Differences in Neural Current Sources of Science Gifted and Normal Children in Creative Reasoning

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과학 영재와 일반아의 창의적 추리과정 시 나타나는 신경 전류원의 차이

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국문초록

본 연구에서는 과학 영재와 일반아의 창의적 추리과정시 나타나는 두뇌사고 패턴을 sLORETA 분석 기법을 통해 분석하고, 신경생리적 특성을 파악하여 과학 영재아 판별의 기초와 활용 가능성을 알아보는 것이다. 본 연구를 위한 대상자는 과학영재아 6명과 동일 학군 및 학년에 속한 일반아 6명으로 총 12명의 오른손잡이로 하였다. 창의적 추리과정을 위해 사용된 과제는 레이븐 도형점진행렬검사를 사용하였고, 안정상태와 과제 수행간 뇌파를 측정하였다. 뇌파는 19개의 전극을 통해 수집된 16초간의 데이터를 통해 분석하였으며, sLORETA 분석 기법을 통해 8개의 주파수 대역(Delta, Theta, Alpha-1/2, Beta-1/2, Gamma, Omega)에 대한 평균 전류밀도값을 그룹별로 비교하였다. 그룹간 두뇌 활성 주파수 대역을 비교한 결과 눈감고 안정 상태에서 과학영재아가 일반아에 비해 알파-2 대역에서, 레이븐 과제 수행시 과학영재아가 일반아에 비해 알파-1과 감마 대역에서 강한 활성이 관찰되었다. 연구 결과 나타난 알파 및 감마 대역 활성과 우반구로의 기능적 편측화(Lateralization)는 창의적 문제 해결시 영재아에게 나타나는 대표적 특성 중 하나이며, 배외측전전두피질(DLPFC)의 활성은 과학영재아의 높은 유동지능을 반영하는 결과라 볼 수 있다.

주요어 : 창의적 추론, 유동지능, 과학영재, 뇌파

I. INTRODUCTION

Gifted child as a person of having an excellent solving ability of creative problems by efficiently demonstrating scientific thinking process through utilization of scientific knowledge and research function may be considered to be outstanding in generating ability for a new knowledge (Kwon, 2005; Kwon *et al*., 2007). Development gifted human resources having sophisticated creativity and problem solving ability could be achieved through discovery of gifted children and education for them (Lee, 2010). However, as interference of private education is intensified together with increased social concern over education for gifted children, verification for feasibility of selecting gifted children is more extensively required in reality (Kim, 2006).

Under this background, diversified attempts to determine selection of gifted children by evaluating cerebral neurologic ability are under progress (Choi & Gang, 2006; Jin *et al*., 2007; Kwon *et al*., 2007; Liu

This work was supported by the National Research Foundation of Korea Grant funded by the Korean Government (NRF-2014S1A5B5A02017406).
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et al., 2008). In particular, a method of measuring human cerebral function by using brain wave has advantages in terms of the fact that noninvasive safety could be secured (Kim & Choi, 2001) and cerebral function could be quantified and analyzed objectively through diversified analytic methods (Kwon *et al*., 2007; Neubauer *et al*., 2004). However, the objective of all of these researches was mostly to confirm features of brain wave by its frequency or difference in neural current sources being represented in scalp like preceding studies (Doppelmayr *et al*., 2005; Liu *et al*., 2008) that were intended to confirm processing of recognized thinking or correlation with intelligence through brain wave. This analysis may confirm quantitative information of bran wave being observed in scalp but it is very hard to identify an interrelationship between actual internal cerebral activation area and signal current sources (Pascual-Marqui, 2002).

Recently, owing to analysis technique of sLORETA (Standardized Low Resolution Brain Electromagnetic Tomography) being suggested by Pascual-Marqui (2002) doctor group, reliability of current density reconstruction of neural current source in internal brain could be promoted through brain wave data. Therefore, in this study, basic information (a foundation) for determining gifted children and its utilization possibility by analyzing brain thinking pattern being represented in a process of creative reasoning of gifted and normal children through sLORETA analysis technique and identifying neurophysiological features was intended to be explored.

