Neural Evidence for Cognitive Style-Specific Strategies in Cognitive Control[*]

Huiyeong Seo   Chobok Kim[†]

Department of Psychology, Kyungpook National University

Cognitive control involves the human ability to attend to relevant information and ignore irrelevant information from environmental inputs. The present study examined neural mechanisms involved in cognitive control for relevant or irrelevant information related to individual cognitive style. Based on the Object-Spatial-Verbal cognitive style questionnaire scores, participants were divided into two preference groups, Spatializers and Verbalizers. The task included two versions of spatial Stroop tasks that required both ignoring spatial distracter while attending to a verbal target (the Word task) or an object target, respectively. Although there was no difference in the behavioral Stroop effects in either task between the two groups, imaging results demonstrated an increase in the neural Stroop effect in the right frontopolar cortex and right superior temporal sulcus for Spatializers compared to Verbalizers during the Word task, with greater activation in the left lingual gyrus and left parahippocampal/fusiform gyrus for Verbalizers compared to Spatializers during the Object task. In addition, functional connectivity between the dorsolateral prefrontal cortex and task-related regions showed group differences in the neural Stroop effect. The current results provide further evidence that individuals appear to use different strategies for cognitive control processes according to their preferential cognitive style.

Key words : cognitive control, cognitive style, spatial Stroop task, neural efficiency, fMRI

Cognitive control refers to the ability to coordinate our thoughts and actions in accordance with our internal goals, which involves both enhancing task-relevant processing and inhibiting task-irrelevant processing (Miller & Cohen, 2001). For example, the Stroop effect is a well-known phenomenon showing these control processes, in which response times (RTs) to name the color of an incongruent color-word combination (e.g., the word "RED" printed in green ink) are longer than for a congruent color-word one (e.g., the word "GREEN" printed in green ink) (Stroop, 1935). In the Stroop task, both attending to relevant information (i.e., color of the written word) and ignoring dominant but irrelevant information (i.e., the meaning of the word) are required.

Interestingly, a recent study proposed that individual differences in cognitive control are closely associated with the preference for a certain type of information, namely cognitive style (Shin & Kim, 2015). Cognitive style is regarded as the consistent way in which individuals process environmental information (Kozhevnikov, 2007). One of the well-known account of cognitive style proposes that cognitive style consists of object, verbal, and spatial dimensions (Blazhenkova & Kozhevnikov, 2009; Kozhevnikov, Kosslyn, & Shephard, 2005). Using this object-verbal-spatial cognitive style

questionnaire and the color-word Stroop task, Shin & Kim (2015) suggested a correlation between the preference for verbal cognitive style and prefrontal control processes based on their neuroimaging results in which neural activation in the cognitive control-related regions increased as preference scores for verbal cognitive style increased.

Considering that there are two cognitive processes in the Stroop task, one for attending to targets and one for inhibiting distracters, it may be expected that preferences for the information to be attended to, or to be inhibited would have different influences on cognitive control processes. This presumption has been only partly investigated by previous studies (Buzzell, Roberts, Baldwin, & McDonald, 2013; Cui, Jeter, Yang, Montague, & Eagleman, 2007; Kraemer, Hamilton, Messing, Desantis, & Thompson-Schill, 2014; Kraemer, Rosenberg, & Thompson-Schill, 2009; Li, Gong, Jia, Zhang, & Ma, 2011; Motes, Malach, & Kozhevnikov, 2008; Shin & Kim, 2015). Specifically, preferences for target information were associated with better behavioral performance and less activation in the task related cortical regions through more efficient use of cognitive resources (Motes et al., 2008). Similarly, a non-preference for target information was closely related with a worse performance, but stronger neural activation (Li et al., 2011). Conversely, a preference for

distracters was related with an increased Stroop effect (Buzzell et al., 2013; Cui et al., 2007) and greater activation in the cognitive control regions, such as the dorsolateral prefrontal cortex (Shin & Kim, 2015).

Although these findings raise a possibility that control processing is affected by preference for both target and distracter, no study has investigated the effect of the preference for both target and distracter in a single task. For instance, task performance or neural activation of those who have a preference for the target and a non-preference for the distracter would be different compared to those who have only a preference for the distracter.

