

Alterations of Power Spectral Density in Salience Network during Thought-action Fusion Induction Paradigm in Obsessive-compulsive Disorder

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Objective: Recent studies highlighted the triple-network model which illustrated the interactions among three large-scale networks including salience network (SN). The functional magnetic resonance imaging used in this study was designed to investigate the characteristics of three large-scale networks associated with the thought-action fusion (TAF) in patients with obsessive-compulsive disorder (OCD) using power spectral density (PSD) analysis.

Methods: This study included 32 OCD patients and 38 age-matched healthy controls (HC). The TAF task was modified from the experiment of Rassin. PSD from time courses in large-scale networks of each subject was measured to compare between the groups for both TAF and resting state.

Results: In SN, OCD reported lower power in the low-frequency domain of SN compared to HC using the two-sample *t* test during the TAF task ($t = -2.395$, $p = 0.019$) but not in the resting state. The PSD in the low-frequency domain of the SN had a significant negative correlation with state score in the guilty inventory ($r = -0.361$, $p = 0.042$) in OCD patients.

Conclusion: This study suggests that OCD patients showed reduced SN power which can be prominent in a certain situation, such as TAF. In addition, the PSD alterations in SN cause difficulty in processing ambiguous emotional cues in social situations, and the difficulty can be connected with a negative feeling (e.g., guilt).

KEY WORDS: Obsessive-compulsive disorder; Power spectral density; Salience network; Triple-network model.

INTRODUCTION

Recent studies have emphasized the significance of the

triple-network model which illustrated the interactions within and between default mode network (DMN), central executive network (CEN), and salience network (SN) in the pathophysiology of psychiatric disorders [1]. The DMN is deactivated during the cognitive task [2] and activated in self-referential processing [3]. Higher-order executive functions that need focused attention, working memory, and decision making were processed using functions of CEN [4]. The SN has been proposed to have an important role in switching brain activity between the DMN and CEN [5].

Obsessive-compulsive disorder (OCD) is characterized by intrusive thoughts termed obsessions and repetitive ritualistic behaviors so called compulsions and has been as-

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sociated with diverse functional brain abnormalities with emphasis on the involvement of cortico-striato-thalamo-cortical (CSTC) circuits in OCD pathology. Further, recent neuroimaging studies have demonstrated the altered functional connectivity within and between these three brain networks may underlie the pathophysiology of OCD. In a study using resting state functional magnetic resonance imaging (fMRI), OCD patients had alteration in SN-DMN and SN-CEN connectivity, and switching difficulties between CEN and DMN [6]. Also, drug-naïve OCD patients had reduced intrafunctional connectivity among regions within the SN and decreased internetwork connectivity between the SN-DMN and CEN [7]. OCD patients had difficulties in decreasing the DMN activation in the non-resting condition [8]. We have paid attention to the fact that many components of CSTC loops overlap regions of SN, and these shared regions, such as anterior cingulate cortex (ACC) and striatum, indeed showed aberrant activity and functional connectivity in OCD patients [9].

While correlations in blood oxygen level dependent (BOLD) signal between brain regions, like aforementioned studies, have been the dominant class of methods for analyzing fMRI fluctuations, correlation-based techniques, focusing on a narrow frequency band, do not fully characterize changes in dynamics that occur across a broader range of frequencies. The power spectral density (PSD) is an alternative approach that quantifies the amount of specific time-frequency range, the temporal dimension of neural processing, in different brain regions. This functional approach of brain functioning enables the investigation of the temporal interplay between different intrinsic brain networks [10]. PSD approach using resting-state fMRI has been applied to find the characteristics of psychiatric illnesses, such as schizophrenia [11]. However, the PSD approach using task-based fMRI is seldom applied to psychiatric illnesses while PSD analysis using task-based fMRI has been applied to cognitive studies. Changes of PSD in DMN were measured during the n-back test to verify the age-related alteration in DMN [12]. Cognitive loads induced by the n-back task can modulate low-frequency fluctuation within the DMN [13]. Accordingly, certain tasks can alter the activity of large intrinsic networks, and these changes might be sensitively detected using the PSD approach. PSD is thought to reflect regional neuronal activity, and long-range neural synchronization affects PSD strengths although the

physiological origin and significance of PSD were still not clear [14].

The current fMRI study used a thought-action fusion (TAF) induction task as an active task, which was adapted from an experimental paradigm [15] and validated for use in fMRI study [16]. In our task [16], participants were instructed that if they thought of the word *apple*, another person in a separate room would receive an electric shock (which did not really happen). The paradigm was designed to increase likelihood TAF responses, resulting in discomfort or feelings of guilt which, in turn, lead to attempts to reduce the thought of *apple*.

TAF, one of the major dysfunctional obsessive-compulsive (OC) beliefs in the cognitive theory for OCD, believes that thinking about something increases its likelihood of occurrence or are morally equivalent to actions [17,18]. TAF is significantly linked to OCD symptoms, such as obsession and guilt [19]. Increased beta frequency in the precuneus of individuals with high OC traits was shown in a previous electroencephalogram study [20]. An fMRI study using the TAF task also reported activation in the insula, dorsomedial prefrontal cortex, and precuneus, which are important components of SN and DMN [21]. Therefore, large-scale networks, such as SN and DMN, can be mainly involved in processing TAF-related stimuli.

