequency bands, delta wave is predominant in the right frontal lobe of HMA group. Delta wave is called a slow wave which is considered an abnormal wave (Jeong, 2007). As slow wave is normally generated during sleeping but, unlikely fast wave, rarely appears in adults awake, it is the slow wave that is important in reading brain waves (Jeong, 2007). It can be considered a temporary phenomenon due to EEG measurement because the delta wave can be generated by eye-blinking, muscle tension, eyeball exercise and eyeball muscle tension. Considering that the delta wave appears with significant difference in HMA group, compared to LMA, while they tried to solve problems, we can know that the subjects experience intense stress and psychological anxiety.

It is in line with the study finding that the brain reaction prompted by math anxiety is similar to the one we have when we experience physical pain (Lyons & Beilock, 2012a; 2012b). Delta wave is a brain wave generated together with pain, for example, when we have a migraine. In other words, when students experience math anxiety, they feel not only emotional and mental uneasiness, but also physical pain, the same kind of headache. Pain is an unpleasant sensory or emotional experience associated with actual or potential tissue damage or described in terms of such damage (IASP, 1994). Therefore, pain is a subjective experience that occurs only in consciousness (Bond, 1976) and a mental state (Andrew, 2003). As it is not external symptoms but subjective experience that matters in pain, it may be a suitable study subject for phenomenologists (Andrew, 2003). As an explanation about cause of pain, “Choice Theory” argues that we choose to feel pain as a breakthrough to solve the present problem (Lee, 2011). The theory developed by William Glasser (MD, psychiatrist, 1925~2013) explains that relationship problem can be expressed as pain. In order words, people have no choice to feel pain when human desires such as desire for power, love, and sense of belonging are not satisfied and headache, for example, a signal to relieve many emotions such as fear, sadness, anger, surprise, depression, and worry. His argument tells us that most important is that the students themselves get rid of stress and fear about mathematics and 'choose' to feel that mathematics is not difficult.

4.2. Brain connectivity in LMA group when they solve arithmetic problem

The study found that in LMA group, clear brain connectivity was identified among 7 points along the 4 paths. It means that LMA group can solve arithmetic problems well, using the close brain networking. That is consistent with existing fMRI study findings that bilateral superior parietal lobe and bilateral middle frontal gyrus regions are activated while performing addition task (Yixuan, Bo, Wenjing, Mark, & Yong-Di, 2012). In addition, it is in line with the study finding that bilateral inferior parietal lobules are activated while solving addition and subtraction problems (Aini et al, 2011). Now, let's discuss each of paths which show brain connectivity in detail.

First, connectivity was identified between the right inferior occipital gyrus and the left superior parietal lobule. The right inferior occipital gyrus, a brain region corresponding to Brodmann are BA 18, is associated with visual function, and activated early when subjects stare the screen (Baars & Gage, 2007). The left superior parietal lobule (BA 7) is a Somatorsensory Association Cortex region (Brodmann, 1909). Connectivity in this area means that they are connected via a dorsal stream which is known to be activated while performing visual tasks involving intentional visual tracing such as observing moving objects and exploring the location of an object (Goodale & Milner, 1992; Goodale & Humphrey, 1998). Therefore, LMA group subjects can concentrate well on tasks involving visual activity.

Second, connectivity was also identified between the left middle frontal gyrus and the left inferior parietal lobule. The third connectivity was shown between the left middle frontal gyrus and left middle frontal gyrus. The latter corresponding to BA 46 is connected to two areas, and also known as dorsolateral prefrontal cortex (DL-PFC) (Brodmann, 1909). It belongs to a frontal lobe and, at the same time, to a prefrontal lobe which plays the most important role. The left middle frontal gyrus is associated with working memory (Baars & Gage, 2007). Working memory is the system to recall information consciously within a short period of time. This working memory system is stored in BA 46, and the memory is saved again in BA 8 specialized for unconscious motion and tension. The more trained this part of the brain is, the more developed it is. DL-PFC is at the highest part of the prefrontal lobe, and functions to store short-term working memory of brain. This region is engaged in decision-making related to human behavior, grasping the situations related to decision-making and developing strategies. Since people with developed DL-PFC are known to is wise and make rational decisions, the brain region is also called "brain of the rich" (Aubele, Freeman, Hausner & Reynolds, 2011).