In addition, when control demands increased, such as in the incongruent compared to congruent conditions in the Stroop task, the prefrontal cortex showed stronger functional connectivity with task-related posterior regions (Haas, Omura, Amin, Constable, & Canli, 2006; Harrison et al., 2005; Kemmotsu, Villalobos, Gaffrey, Courchesne, & Muller, 2005). This enables us to predict that connectivity between the prefrontal cortex and task-related posterior regions would be different according to preference or non-preference for targets or distracters. However, no study has yet investigated this possibility directly. Therefore, identifying functional connectivity between prefrontal control regions and regions related

with preference or non-preference for specific types of information included in a task may provide further evidence for how cortical regions interact with one another according to individual preferences for cognitive style. The current study aimed to investigate the underlying neural mechanisms involved in cognitive control processes related to preferences in attending to targets and for inhibiting distracters. For this purpose, we employed a modified version of the Stroop task, including a word-spatial task and object-spatial task that each included the same distracter, the spatial location. In the word-spatial task, participants required control processes for a verbal target and a spatial distracter; in the object-spatial task, participants required control processes for an object target and a spatial distracter. We divided participants into two preference groups who had equivalent preference for object information but relatively higher preference for verbal (i.e., Verbalizers) or spatial information (i.e., Spatializers). We presume that Spatializers recruit more control processes to inhibit distracters relative to Verbalizers since the task would require them both to attend to non-preferred verbal targets and to inhibit the preferred spatial distracters in the word-spatial task, and because they would be required to inhibit preferred spatial distracters in the object-spatial task.

Methods

Participants   Fifty-four right-handed healthy volunteers (26 females and 28 males, mean age 21.5 years, ranged from 18 to 32 years) participated in the experiment. All participants were native Korean speakers and had normal or corrected to normal vision and had a history of neither neurological disease nor head injury. Participants provided written informed consent as approved by the Brain Science Research Center at KAIST, Daejeon, South Korea. All participants were monetarily compensated for participation. It is important to note that data from ten participants were excluded from the analyses as they were classified into another group (see the behavioral data analyses section). As a result, a total of 44 participants were included in the analyses (21 women and 23 men; mean age 21.65, SD 2.87 years).

Materials and procedure   The experimental paradigm included two types of spatial Stroop tasks (the word-spatial task and the object-spatial task) which are spatial analogues of the classic color-word Stroop task (Stroop, 1935). Both of the tasks required participants to ignore physical locations of the stimuli and to respond to the direction indicated by the target stimuli. As shown in Figure 1, the target stimuli of the word-spatial task (i.e., the Word task) were

composed of the word, "left" or "right," while the object-spatial task (i.e., the Object task) consisted of a rightward or leftward pointing arrow. the target stimuli were presented For both tasks, the directions of target stimuli were counterbalanced. The stimuli were presented in white on the left or right side (i.e., one or three quarters of the horizontal plane) of a black background screen. The words used in the Word task were presented in Korean. The size of the target stimuli was 1/6 and 1/10 of the horizontal and vertical size of the screen, respectively.

Two conditions were included in each task: in the congruent condition (CON), the direction indicated by the target stimuli and the location where the target was presented were the same. In the incongruent condition (INC), conversely, the identity of the target and its location were inconsistent with one another, as depicted in Figure 1. Consequently, two types of conflict were included in the experiment: one was evoked by conflict between verbal (target) and spatial (distracter) information in the Word task, and the other induced conflict between the object (target) and spatial (distracter) information in the Object task.

A blocked design was used to maximize power to detect different types of the Stroop effects associated with the two tasks. Accordingly, the experiment consisted of four
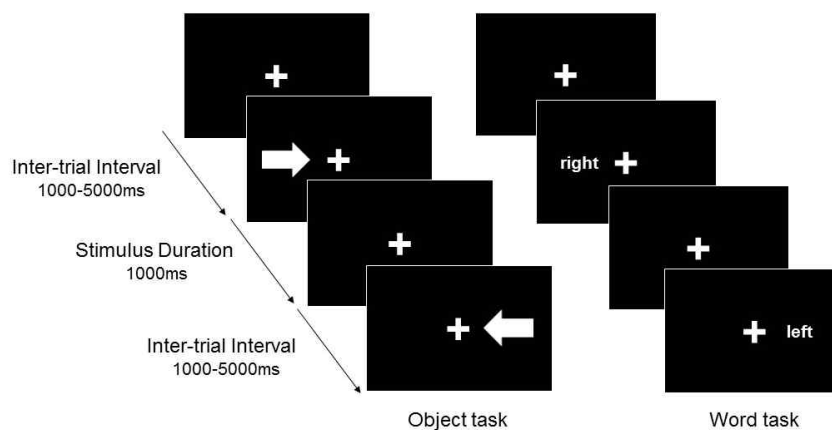
Figure 1. Examples of the task paradigm used in the fMRI experiment. Two types of tasks were included in the experiment: the Object task and Word task. Subjects were instructed to respond to the directions indicated by the head of the arrow stimulus (Object task) or by the meaning of the word stimulus (Word task) while ignoring the location where the stimulus was presented. The sample stimuli represented examples of the incongruent conditions for the Object task (left) and Word task (right), respectively. Note that the words for the Word task were presented in the participant's native language (i.e., Korean).