The purpose of this fMRI study was to investigate the characteristics of three large-scale networks associated with the TAF cognitive model in patients with OCD using PSD analysis. It is believed that this is the first study to find the differences of three large-scale networks in OCD using the TAF task modified from the experiment of Rassin [15]. During the task, participants should monitor the thought of *apple* as a salient stimulus, which was supposed to potentially harm to another person. Therefore, based on the overlap between CSTC loop and SN and previous reports of impaired SN in OCD, it is hypothesized that OCD patients have PSD alterations in SN during the TAF task and these alterations relate to dysfunctional belief of TAF or associated psychological phenomenon.

METHODS

Subjects

This study included 32 OCD patients and 38 age-matched healthy controls (HC). All participants were male, 18–46 years old. The handedness of each partic-

ipant was checked using the Edinburgh Handedness Inventory. All participants were provided written informed consent following the procedures approved by the Institutional Review Board of Kyungpook National University Hospital (2018-04-029). A previous study using part of the data from healthy participants has been published [16].

Experimental Design

All subjects were scanned during both resting state and TAF task. An 8-minutes resting-state fMRI was implemented to avoid being affected by prior tasks before getting the TAF task data. The subjects were asked to relax and keep still with eyes closed but to avoid falling asleep during the resting state. The subjects played the TAF task with visual stimuli using SuperLab (version 4.5; Cendus Corp., San Pedro, LA, USA) and binocularly presented through an MRI-compatible visual stimulator mounted on the head coil (NordicNeuroLab, Bergen, Norway).

The subjects were instructed that if they think of *apple* before entering the MR scanner, the brain activity could be detected and verified by monitoring the MR scanner. Additionally, the subjects received the instructions that an electrical shock would be administered to the person outside the MR shielding room whenever the thought of *apple* comes to mind. Subsequently, they tested a real but low-intensity electrical pulse as a test using a portable low-frequency massager. Finally, they met the other participant (one of the investigators) who has two sham electrode patches attached to her hands.

The TAF task paradigm consisted of three phases: the thought of *apple*, evaluation, and fixation. The thought of *apple* had four different conditions. These conditions were combinations of the electric shock (Esk+/Esk-) and suppression of the thought of *apple* (Sup+/Sup-). The subjects could recognize the existence of the electric shock through a red lightning bolt sign on the screen. In the following evaluation phase, the subjects responded to how much they thought about *apple* using the response grip according to four frequency ranges of 1 (0–25%), 2 (25–50%), 3 (50–75%), and 4 (75–100%). In total, the TAF task paradigm lasted 8 minutes (thought of *apple*, 10 seconds; evaluation, 4 seconds; and fixation, 10 seconds; 24 seconds for each trial × 4 conditions × 5 repetitions). This TAF task was applied in a previous fMRI study [16].

Psychological Measures

Psychological symptoms were assessed using the Obsessive-Compulsive Inventory-Revised (OCI-R) [22,23], Thought-Action Fusion Scale (TAFS) [18,24] and Guilt Inventory [25]. The OCI-R is an 18-item self-reported questionnaire that measures six symptom domains: washing, checking, obsessing, neutralizing, ordering, and hoarding, with each subscale ranging from 0 to 12. Korean version of the OCI-R was validated [23]. The TAFS [18] is a 19-item (12 for moral TAF and seven for likelihood TAF) self-reported measure that evaluates the tendency of TAF-like cognition. Each of the items is rated from “disagree strongly” (coded as 0) to “agree strongly” (coded as 4). Korean version of TAFS was used in our study [24]. The guilt inventory (GI) is a self-reported questionnaire to evaluate three domains of guilt (state-guilt, trait-guilt, and moral standards), consisting of 45-item with 5 point Likert scale [25]. We only used state-guilt score in this study.

Data Acquisition and Preprocessing

The whole-brain function was acquired by using a Discovery MR750w 3.0 T (GE Healthcare, Milwaukee, WI, USA) with a 24-channel head coil. The functional data were obtained with the parameters of repetition time (TR, 2,000 ms), echo time (TE, 30 ms), field of view (FOV, 23 cm), matrix (64 × 64), and slice thickness:gap (4:0 mm) using the echo-planar imaging sequence. Both functional data consisted of 240 volumes. The T1-weighted fast spoiled gradient brain volume imaging were acquired as a structural reference image with high resolution (TR = 8.5 ms, TE = 3.2 ms, FOV = 25.6 cm, flip angle (FA) = 12°, and voxel dimension = 1 × 1 × 1 during 4 minutes 14 seconds).

Image data were preprocessed and statistically analyzed using the Statistical Parametric Mapping program (SPM12; Wellcome Centre for Human Neuroimaging, London, UK). The functional data were preprocessed with motion correction for the first volume, slice timing correction, co-registration with high-resolution T1 image and realigned mean echo-planar imaging for normalization to standard space, and spatial smoothing using an 8-mm Gaussian kernel.