II. METHODS AND MATERIALS

1. Participants

Total 12 healthy volunteers (mean age = 13.2 years; males) including 6 gifted children belonged to education institute for gifted children of provincial education office being selected through multiphasic identification of gifted children and 6 normal children belonged to same school district and grade were targeted for this study and normal students were composed of students whose academic achievement level was fair in their class.

In addition, in order to eliminate deviation in gender ratio, each 3 persons of different sex were composed per each group and only persons of right-hander were targeted for this study through Edinburgh Handedness Inventory (Oldfield, 1971). Edinburgh Handedness Inventory that is to confirm which side hand is mainly used through 10 kinds of motion being frequently performed in a daily life comprises 10 question items. All those subjects who did not have psychiatric and family history participated in this study voluntarily. Considering their status of minor, this test was performed only for the students who received consent form from their parents and letter of recommendation from their teachers and before performing measurement of brain wave, the students were informed of general explanation for EEG, noninvasive features and directions for measurement.

2. Methods

1) Creative Reasoning tasks

In this study, brain thinking pattern being represented in a process of creative reasoning of gifted and normal children was intented to be explored. The task used for creative reasoning process was Raven's progressive matrices test which is a countercultural intelligence test method that reasons figure relationship (Raven *et al.*, 1998). In addition, Raven's test as a sophisticated cognitive ability test that measures fluid intelligence comprises question items requiring ability of reasoning complicated relationships rather than identification of simple contents of information (Cattell, 1963; Horn, 1985). 3 types of task corresponding to the same level of difficulty among total 60 standardized question items (Ha *et al*., 1999) comprising figure, line and non-linguistic pattern were selected and presented.

Presented task was directed to select one of the 8 figures in which a figure to be entered into last space was presented as an example after reasoning relation pattern from various figure stimulations (Fig. 1).

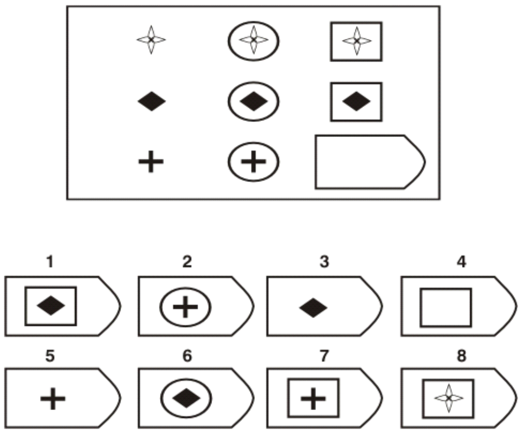

Fig. 1. Raven's progressive matrices test

The task was printed in A4 paper and presented by coating it with dim film sheet. Before presenting this Raven task, rules of the task was explained through similar question items and main task for EEG measurement was presented after preliminary task.

2) EEG recording and processing

In this study, evoked potential (EP) was measured by using E-series EEG system (Compumedics) and for collection of EEG data, E-series (Ver 3.4 Release) was used. Location of EEG measurement comprised 19 channels including Fp1/2, F3/4, C3/4, P3/4, O1/2, F7/8, T3/4, T5/6, Fz, Cz, Pz based on Jasper(1958)'s 10~20 electrode system that is international electrode displacement system. Electrode system montage confirmed the current induced from each channel by using monopolar induction mode that measures potential between specific electrode and reference electrode, contrary to bipolar induction mode that is mainly used for detecting lesion between electrodes (Fehmi & Collura, 2007).

The sampling rate was 256Hz, high pass filter maintains 0.1Hz, low pass filter 70Hz, respectively, data was collected within the range being used for most of EEG analysis. In addition, in order to remove commercial A/C artifacts by induction, 60Hz was applied for Notch filter. In order to minimize diversified artifacts that may be mixed during EEG measurement, condition of test subjects was frequently confirmed so that their resting condition would be maintained to maximum and by indicating specific points in individual record sheet, it was referenced for analysis. Spontaneous background wave being measured under eyes closed/open resting condition was used for identifying test subjects relevant to normal EEG range and any test subjects showing abnormal brainwave were excluded from the study.