different types of blocks including Word-CON, Word-INC Object-CON, and Object-INC blocks that were pseudorandomly presented in each session. The task was divided into three sessions and each session included two blocks for each block type, resulting in eight blocks per session. Each task block included eight trials. For each trial, a stimulus was presented for 1,000 ms, followed by an inter-stimulus-interval ranging from 1,000 ms to 5,000 ms (mean ITI = 3,000 ms). Rest periods were presented between task blocks with a fixation cross for 10 s.

Before the fMRI experiment, participants performed a practice session including eight trials for each block type. During the fMRI experiment, participants were required to press correct response buttons as quickly and accurately as possible corresponding to the direction indicated by the target with their left or right thumb. The task was programmed and presented via E-Prime 2.0.

After the fMRI experiment, participants were administered the Korean version of the Object-Spatial-Verbal cognitive style questionnaire (K-OSIVQ) (Blazhenkova & Kozhevnikov, 2009, Shin & Kim, 2013), which is a self-reporting instrument designed to assess individual differences in preference for object, spatial, and

verbal cognitive styles. For example, "My verbal skill is outstanding." was used to measure preference on verbal style and was answered with a 5-point Likert scale. Internal consistency reliability coefficients (Cronbach's alpha) were 0.802, 0.859, and 0.826 for object, spatial, and verbal cognitive styles, respectively.

Imaging acquisition   Imaging data were acquired on a 3-T Siemens Verio scanner at the Brain Science Research Center at KAIST in Daejeon, South Korea. T2*-weighted images were acquired using a gradient-echo planner imaging (EPI) sequence (33 interleaved slices, TR = 2,000 ms, TE = 28 ms, flip angle = 90°, matrix = 64×64, voxel size = 3.5×3.5 mm, thickness = 3.5 mm). Functional scans were composed of three sessions (171 volumes per session). T1-weighted images for all participants were also collected using a magnetization-prepared rapid gradient-echo (MPRAGE) sequence (TR = 1,800 ms, TE = 2.52 ms, inversion time = 1,100 ms, flip angle = 9°, FOV = 256×256 mm, voxel size = 1×1×1 mm, sagittal partitions).

Behavioral data analyses   First, participants' preference scores for object, spatial, and verbal styles as measured by K-OSIVQ were submitted to calculate their relative preference for each style by subtracting the average of the other scores (i.e., for the relative verbal preference score, the average of the object and spatial scores were subtracted from the verbal score). Next, participants were divided into different groups based on these relative preference scores. Specifically, if any cognitive style score was greater than zero (i.e., one was greater than the others), the participant was classified into that cognitive style group. In this way, 22 participants were classified as a verbal preference group (i.e., Verbalizers) and another 22 participants were classified as a spatial preference group (i.e., Spatializers). The remaining participants constituted another group who preferred object style, but these were excluded from the analysis since there were only ten participants in the group. As a result, 44 participants were included in further analyses. To minimize any effect due to individual differences in their object scores, participants' object scores were included as a nuisance variable in the following analyses.

In order to test whether there were differences in reaction times (RTs) or accuracy between groups, tasks, and task conditions, 3-way repeated-measures ANOVAs were performed with the group as a between factor and the task and task condition as within factors. Behavioral data, including the spatial Stroop task and K-OSIVQ data, were analyzed by using SPSS (Statistical Package for Social

Sciences) 21.0.