Independent Components Analysis and Power Spectral Density

The spatial independent component for the TAF task and the resting state was separately analyzed with GroupICAT v4.0b (GIFT v3.0b; <http://mialab.mrn.org/software/gift>) running in MATLAB 2018b (MathWorks, Natick, CA, USA). Spatial independent components analysis (ICA) was used to classify the neural networks with the InfoMax algorithm to separate the mixed signal. The pre-processed TAF data were decomposed into 39 components selected by minimum description length (MDL) criteria to estimate the optimal number of components as a dimension estimation using principal component analysis. The estimated optimal number of components for the resting state was 40 using the MDL criteria, but the resting

state data was separated into 39 components similar to the TAF data to compare with the TAF data based on a previous study [26]. ICA was performed using the InfoMax algorithm for each subject and repeated 20 times in ICASSO to estimate the stability of the components. All the data were back-reconstructed into single-subject space scaled to Z-scores using the grounded inter-subjective concept analysis method.

Spatial correlation sorting using the GIFT program was performed with established templates that had consistent meta-analysis activation to sort components which represent the triple-network model [27]. The sorted components had the greatest absolute spatial correlation value with each default mode, executive, and salience map.

A voxel-wise one-sample *t* test was used to generate

Table 1. Demographic, clinical and psychological data

Variable	OCD (n = 32)	HC (n = 38)	t/χ^2	<i>p</i> value
Demographic data				
Age (yr)	25.3 ± 7.2	23.0 ± 2.1	1.8	0.085
Level of education (yr)	14.3 ± 1.7	14.7 ± 1.2	-1.2	0.231
Handedness (right/left/both)	26 (81.2)/6 (18.8)	37 (97.4)/1 (2.6)	5.0	0.042
Clinical data				
Age of onset	19.0 ± 5.4	-	-	-
Duration of illness	6.4 ± 5.6	-	-	-
Medication vs. no current medication or drug-naïve	21 (65.6)/11 (35.4)	-	-	-
Types of medication				
Antidepressants (escitalopram/others)	19 (90.5)/9 (42.9)	-	-	-
Anxiolytics (benzodiazepines/others)	14 (66.7)/11 (52.4)	-	-	-
Antipsychotics	8 (38.1)	-	-	-
Comorbidities				
Depressive disorder (except MDD)	3	-	-	-
Panic disorder or agoraphobia	3	-	-	-
Tic disorder	1	-	-	-
Psychological symptoms				
Dimensional OC scale				
Contamination	7.7 ± 4.7	3.2 ± 1.8	5.3	< 0.001
Responsibility for harm	8.6 ± 5.0	2.8 ± 2.5	6.3	< 0.001
Unacceptable thoughts	9.6 ± 4.5	3.0 ± 2.7	7.6	< 0.001
Symmetry	6.1 ± 6.0	1.8 ± 2.1	4.2	< 0.001
Obsessive compulsive inventory-revised, total	34.7 ± 13.6	12.3 ± 5.9	8.7	< 0.001
Checking	6.1 ± 3.3	1.8 ± 1.4	6.9	< 0.001
Hoarding	4.3 ± 3.1	2.5 ± 1.8	2.8	0.008
Neutralizing	4.8 ± 3.6	1.4 ± 1.7	5.0	< 0.001
Obsessing	8.6 ± 2.7	2.3 ± 1.9	11.2	< 0.001
Ordering	5.3 ± 2.9	3.1 ± 2.0	3.7	0.001
Washing	5.6 ± 3.3	1.2 ± 1.2	7.1	< 0.001
Guilty inventory, state	33.7 ± 6.6	25.7 ± 5.9	5.4	< 0.001
Thought-action fusion scale	30.8 ± 13.5	18.4 ± 12.5	4.0	< 0.001
Beck depression inventory	19.5 ± 11.6	4.9 ± 4.4	6.8	< 0.001

Values are presented as mean ± standard deviation or number (%).

OCD, obsessive-compulsive disorder; HC, healthy controls; MDD, major depressive disorder.

each network map of groups for both functional data, and the results were at a threshold of $p < 0.05$ with family-wise error (FWE) correction. A two-sample t test was used to find group differences within large-scale networks at uncorrected $p < 0.001$ (cluster size > 85).

The Welch method in MATLAB Signal Processing Toolbox was used to calculate PSD from time courses in independent components of each subject to compare between the groups for both TAF and resting state. Each PSD was divided into five equally spaced frequency bins between 0 and 0.25 Hz with 0.05 Hz intervals. Several previous studies equally divided the frequency bins [28–30]. Thus, the current study equally divided five frequency bins for the inclusion of one trial of the TAF task which lasted 24 seconds. The extracted PSD was converted to fractional PSD as normalized with summation PSD in total frequency in each bin.