As Raven task is a visual observation task, artifacts of low frequency band of diversified forms relevant to ocular and muscular movement are likely to be mixed. Electrooculogram (EOG) such as eye-blink or eye movement, electromyogram (EMG) being generated when putting one's brain to work or moving hand or foot and electrocardiogram (EKG) representing heartbeat are typical artifacts and these wave may exert a serious influence on the analysis result of EEG. In this study, in order to remove diversified mixed artifacts, independent component analysis (ICA) was used. Contrary to the existing studies in which low frequency band (0.1~3Hz) commonly included in brainwave band was completely removed through high pass filtering, analysis was made to be enabled in the total bands of brainwave frequency.

In case of test subjects whose impedance value is high, impedance value between scalp and electrode was maintained below 10KΩ by using EEG skin preparation gel (Nuprep gel). Its mild abrasive formula improves conductivity and helps achieve maximum efficiency with EEG equipment. By informing basic information and attentions for brainwave before measurement, psychological resting condition of the test subjects was made to be maintained and features and mode of Raven task were explained to them through preliminary task. EEG measurement was performed in an isolated room that may block outside noise while maintaining a constant illumination.

Paradigm of presented task was progressed based on 3 Raven tasks after measuring background wave under the resting condition of eyes closed/open. After one Raven task was finished, break time of 3 minutes was provided. EEG was collected for more than 1 minute at every stage and 4096 (256Hz) data points of data being collected for 16 seconds per each stage were used for its analysis.

3) Independent Component Analysis (ICA)

ICA is one of Blind Source Separation (BSS) methods and in this study, Matlab-based source to which InfoMax algorithm was applied was used (Lee, 1998). As EEG data is measured in scalp while independent signals in brain inside are combined in a linear form, it has an inverse problem. In order to solve this problem, a process of dividing independent sources in brain inside is required. Contrary to the fact that Principal Component Analysis (PCA) considers even secondary correlation, as independent component analysis considers even high-order correlation, separation into most independent sources is enabled (Jin *et al*., 2006a; Lee, 1998). At the time of EEG analysis, ICA is used for internal source localization or artifacts removal and in this study, it was used for artifacts removal of EOG, EMG or EKG.

4) sLORETA (Standardized Low Resolution Brain Electromagnetic Tomography)

LORETA technique is an analysis method that enables quantitative neuroanatomical positioning for nerve potential activation. This technique enables not only quantitative analysis of nerve activation but also tracing activated current source and functional localization as well (Pascual-Marqui, 2002). As sLORETA is synchronized by standard 3D Talairach-Tournoux coordinate system being established through MR images of 305 persons, estimated image of current source could be obtained even without individual MR image. In addition, as estimation of current source being induced from deep cerebral structures such as hippocampal and subgenual cingulate foci is enabled, a study on both cognitive and sensory area is enabled as well. Contrary to existing study of frequency analysis through potential being represented in scalp (Kwon *et al*., 2007; Jin *et al*., 2006a; 2006b), current source in brain inside could be demonstrated empirically.

sLORETA (Pascual-Marqui, 2002) being used in this study is to estimate current density count (value) in each voxel after dividing total brain into 6239 voxels at 5 mm spatial resolution. As this study targets time series data of EEG as its analysis, voxel data being averaged by each group was made to enable estimation in a form of linear function through log transform without smoothing. Comparison by each group determined probability threshold values for maximum activated t value being detected by randomly comparing voxel data of brain current density of each comparison group for 5,000 times (p<0.05) at the time of independent t-test. This statistical non-parametric mapping (SnPM) mode may minimize error by repeated measurement. The analysis targeted average current density value for total 16 seconds section and 8 frequency bands (Delta, Theta, Alpha-1/2, Beta-1/2, Gamma, Omega) during task measurement. Last omega band among 8 frequencies was based on 1~50Hz corresponding to total frequency area being used for the analysis. Segmented frequency band being divided in order to perform cross spectrum analysis of EEG data is as follows Table 1.