Image preprocessing and voxel-wise analyses

Functional MRI data were preprocessed and analyzed using an SPM8 software package (Statistical Parametric Mapping; www.fil.ion.ucl.ac.uk/spm). The first three volumes of each session were excluded prior to preprocessing to allow the magnet to achieve a steady state. Functional images were corrected for differences in slice timing, and head motion was corrected using a 6-parameter rigid body correction to realign each image to the first volume of the first session. These realigned images were coregistered with corresponding structural MR images (MPRAGE) using mutual information and were spatially normalized to the International Consortium for Brain Mapping (ICBM) 152 template using a 12-parameter affine registration, followed by nonlinear transformations, resulting in 2 mm cubic voxels. These images were then spatially smoothed with an 8-mm full-width at half-maximum (FWHM) Gaussian kernel.

The first-level analysis was performed in the context of the general linear model (GLM) using a canonical hemodynamic response (HRF). Four task blocks (i.e., Word-CON, Word-INC, Object-CON, and Object-INC) were separately modeled into the GLM model. In addition, six head motion parameters generated from the realignment procedure were included in the model as covariates of non-interest. Subsequently, Object-INC and Word-INC were contrasted with Object-CON and Word-CON, respectively. Consequently, two regressor images representing the two types of the Stroop effect were submitted to the group analysis.

The second-level analysis was performed to identify brain regions selectively associated with two different cognitive style groups in two different types of conflict processing. Two contrast images of each participant were used in the context of a 2×2 random effects repeated measures ANOVA with the group (Spatializers vs. Verbalizers) as a between factor and the Stroop effect type (the Word Stroop effect vs. the Object Stroop effect) as a within factor. Additionally, the object score was added as a covariate of non-interest. A statistical threshold of uncorrected $p < .001$ at the voxel level and family-wise error (FWE) correction of $p < .05$ at the cluster level were applied to the whole-brain analysis.

Psychophysiological interactions analysis analyses

Psychophysiological interaction (PPI) analyses (Gitelman, Penny, Ashburner, & Friston, 2003) were conducted to examine whether the regions of interest (ROIs) observed in the group differences in the whole brain analysis also show differences in functional connectivity between

those regions and the dorsolateral prefrontal cortex (DLPFC), a region known to be critically associated with cognitive control. In order to test inter-regional functional coupling between the DLPFC and the selected ROIs, the seed volumes of interest (VOIs) were defined as spheres with 4-mm radii in the bilateral DLPFC regions and then the first eigenvariate of the VOI time series was extracted. For defining VOIs, DLPFC seed regions were selected based on the coordinates reported in a recent meta-analysis (Niendam et al., 2012) to avoid any potential bias due to circularity (Kriegeskorte, Simmons, Bellgowan, & Baker, 2009). As a result, the left and right DLPFC (x, y, z = -38, 30, 12 and 40, 32, 24, respectively) were defined as seed regions.

On the subject level, PPI analyses compared the temporal correlations between seed regions and other regions associated with the two Stroop effects during different task types. Accordingly, the design matrix for each analysis included three variables: (1) the time-series of the seed region (i.e., the physiological variable), (2) the task contrasts of interest (i.e., the psychological variable corresponding to INC > CON), and (3) an interaction between the psychological contrast of interest and time series of the seed region (i.e., the PPI variable). The physiological variable was extracted from the seed region, which was deconvolved with the HRF, and the psychological variable was generated by convolving the task effect of interest, that is, the Stroop contrast (i.e., INC > CON), for each task. The PPI variable was obtained by calculating an interaction between the deconvolved physiological variable and psychological variable; this was then entered into the PPI model. Additionally, six motion regressors were included in this model as nuisance variables. These steps were replicated for the left and right DLPFC regions, separately. Accordingly, four PPI contrast images associated with the contrasts for the Stroop effects in the Object and Word tasks of both preference groups, resulting from the first-level analysis at the subject level, were submitted to the group-level analyses.

To test group differences in PPI connectivity, the individual PPI contrast images were entered into the one-way ANOVA for each of the Object and Word tasks. For these analyses, brain regions were constrained to clusters showing group differences in the two Stroop effects at the whole-brain analysis level. The statistical threshold was p < .05 at a cluster-level (corrected with a threshold p < .01 for the voxel level), using an AlphaSim Monte Carlo simulation, resulting in two minimum cluster sizes (18 and 11 voxels for the two masks related to the Object and Word Stroop effects, respectively).