Additionally, general linear model (GLM) analyses were conducted to confirm the brain activation at each contrast. Methods and results of GLM analyses were presented in Supplementary Materials (Supplementary Fig. 1; available online).

Statistical Analysis

Statistical analyses were performed using the IBM SPSS Statistics for Windows version 25 (IBM Corp., Armonk, NY, USA). The independent two-sample t test at $p < 0.05$ measured the group differences in psychological meas-

urements, response data during the TAF task, and frequency domains of PSD. Additionally, Pearson's correlation analyses were conducted to assess the relationship between psychological measurements and frequency domains of PSD to find group comparison results in PSD analyses.

RESULTS

Physiological Assessment and Behavioral Data

The demographic and clinical variables for each group are presented in Table 1. The subjects in both groups did not have a significant age difference, but the ratio of handedness showed a significant difference between the groups ($\chi^2 = 5.02$, $p = 0.042$). OCD patients showed higher OC, state guilt, and TAFS scores on average compared to the HC. Eleven patients (35%) were drug-naïve or had been drug-free for three months, whereas 21 patients (65%) were taking antidepressants, mostly selective serotonin reuptake inhibitors (SSRIs).

Both OCD and healthy groups showed the successful thought suppression of *apple* in the suppression condition, regardless of the presence of electrical shock, during the performance of the TAF task. However, OCD showed a lower degree of thought of *apple* in Esk+/Sup− ($t = -2.06$, $p = 0.043$) and Esk−/Sup− ($t = -1.96$, $p = 0.054$), indicating that OCD patients thought about *apple* less than HC in the non-suppression condition (Table 2).

Table 2. Behavioral data on thought-action fusion experiment during magnetic resonance scan

Variable	OCD (n = 32)	HC (n = 38)	t	p value
Degree of thought of apple ^a				
Sup+/Esk−	1.5 ± 0.5	1.3 ± 0.4	1.5	0.146
Sup+/Esk+	1.6 ± 0.7	1.4 ± 0.4	1.5	0.133
	$t = -1.4$, $p = 0.223$	$t = -0.9$, $p = 0.391$		
Sup−/Esk−	2.9 ± 0.7	3.3 ± 0.6	−2.0	0.054
Sup−/Esk+	2.7 ± 0.7	3.1 ± 0.8	−2.1	0.043
	$t = 2.1$, $p = 0.042$	$t = 1.6$, $p = 0.121$		
Reaction time (msec)				
Sup+/Esk−	1,958.2 ± 590.5	1,852.5 ± 551.5	0.8	0.442
Sup+/Esk+	1,800.2 ± 565.7	1,727.9 ± 538.2	0.6	0.586
	$t = 2.3$, $p = 0.026$	$t = 1.7$, $p = 0.092$		
Sup−/Esk−	1,917.1 ± 650.8	1,881.8 ± 457.2	0.3	0.798
Sup−/Esk+	1,931.7 ± 536.4	1,810.7 ± 454.7	1.0	0.311
	$t = -0.2$, $p = 0.865$	$t = 1.2$, $p = 0.255$		

Values are presented as mean ± standard deviation.

OCD, obsessive-compulsive disorder; HC, healthy controls; Esk, electric shock condition; Sup, thought suppression condition. Paired t test for within-group comparison, independent t test for between-group comparison.

^aLikert degree was measured by frequency range with 1 (0–25%), 2 (25–50%), 3 (50–75%), and 4 (75–100%).

No differences were evident in reaction time in each condition.

In addition, participants as a whole showed positive correlation between total scores of TAFS and degree of thought of *apple* ($r = 0.28$, $p = 0.019$) as well as reaction time ($r = 0.29$, $p = 0.015$) in Esk−/Sup+. Scores of state guilt also had a relationship with degree of thought of *apple* ($r = 0.28$, $p = 0.019$) in Esk+/Sup+.

Independent Components Analysis

The triple networks separately sorted 39 independent components by spatial correlation implemented in the GIFT toolbox with a template (Table 3). Moreover, sorted components of each network showed highly spatial sim-

Table 3. Spatial correlation value with each network templates and dice similarity between OCD and HC

Description	TAF	Resting
Spatial correlation		
(a) DMN	0.526	0.580
(b) CEN	0.399	0.438
(c) SN	0.317	0.316
Dice similarity between groups		
(a) DMN	0.767	0.791
(b) CEN	0.740	0.783
(c) SN	0.803	0.770

TAF, thought-action fusion; OCD, obsessive-compulsive disorder; HC, healthy controls; DMN, default mode network; CEN, central executive network; SN, salience network.

ilarity between groups when using dice similarity regardless of experimental condition.

In resting and TAF condition, both groups showed that DMN was included in the middle, posterior cingulate, middle occipital, middle temporal cortices, and angular gyrus. CEN was shown in the left inferior temporal, inferior parietal, precentral, bilateral inferior frontal, middle occipital cortices, right angular gyrus, and precuneus. Also, SN was shown in the putamen, hippocampus, parahippocampus, anterior insula, ACC, and middle prefrontal cortex (Figs. 1 and 2; FWE-corrected $p < 0.05$).