Table 1. Frequency ranges of cross spectrum analysis

Frequency band name	Frequency range (Hz)	Frequency band name	Frequency range (Hz)
Delta	1~3	Beta-1	13~20
Theta	3~8	Beta-2	20~30
Alpha-1	8~10.5	Gamma	30~50
Alpha-2	10.5~13	Omega	1~50

III. RESULTS AND DISCUSSION

This study was intended to confirm difference of neural activation level being represented in creative reasoning process of gifted and normal children. Group analysis was performed through comparison of measured EEG data between individual resting condition and Raven task performance. Analysis of nerve activation was performed in 8 frequency bands through sLORETA mode among current density reconstruction methods of neural current source being generated from the brain. A limitation of the study was the relatively small sample size. For this reason, these findings cannot be generalized to the broader community based on this study alone.

1. Resting condition

Before performing the task, the test subjects were arranged to arrive at sufficiently resting condition and then directed to measure their resting condition under eyes closed/open. The result of comparing brain nerve activation level under resting condition among the groups through measurement of background wave is as follows. As a result of comparing frequency bands of brain activation among the groups, gifted children showed higher activation level in Alpha-2 band under resting condition of closed eyes than that of normal children but under resting condition of open eyes, any significant difference was not represented in all the frequency bands. In general, activation in Alpha-1 band is clearly observed under the condition of closed eyes, meditation or under the condition that attention is not concentrated but in case of activation in Alpha-2 band, it has been reported that such activation is mainly confirmed when wide recognition for sensory information such as awakening condition or alert state exists (Budzynski *et al*., 2009). In case of resting condition of closed eyes, loading level of task is generally at the very low stage as visual information is not presented to the test subjects but according to the result of this study, it is considered that comparing with normal children, gifted children seem to arrive at warming up state of preparing task to be performed in the future in advance.

This result has something in common with the result of a study (Klimesch *et al*., 2006; Doppelmayr *et al*., 2005) reporting that activation in Alpha band has correlation with processing of cognitive thinking or intelligence and that of other study (Jausovec, 1997; Klimesch *et al*., 2006) reporting that gifted children show higher activation in Alpha band than that of normal children. A report that in case of test subject whose intelligence or academic achievement level is high, current source activation and event-related synchronization (ERS) are represented to be higher in Alpha-2 band than that of normal test subject shows that Alpha-2 band is a typical frequency section reflecting giftedness.

As a result of comparing inter-group brain activation area, compared with normal children, gifted children showed higher synchronization of neuronal oscillation in total 62 voxels in Alpha-2 band (Table 2).

The site where activation of neural current source is the highest was right inferior temporal gyrus and main activation area being included in significant level

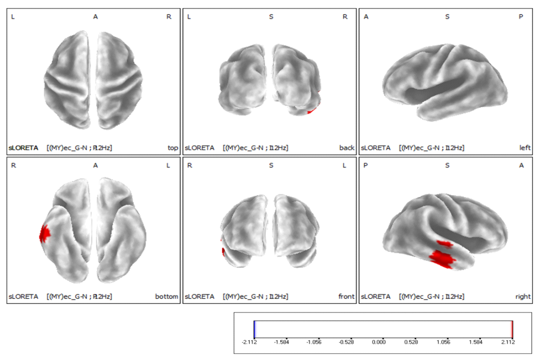

Fig. 2. Brain activation in gifted group during resting condition (alpha 2 range). Gifted group vs. normal group (bold; right Inferior Temporal Gyrus)

Table 2. The results of inter-group brain activation during resting condition (Alpha 2, corrected, $p<0.05$)