Results

Behavioral results Prior to analyzing the experimental data, cognitive style scores were analyzed and participants were assigned into different groups based on these analyses. First, relative cognitive style scores were calculated based on the raw preference scores for object (mean [M] = 3.37, standard deviation [SD] = 0.52), verbal (M = 3.19, SD = 0.70), and spatial (M = 3.00, SD = 1.04) scores. The relative scores ranged from -1.4 to 1.5 (M = 0.27, SD = 0.59) for object style, from -1.93 to 2.54 (M = 0.01, SD = 1.07) for verbal style, and from -2.75 to 2.17 (M = -0.28, SD = 1.32) for spatial style. Using these relative scores, all participants were divided into three groups (twenty-two participants in the Verbalizers, another twenty-two participants in the Spatializers, and the remaining ten participants in the object group). Note that, as described above, the remaining object group was excluded from the analyses. There were significant differences between Verbalizers and Spatializers for the verbal [$t(42)$ = -7.57, p < .001] and spatial [$t(42)$ = 10.40, p < .001] scores. Conversely, object scores were not different between the groups [$t(42)$ = -0.93, p = .36].

Mean accuracy and RTs were analyzed in the context of a 2×2×2 (group × task type × task condition) mixed ANOVA with the group as a between factor and the task type and condition as within factors. All participants performed both the Object and Word tasks with high accuracy (higher than 96% for each of the task and condition). For accuracy, the main effect of the task condition was significant [$F(1, 42)$ = 18.97, p < .001], with higher accuracy in CON (M = 98.96%, SE = 0.30) compared to INC (M = 97.21%, SE = 0.48). Conversely, the main effects of the task type and group and all two- and three-way interactions were not significant (ps > .05).

Mean RTs for both Verbalizers and Spatializers for the two tasks and conditions are presented in Figure 2. The main effect of the task condition was significant [$F(1, 42)$ = 106.14, p < .001], due to longer RTs for INC (M = 543.47 ms, SE = 12.70 ms) compared to CON (M = 504.69 ms, SE = 11.26 ms). The main effect of the task type was also significant [$F(1, 42)$ = 5.67, p < .05], indicating that participants performed faster in the Object task (M = 518.57 ms, SE = 12.07 ms) than in the Word task (M = 529.59 ms, SE = 12.06 ms). However, the main effect of the group was not significant [$F(1, 42)$ = 0.789, p = .379]. Additionally, all two-way and a three-way interactions were not significant (ps > 0.05).
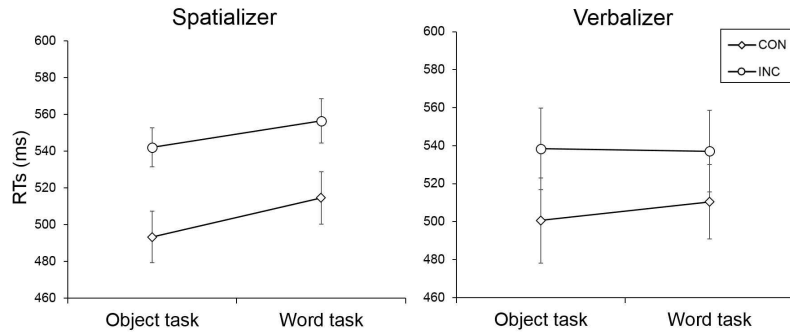
Figure 2. Mean response times (RTs) for two groups in each of the task type and task condition. Error bars represent the standard error of the means.

Imaging results fMRI data were analyzed to identify regions associated with the group differences between the two Stroop effects (i.e., one for the Word task and the other for the Object task). These results are shown in Figure 3 and the cluster details are listed in Table 1. Compared to Verbalizers, Spatializers demonstrated increased activations in the right frontopolar cortex (FPC, BA 10) and right superior temporal sulcus (STS, BA21) with the Word Stroop effect (i.e., the INC - CON contrast from the Word task) (Figure 3A). Conversely, the Verbalizers as compared to the Spatializers showed stronger activations associated with the Object Stroop effect (i.e., the INC - CON contrast from the Object task) in two inferior temporal regions, including the left lingual gyrus (LING, BA 19) and left parahippocampal and fusiform gyri (PHG/FG, BA 37) (Figure 3B). Other than these contrasts, the opposite contrasts showed no differences between the groups.