OCD showed reduced activity in the ACC within SN during the TAF task (uncorrected $p < 0.001$, cluster size ≥ 85 ; Fig. 3) in the two-sample t test. DMN and CEN did not have significant differences during the TAF task, and no significant difference existed within each network in the resting state.

Analyses of Power Spectrum Density

DMN and CEN had no difference in all of the frequency domains of PSD in a comparison between OCD and HC in the TAF and the resting state (Fig. 4). In SN, OCD reported lower power in bin1 of SN compared to HC using two sample t test during TAF task ($t = -2.395$, $p = 0.019$, Fig. 4C) but not in the resting state. The PSD in bin1 of SN had significant negative correlation with state subscale score in guilty inventory ($r = -0.361$, $p = 0.042$) in OCD patients (Fig. 5). However, no correlation between bin1

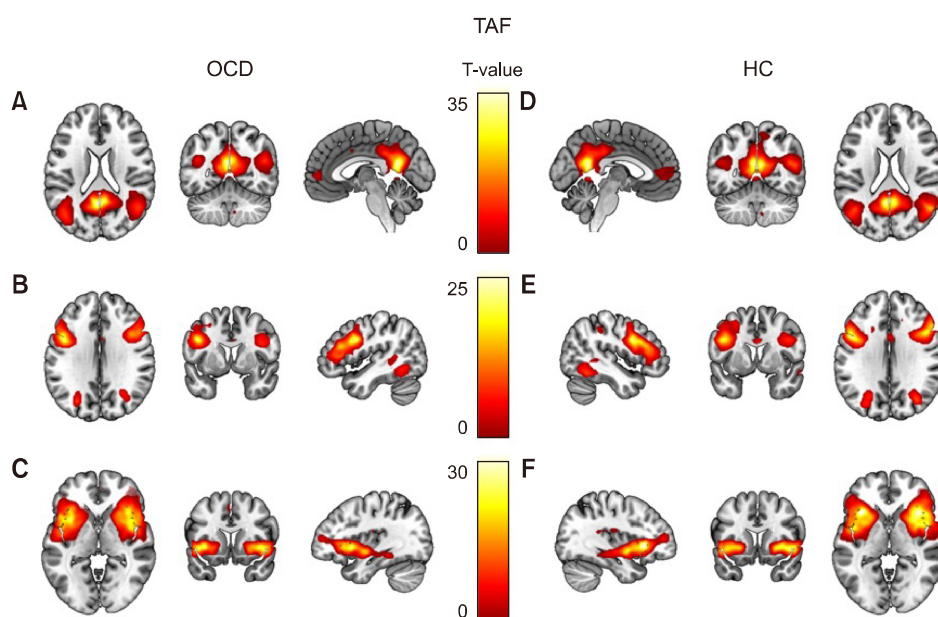


Fig. 1. Spatial maps of the default mode network (A, D), central executive network (B, E), and salience network (C, F) during the thought-action fusion (TAF) task (one sample t test, FWE corrected $p < 0.05$). OCD, obsessive-compulsive disorder; HC, healthy control; FWE, family-wise error.