Maximum activation area	Broadmann area & side	Voxels	MNI coordinates			*t*-value
			X	Y	Z	
Temporal lobe						
Fusiform gyrus	20 R	5	60	−15	−30	2.26
Superior temporal gyrus	22(21) R	5	65	−20	0	2.16
Middle temporal gyrus	21 R	33	65	−20	−15	2.30
Inferior temporal gyrus	20 R	15	65	−25	−20	2.33
	21 R	4	65	−15	−20	2.29

was right temporal lobe and fusiform gyrus (Fig. 2). Both upper-middle inferior temporal gyrus (BA20, 21, 22) and fusiform gyrus are the areas relevant to right temporal lobe and lateralized activation features was observed in right hemisphere of the brain. In case of activation of right temporal lobe, it is relevant to autobiographical memory or theory of mind (ToM) (Fink *et al*., 1996; Brunet *et al*., 2000). Recently, in connection with ToM, in view of a study (Den Ouden *et al*., 2005; Bucker & Carroll, 2007) reporting that all of recognition of memory, identifying disposition of intention, forecasting the future and ability of being able to command overall situation are created by works of similar brain networks, it could be realized that even before presenting a task, gifted children group showed a strong disposition of trying to identify an intention of experimenter by reflecting episodic memory in their empirical system.

2. Performance of Raven Task

At the time of performing Raven task, it was observed that compared with normal children, gifted children showed more strong activation in Alpha-1 and Gamma band and any significant difference was not represented in other frequency bands (Table 3). Activation in Alpha-1 band could be clearly observed at the time of closed eyes or under the condition that meditation or attention is not concentrated and it is usually called as 'idle rhythm' because activation in Alpha-1 band has relation with decreased activation of cerebral cortex (Budzynski *et al*., 2009). In performing the task, as gifted children used to solve the problem with more ease than normal children even under the condition that attention is not required to be concentrated, it is considered that they lowered load level of cerebral activation at the time of problem solving. From the past, a study on confirming correlation with cognitive pattern or intelligence through Alpha power has been performed in many cases and according to this study, activation in Alpha-1 band being represented at the time of performing a task has also been known to reflect recognition process mainly from long-

Table 3. The results of inter-group brain activation during Raven's task states (Alpha 1, corrected, $p<0.05$)

Maximum activation area	Broadmann area & side	Voxels	MNI coordinates			*t*-value
			X	Y	Z	
Frontal lobe						
Precentral gyrus	4 R	10	60	−10	25	1.12
	6 R	40	50	−5	35	1.12
	9 R	5	40	5	40	1.08
	43 R	1	55	−10	15	1.04
Superior frontal gyrus	8 R	1	40	15	55	1.04
Middle frontal gyrus	6 R	7	40	0	40	1.08
	8 R	8	45	20	50	1.09
	9 R	16	45	10	40	1.10
Inferior frontal gyrus	9 R (6, 45)	19	50	5	35	1.11
Parietal lobe						
Postcentral gyrus	3 R (1, 2)	10	65	−10	25	1.11
	40 R	4	65	−20	15	1.08
	43 R	7	65	−15	20	1.10
Inferior parietal lobule	40 R	1	65	−25	25	1.05
Temporal lobe						
Transverse temporal gyrus	42 R	4	60	−10	15	1.04
Superior temporal gyrus	42 R	1	65	−25	15	1.05

term memory (Klimesch *et al*., 2006; Sauseng *et al*., 2002). Raven task being used in this study as a test tool requiring creative sophisticated cognitive ability of reasoning a relationship between presented figures requires ceaseless recognition and analogical process for problem solution from the past empirical situation. In Fig. 3, the fact that strong neuron synchronization is confirmed based on right medial anterior gyrus supports above features of Raven task. In view of a study (Doppelmayr *et al*., 2005) reporting that the more a person' intelligence level is high, the more is activation in Alpha band increased at the time of performing Raven task having high level of difficulty, Alpha activation being represented when performing a task is considered to reflect creative problem solving ability being represented in reasoning process.

In addition, a phenomenon that activation level in Alpha band of gifted children is represented to be higher than that of normal children is coincided with the existing result of study reporting that in gifted children group, activation is outstandingly represented in Alpha and Gamma band when performing a insight task through problem solving process (Jausovec, 1997).