Although the whole brain analyses identified group differences in the aforementioned regions, further analyses were conducted to determine whether these regions were associated with different levels of activation associated with neural Stroop effects in the regions between groups or with deactivation, namely, greater activation for the CON condition than the INC condition, of either Verbalizers or Spatializers in the regions. Namely, For these analyses, the above four brain regions (i.e., right FPC, right STS, left LING, and left PHG/FG) were defined as ROIs, and BOLD signal changes for each condition (i.e., Word-CON, Word-INC, Object-CON and Object-INC) were extracted from the ROIs. Next, the neural Stroop effects for both tasks were calculated based on the extracted BOLD signal changes by subtracting the signal changes during the CON condition from the INC condition. The computed neural
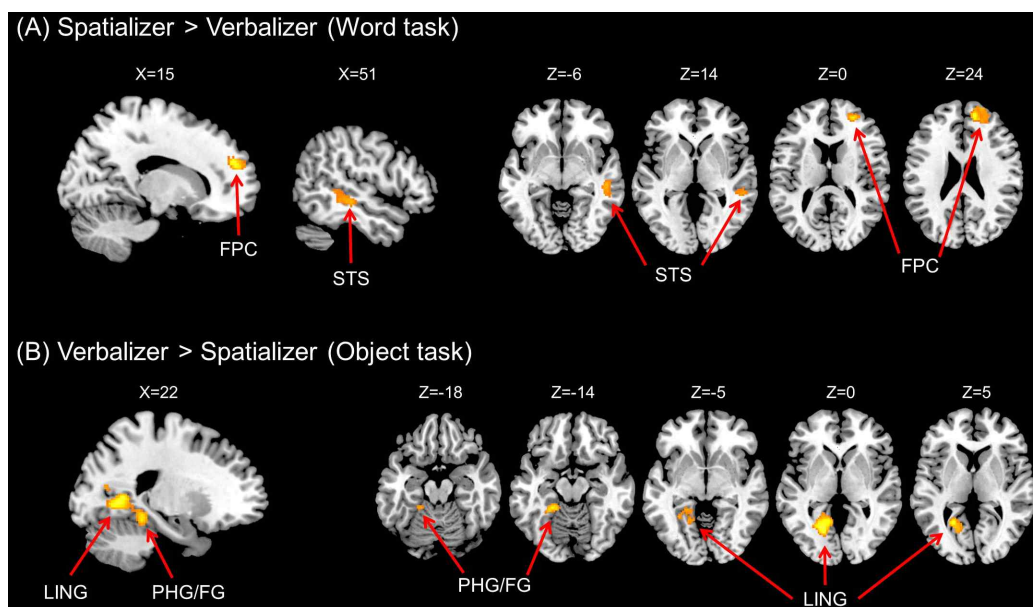
Figure 3. Significant brain activation associated with the Stroop effect. (A) Significant activations of right FPC and right STS for the Spatializers – Verbalizers contrast during the Word task. (B) Activation in the left LING and left PHG/FG for the Verbalizers – Spatializers contrast in the Object task. FPC, frontopolar cortex; STS, Superior Temporal Sulcus; LING; Lingual Gyrus; PHG/FG; parahippocampal/fusiform gyrus. Clusters significantly activated by each contrast, are presented as colored regions.

Table 1. Clusters revealed by the main effect of the group for each Stroop effect

Region	L/R	BA	MNI coordinates			Size	z-score
			X	Y	Z		
Spatializers > Verbalizers in the Word task							
FPC	R	10	12	52	24	579	4.60
STS	R	32	50	-26	-6	209	3.70
Verbalizers > Spatializers in the Object task							
LING	L	19	-18	-64	0	716	4.48
PHG/FG	L	37	-22	-40	-14		3.98

Note: FPC, frontopolar cortex; STS, Superior Temporal Sulcus; LING; Lingual Gyrus; PHG/FG; parahippocampal/ fusiform gyrus.

Stroop effects for each group were then tested using one sample t-tests (with the test value equal to zero) with a Bonferroni correction at p < .05 (corresponding to p < 0.006 at uncorrected level).

As shown in Figure 4, with regard to the Word Stroop effect, there were marginally significant deactivations for Verbalizers in the right FPC [$t(21)$ = -2.871, uncorrected p = -0.009] and the right STS [$t(21)$ = -2.871, uncorrected p = 0.009], and Spatializers demonstrated significant activation in the right FPC [$t(21)$ = 3.362, p < .05] and marginally significant activation in the right STS [$t(21)$ = 2.894, uncorrected p = 0.009]. However, Verbalizers revealed a significant activation related to the Object Stroop effect in the PHG/FG [$t(21)$ = 4.011, p < .05] and

marginally significant activation in the left LING [$t(21)$ = 2.875, uncorrected p = 0.009], whereas Spatializers yielded no significant activation or deactivation for the Object Stroop effect (ps > 0.05).