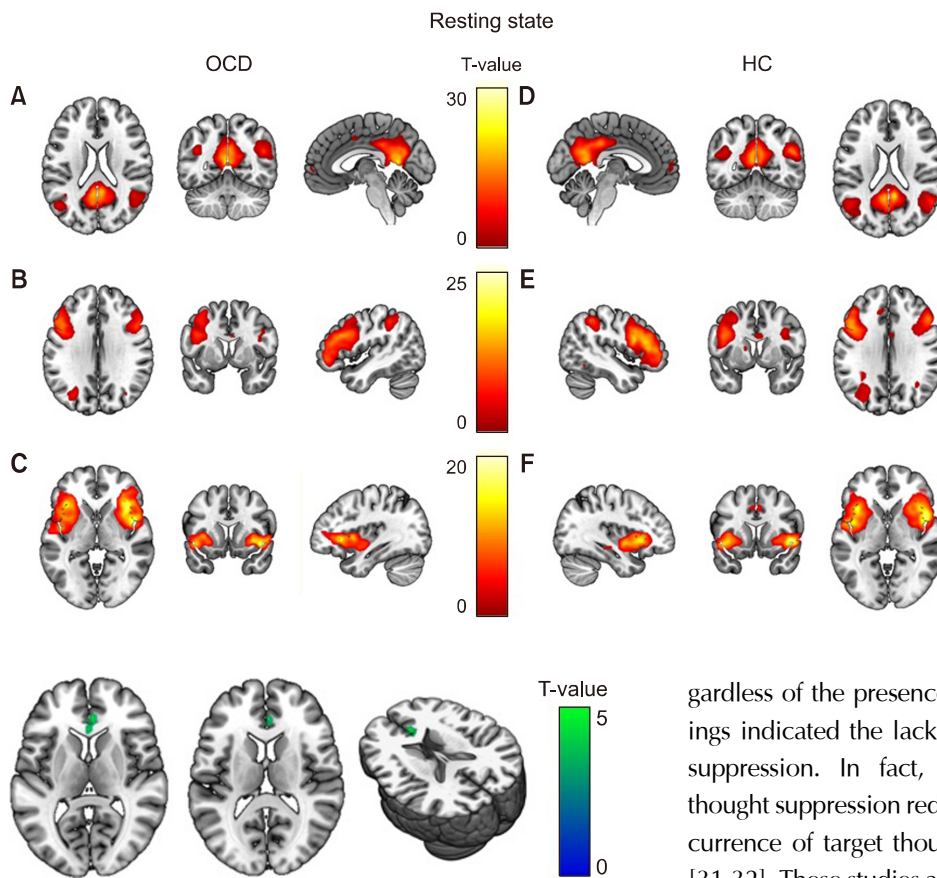


Fig. 3. Group differences in brain activity within salience network (two sample t test, uncorrected $p < 0.001$, cluster size > 85). Healthy controls showed higher activation in the ACC than OCD patients. ACC, anterior cingulate cortex; OCD, obsessive-compulsive disorder.

PSD and scores of guilty inventory was evident in the HC ($r = -0.021$, $p = 0.903$).

DISCUSSION

The results of the present study showed that OCD patients represented a reduced low-frequency PSD signal in the SN during the TAF task while the other large-scale networks of DMN and CEN did not show any significant group differences. Also, reduced power in low-frequency PSD in the SN was related to a state of guilt. In ICA analyses, OCD patients reported reduced activities in the ACC within the SN. This study reported that alterations in the SN during the TAF situation can be a potential neural feature of OCD patients.

The behavioral data in this study demonstrated that both OCD and healthy groups could successfully suppress the target thought in Sup+ compared to Sup-, re-

Fig. 2. Spatial maps of the default mode network (A, D), central executive network (B, E), and salience network (C, F) during the resting state (one sample t test, FWE corrected $p < 0.05$).

OCD, obsessive-compulsive disorder; HC, healthy control; FWE, family-wise error.

gardless of the presence of electrical shock. These findings indicated the lack of paradoxical effect of thought suppression. In fact, two meta-analyses found that thought suppression reduces rather than increases the occurrence of target thoughts during thought suppression [31,32]. These studies argued that the ironic effect cannot be developed since people can successfully suppress thought over short periods of time, as was in our paradigm. However, although statistically insignificant, the target thought tended to increase with Esk+ during thought suppression while it seemed to decrease with Esk+ during thought non-suppression. These findings are consistent with a recent report that immediate enhancement effects were observed only in the presence of cognitive load [33]. Furthermore, overall patterns of OCD seemed to show more thinking of *apple* on suppression conditions and less thinking of *apple* on non-suppression conditions compared to healthy participants (Table 2). Consistent with our results, Rassin *et al.* (2008) [34] concluded that evidence for amplification of thought suppression failures in psychopathology is generally weak. OCD samples experienced even less amplification of intrusive thoughts while suppressing than did non-clinical groups [32].

Although general response patterns were similar between two groups in this study, between-group differences on the Likert scale were also found. The OCD group suppressed thought of *apple* more in Esk+/Sup- con-