In case of Alpha-1 band, the area where highest activation deviation was observed as a result of estimating cerebral current source based on frequency band was medial anterior gyrus (BA 4, 6), inferior anterior gyrus (BA 9), medial posterior gyrus (BA 3, 43) and upper temporal gyrus of parietal lobe (BA 42)

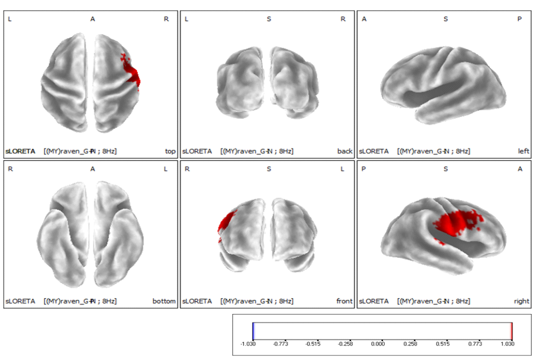

Fig. 3. Brain activation in gifted group during Raven's task states (alpha 1 range). Gifted group vs. normal group (bold; right Middle Frontal Gyrus)

(Table 3). In case of Gamma band, activation area similar to activation in Alpha-1 band was observed in frontal and parietal lobe and activation was additionally observed in traverse temporal gyrus (BA 41, 42) of temporal lobe and insula lobe (BA 13) of subcortical region (Table 4).

According to a study of Jausovec (1997), activation of Alpha and Gamma band was reported to be occurred in right posterior parietal cortex at the time of performing insight task by gifted children.

In addition, according to a study of Jin (2007), features of functional lateralization of right hemisphere is a major cerebral traits of gifted children when comparing with normal children. Through this, it could be realized that activation of Alpha and Gamma band and functional lateralization to right hemisphere are one of the typical traits being represented in gifted children at the time of solving creative problem. Even in this study, as a result of comparing inter-group Alpha-1 band source with that of normal children, high neural current sources synchronization for gifted children was observed in total 134 voxels in Alpha-1 band and total 177 voxels in Gamma band and both bands were confirmed to show activation features lateralized to right hemisphere.

Additionally, it could be realized that activation pattern of Alpha-1 band is taken place mainly at frontoparietal circuit and that of Gamma band at parietotemporal circuit (Fig. 3, 4). In case of frontoparietal circuit, it is a circuit being activated at the time of controlling thinking for visual observation object (Binkofski *et al*., 1999) and in case of parietotemporal circuit, it is a circuit relevant to association of somesthesis and movement (exercise) (Pa & Hickok, 2008) and it is known to be a circuit being activated mainly at the time of observing object, not human being (Clower *et al*., 2001; Dum & Strick, 2003). Recently, a result of study reporting that the more complication of a task is increased at the time of performing a task, cerebral activation of fronto-parietal network is being more highly represented in a group of high IQ than that of low IQ (Perfetti *et al*., 2009) supports above mentioned report. In addition, this

Table 4. The results of inter-group brain activation during Raven's task states (Gamma, corrected, p<0.05)

Maximum activation area	Broadmann area & side	Voxels	MNI coordinates			*t*-value
			X	Y	Z	
Frontal lobe						
Precentral gyrus	4 R	7	60	−10	25	1.09
	6 R	8	65	−5	25	1.08
	43 R	5	55	−10	15	1.10
Parietal lobe						
Postcentral gyrus	1 R	1	65	−20	30	1.03
	3 R	4	65	−10	25	1.09
	40 R	6	65	−20	15	1.09
	43 R	7	50	−15	15	1.11
Temporal lobe						
Fusiform gyrus	20 R	2	55	−20	−30	1.04
Transverse temporal gyrus	41 R	7	55	−20	10	1.11
	42 R	8	55	−15	10	1.11
Insula	41 R	1	45	−25	15	1.06
Superior temporal gyrus	13 R	3	45	−20	10	1.10
	21 R	4	55	−25	−5	1.08
	22 R	34	50	−15	10	1.11
	41 R	8	55	−20	5	1.10
	42 R	9	60	−25	10	1.08
Middle temporal gyrus	21 R (22)	37	60	−20	−5	1.07
Inferior temporal gyrus	20 R	8	55	−25	−20	1.05
Sub-lobar						
Insula	13 R	18	45	−15	15	1.09