DL-PFC plays a key role in working-memory. The correlation between prefrontal cortex and short-term memory has been known since the 1930s (Baars & Gage, 2007). It was observed that when DL-PFC delay-period activity is weak, there is a greater likelihood of forgetting (Funahashi, Bruce & Goldman-Rakic, 1993), and that the lesions to the DL-PFC impair short-term working memory (Fuster, 1997). That means that DL-PFC plays a role as a cause of working-memory. In addition, working memory is closely related to key roles of the frontal lobe such as organizing behaviors based on time and manipulating the proper sequence of various mental activities for the purpose of life (Fuster, 1985). Deficiencies related to anxiety generally impair attention and working memory. These performance deficiencies are often attributed to high levels of worry and cognitive interference, (Cassady & Johnson, 2002; Sarason, Sarason & Pierce, 1995) or to loss of functionial working memory (Ashcraft & Kirk, 2001). Studies about math anxiety and working memory showed that high math anxiety have a negative effect on working memory, impeding cognitive processes, and dropping mathematical performance (Ashcraft & Krause, 2007). Vukovic et al (2013) also found that math anxiety affects how we use working memory which is a source in learning mathematical applications. Ramirez et al (2013) also found a negative relation between math anxiety and working memory. The fact that in LMA group, the connectivity involving the left middle frontal gyrus, known as DL-PFC was identified indicates that the lower math anxiety is, the less influenced working memory is, contributing to mathematic performance.

The left inferior parietal lobule is a region corresponding to BA 40 (Brodmann, 1909) and a supramarginal gyrus part of Wernicke's area. This region is not only associated with language, but also activated when numbers are used and calculation is performed according to a recent study using fMRI (Arsalidou & Taylor, 2011). Therefore, LMA group students use information from the left middle frontal gyrus to solve arithmetic problems in left inferior parietal lobule. The right inferior parietal lobule belongs to BA 40, like the left inferior parietal lobule (Brodmann, 1909). Our observation is consistent to a fMRI study finding that the right inferior parietal lobule, and the left inferior parietal gyrus were activated are activated when addition tasks are performed (Aini et al, 2011).

Therefore, we can know that LMA group students use related brain regions to solve arithmetic tasks including addition, subtraction, and multiplication.

Finally, brain connectivity between the right middle frontal gyrus and right inferior parietal lobule were identified. The right middle frontal gyrus belongs to BA 10 (Brodmann, 1909) and a DL-PFC, along with the left middle frontal gyrus. BA 10 region corresponds to the forehead area, and is developed the most in the current mankind. It is a brain region related to abstract abilities such as planning and imagining (Baars & Gage, 2007). Therefore, we can know that LMA group subjects use the DL-PFC related to working memory to develop a plan for problem solving and retrieve information, and use the inferior parietal lobules of the both hemispheres to solve the arithmetic problem.

LMA students showed clear brain connectivity among 7 points along 4 paths while they solve arithmetic problems, which indicates that they can solve the problems well, using their close brain networking. That is consistent with existing fMRI study findings that bilateral superior parietal lobe and bilateral middle frontal gyrus regions are activated while performing addition task (Yixuan et al, 2012) and that middle frontal gyrus is a DL-PFC related to working-memory which is associated with math anxiety (Ashcraft & Kirk, 2001; Ramirez et al, 2013; Vukovic et al, 2013). In addition, it is in line with the study finding that bilateral inferior parietal lobule and left middle temporal gyrus are activated while solving addition and subtraction problems (Aini et al, 2011).

In summary, more delta wave is generated in right frontal lobe of HMA individuals, compared to LMA individuals, which indicates that when we encounter math tasks, we take the uneasiness as a unpleasant experience similar to pain. With such difference alone, it was found that LMA students showed clear brain connectivity along 4 paths while they solve arithmetic problems, compared to HMA students who expecially showed no connectivity involving DL-PFC related to working memory which plays an important role in mathematic performance. Such observation is in line with existing study findings that math anxiety has a negative effect on DL-PFC, impeding mathematical performance (Ashcraft & Kirk, 2001; Ramirez et al, 2013; Vukovic et al, 2013).

As mentioned in Introduction, anxiety is not always detrimental, and sometimes it can even be helpful because it can make a person to quickly respond to potential dangers. It is a so common feeling that if someone does not experience it, that can be rather a maladjustment. (Andrew, 2003). A study (Lyon & Beilock, 2011) found that not all of people with high math anxiety have shown poor mathematical performance, in some of them, brain regions associated with mathematics are highly activated (Lyon & Beilock, 2011). Therefore, it is expected that if we regard math anxiety as a common emotion anyone can experience in the face of mathematical tasks, not as fearful thing which impede mathematical performance and take it as a stimulus to make us prepare and challenge, we can overcome it and achieve successful mathematical performance.

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