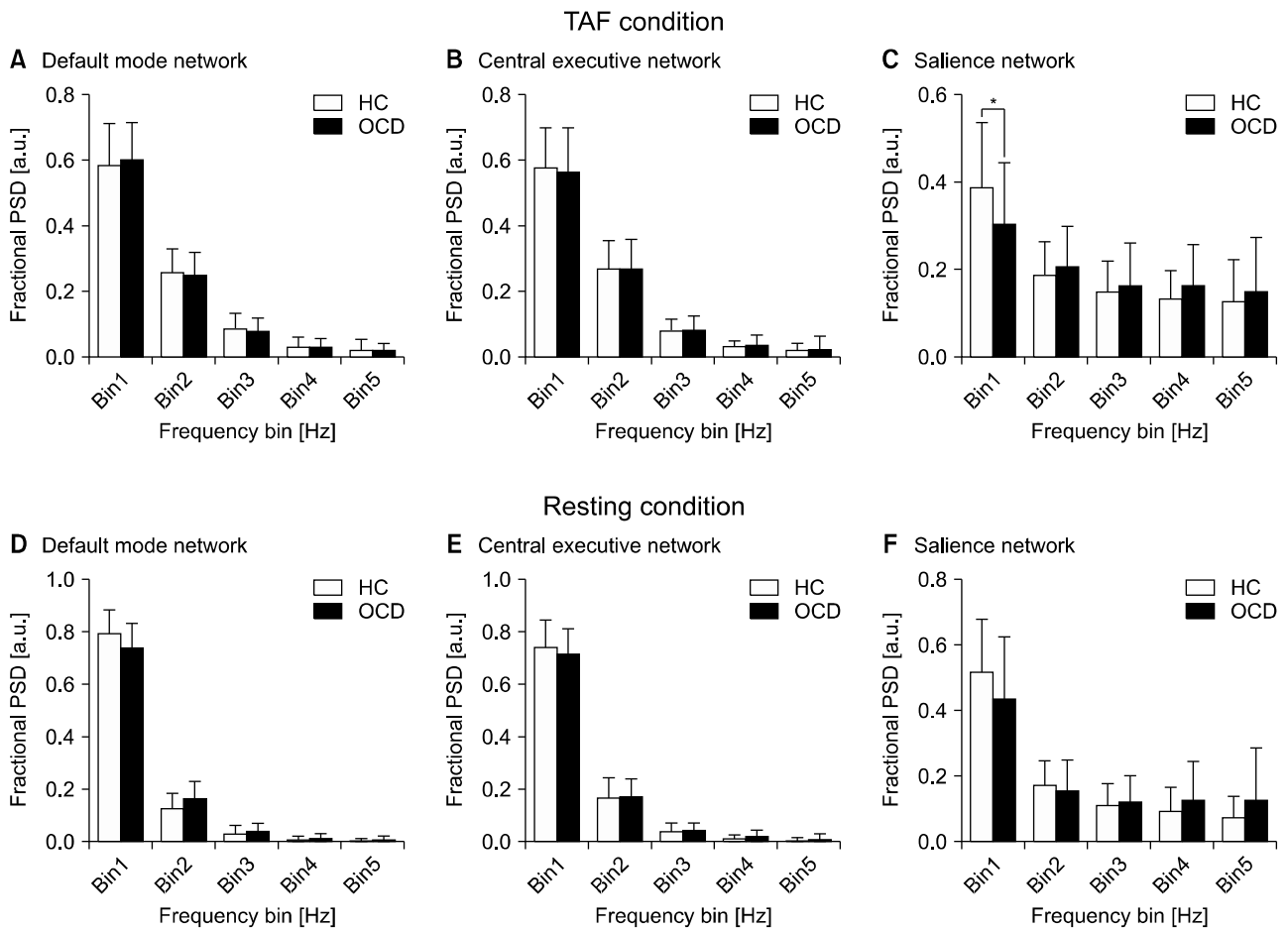


Fig. 4. Results of group differences during the TAF task (A–C) and resting state (D–F) with power spectrum density (PSD) analyses (two sample *t* test, **p* < 0.05). Error bars indicated standard deviation of the mean PSD. The frequency bands are: 0.00–0.05 Hz (bin 1), 0.05–0.1 Hz (bin 2), 0.1–0.15 Hz (bin 3), 0.15–0.2 Hz (bin 4), and 0.2–0.25 Hz (bin 5). TAF, thought-action fusion; OCD, obsessive-compulsive disorder; HC, healthy control; a.u., arbitrary unit.

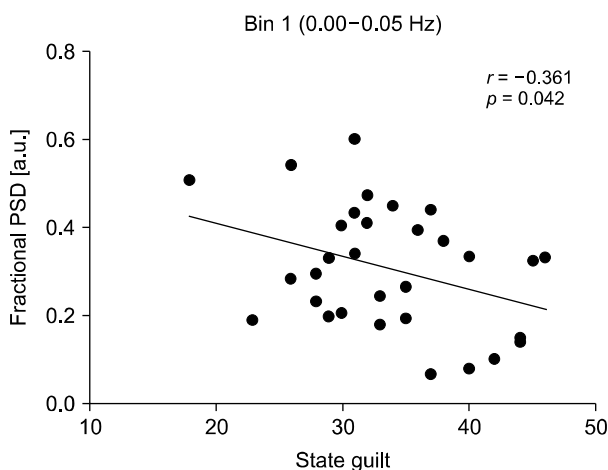


Fig. 5. Relationship between guilty feeling and power of low frequency (0.00–0.05 Hz of bin 1) power spectrum density (PSD) in OCD patients. OCD, obsessive-compulsive disorder; a.u., arbitrary unit.

dition compared to the healthy control. One may assume that OCD patients may believe that thinking about *apple* increases the likelihood of occurrence of hurting the other person and thus still inhibit their thoughts more greatly than healthy participants even in the condition when thinking *apple* was freely allowed. Another explanation is that the condition contains two conflicting instructions—think of *apple* freely vs. thoughts of *apple* harm another person—that may affect the result. This highly conflicting situation can arouse overactive monitoring in OCD patients as mentioned in a previous study [35]. Based on these observations, while the paradoxical effect of thought suppression was small, TAF may exert its influence throughout our paradigm. These results may also validate this study.