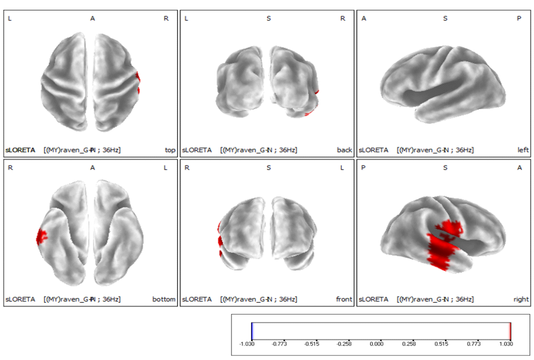

Fig. 4. Brain activation in gifted group during Raven's task states (gamma range). Gifted group vs. normal group (bold; right Middle Frontal Gyrus)

result has something in common with a study (Gray *et al*., 2003) reporting that at the time of performing a task that requires fluid intelligence of high level, functional network connection is highly represented in overall brain activation site.

In case of right parietotemporal circuit, this circuit is reported to be involved in visual handling of moving object (Grossman & Blake, 2002; Pavlova *et al*., 2009). Pavlova and his colleagues (2010) performed a pattern recognition experiment by which basic human sociality is identified through interaction of moving figures (triangle and circle) in a certain space and as a result of this study, they discovered the fact that activation of right parietotemporal circuit has a close relation with human sociality. Raven task being used in this study recognizes pattern of given figure matrix, reasons patterns to be represented in the future and further requires an ability of identifying social interrelationships. Therefore, synchronization of neural current sources being represented in parietotemporal circuit is considered to be a result showing that determination of interrelationships is an important item in giftedness element of gifted children.

BA 8 area among the areas that commonly represent activation in performing Raven task is an area relevant to control of uncertainty and when uncertainty of a task is increased, activation is known to be highly represented (Volz *et al*., 2005). This result reflects a process of decision-making that solves uncertainty in order to achieve a future compensation (Volz *et al*., 2005). In addition, through a result of study reporting that the more a process of inference (reasoning) is difficult, nerve action in the area of dorsal lateral prefrontal cortex (DLPFC) is increased, the scientists have regarded DLPFC as a site of playing a decisive role in fluid intelligence (Kroger *et al*., 2002; Prabhakaran *et al*., 1997). Brodmann area No. 9 that was commonly observed in Alpha-1 and Gamma band is a typical DLPFC and its activation is considered to be a result of reflecting creative problem solving through high fluid intelligence of gifted children.

Ⅳ. CONCLUSION AND IMPLICATION

The objective of this study is to identify brain thinking pattern being represented in a process of creative reasoning of gifted and normal children.

The task being used for this objective was Raven's Progressive Matrices test and EEG test was performed by selecting 3 tasks among this test items. Number of test subjects was total 12 persons including 6 gifted children and other 6 normal children and only persons of right-hander were targeted for this test. Conclusion drawn from the result of this study is as follows.

First, the result of this study shows that brain activation pattern of gifted and normal children could be confirmed not only in a process of performing a task but also in the resting condition. Resting condition of closed eyes means a peaceful state of not being stimulated and recently, this state is known to be a concept of default mode network. In studies of brain for generally confirming traits of gifted children, most of the study was performed through presentation of a specific task. Under this background, this study shows a possibility of default mode network in a study of brain traits pattern.

Second, it could be realized that brain use pattern is different in a process of creative reasoning of gifted and normal children. This difference represents a difference in fluid intelligence in using a specific circuit at the time of mainly performing a task.

Third, it could be realized that compared with normal children, nerve activation in Alpha-1 and Gamma band of gifted children was mainly represented in right hemisphere. This means that lateralized activation of right hemisphere is a unique brain activation pattern of gifted children at the time of performing a task.

Through an experiment of this study comparing brain using pattern of gifted and normal children at the time of solving creative reasoning problem, a neurophysiological foundation relevant to gifted children's traits was presented. In addition, we may find a significance of this study in that a neurophysiological foundation was presented in preparing an efficient teaching learning method that may be applied to normal children whose creative problem solving ability is insufficient.

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