OCD patients represented reduced low-frequency PSD

in SN compared to healthy participants during the TAF task. Low-frequency PSD is known to be generated by both spontaneous activity and task-related responses. Similar to that of resting-state fMRI [36,37], spontaneous fluctuation of activity during task-fMRI can affect low-frequency PSD. In terms of task-related responses, the length of the task block in this study was 24 seconds which corresponds to 0.0417 Hz in the frequency domain. Responses of large-scale networks on TAF stimuli were included in low-frequency PSD (range, 0–0.05 Hz). A large-scale network such as the SN is important for the integration of internal/external stimuli and the modulation of the function of other large-scale networks [5]. However, the findings were rather inconsistent although several studies with resting-state fMRI reported aberrant function of SN in OCD patients. A recent meta-analysis revealed a reduced intrinsic functional connectivity of supramarginal gyrus (SMG) within the SN. However, the SMG is an overlapped region with other large-scale networks (e.g., CEN and DMN) rather than a specific component of SN [38]. Also, a study showed that OCD patients have increased functional connectivity in the ACC within the SN network [6]. Another recent study represented reduced intrinsic functional connectivity among SN subregions, such as ACC and insula [7], but not SMG. Furthermore, it should be noticed in the current study that no significant group differences were found in ICA and PSD analyses when using resting-state fMRI data. Only significant group differences were shown in the SN in PSD analysis when using the TAF data. Previous literature implicated that the SN activity can change depending on the difficulties or ambiguity of the task. The activities in the SN components (e.g., insula and ACC) increased with tasks with high ambiguity or difficulty [39,40]. The SN may be engaged with sensory integration to resolve stimuli ambiguity [39-41]. The results of the current suggest that OCD patients may fail to engage more SN function in ambiguous and emotional situations, such as TAF, following previous studies. Therefore, alterations in the SN of OCD patients can be prominent in the TAF compared with the resting condition. Moreover, the results of the present study also suggest that the PSD analysis can be a sensitive method to reveal the responses of large-scale networks on TAF. The PSD approach has an advantage in measuring the intrinsic functional dynamics of specific regions compared with the functional connectivity approach [10]. This study

found that only PSD analyses but not ICA showed significant group differences in the SN.

The TAF response increase thought-related uncomfortable feelings, such as guilt [42]. In Rassin's experiment that was modified in our study, the subjects felt guilty during the experiment, and the guilty feeling was negatively correlated with a socially desirable behavior [15]. Also, the previous fMRI study applying the same TAF task revealed that activities of visual association cortexes were related to a feeling of guilt [16]. The TAF task of the current study contains a social context that has a target person who could suffer from the subjects' thoughts of *apple*, and the specific object might amplify the subjects' feelings of guilt. The CSTC loop of the SN has been described to be involved in filtering a cortical input that leads to different responses [43]. The result of this study suggests that OCD patients showed an SN alteration which is related to inappropriate filtering of ambiguous situations, and this alteration can contribute to a maladaptive response, such as the feeling of guilt. However, the DMN and CEN did not show any group differences in this study. The result suggested that the TAF task of the current study was focused on the evaluation of salience of the stimuli rather than the cognitive or self-referential processing.

Furthermore, the results in this study for group differences in brain activities within the SN showed reduced activation in the ACC in OCD patients. The ACC was important in making an appropriate prediction on the current stimuli within the SN [44]. Also, the ACC involves in high-demand cognitive processes, such as conflict monitoring and attentional control [45,46]. Conflicting situations induced by the TAF task in this study can arouse ACC activation. Another important role of ACC is inhibitory control, such as thought suppression [47]. Successful thought retrieval and suppression can be related to the function of ACC [48]. Deficits of inhibitory control have been an important model for OCD symptoms [49], and reduced activity in ACC during response inhibition was reported in OCD patients [50]. Although alterations of ACC seems rather inconsistency by types of stimuli [51], functional and structural alterations of the ACC in OCD patients have been frequently reported in previous studies [52,53]. The results of the present study, which reported reduced activity in ACC, were in line with previous studies. In sum, there were three possible effects that can contribute to reduced activities in SN, especially

the ACC, during TAF situation: 1) deficits in monitoring the importance of the current stimuli, 2) deficits in predicting the consequences of the stimuli, and 3) deficits in inhibitory control, such as thought suppression.

Several limitations should be noticed. First, the statistical level of ICA analyses of group differences was relatively low (uncorrected $p < 0.001$). Therefore, the interpretation of the results was minimized. However, the ACC cluster size was the largest in the uncorrected analyses of the present study, and the results were in line with previous literature that reported alterations in the ACC in OCD patients. Second, task-based PSD analyses need more replicative results because only small amounts of previous studies were conducted using task-based PSD. Additionally, in our study, the statistical power in PSD comparison between OCD and HC was relatively low (uncorrected $p < 0.05$). It does not show significant results with correction about multiple comparison problems. Third, medication effects can affect our fMRI results. About two-thirds of patients take their medications, mostly SSRIs. SSRI medication has significant effects on the strengths of brain functional connectivity [54,55]. Fourth, limitations on sample characteristics exist. The handedness showed group differences, and only young and male subjects were recruited in this study. Further pieces of evidence would be needed to generalize the results.

In conclusion, the results of the present study suggest that OCD patients showed reduced SN power which can be prominent in certain situations, such as the TAF. In addition, the PSD alterations in the SN enables difficulty in processing ambiguous emotional cues in social situations, and the difficulty can be connected with a negative feeling (e.g., guilt).

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■ Conflicts of Interest

No potential conflict of interest relevant to this article was reported.

■ Author Contributions

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