PPI results In order to investigate changes in the functional coupling between the bilateral DLPFC and the above ROIs according to the groups and task types, the PPI analysis was conducted using bilateral DLPFC as seed regions. The PPI results and cluster details are presented in Figure 5 and Table 2. For the Spatializers compared to the Verbalizers (as shown in red within Figure 5A), the PPI analysis with the left DLPFC revealed significantly increased functional connectivity with the FPC region associated with the Word Stroop effect, and with the left LING
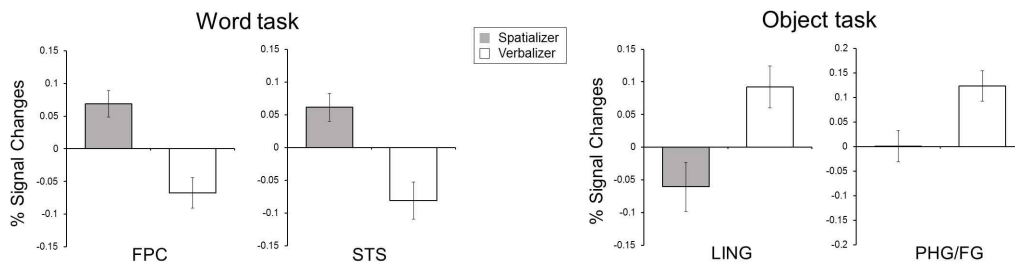

Figure 4. Blood oxygenation level-dependent (BOLD) signal changes for task conditions within functional regions of interest. During the Word task, the right FPC and right STS showed stronger signal changes in Spatializers than Verbalizers. Left LING and left PHG/FG showed stronger signal changes in Verbalizers than Spatializers while performing the Object task: Error bars represent the standard error of the means. FPC, frontopolar cortex; STS, Superior Temporal Sulcus; LING; Lingual Gyrus; PHG/FG; parahippocampal/fusiform gyrus.
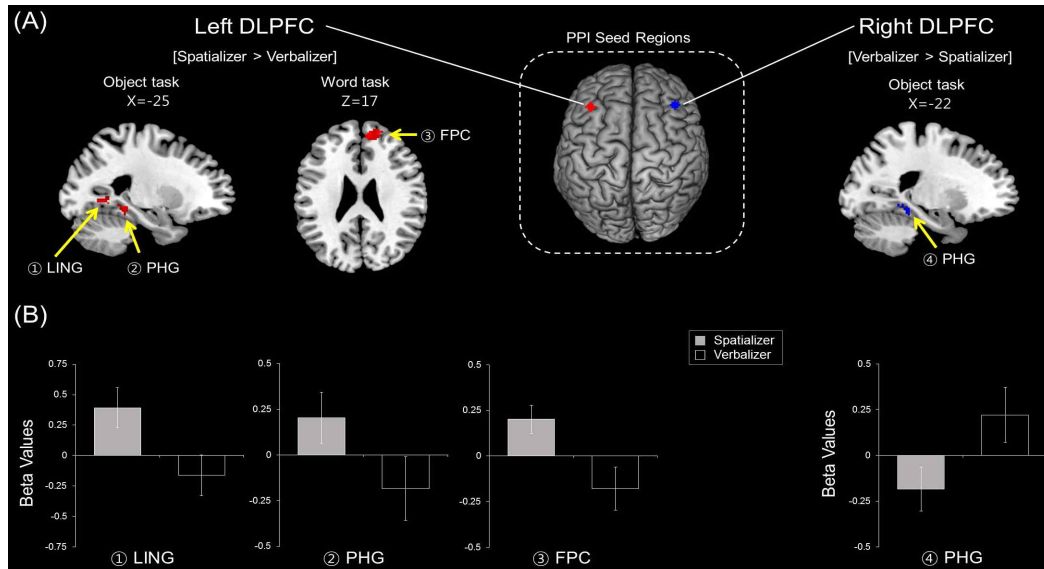
Figure 5. Results of the psychophysiological interaction analysis. (A) Brain regions coupling with the seed regions. Regions shown in red indicate stronger connectivity between left DLPFC and right FPC in Spatializers compared to Verbalizers during the Word task, and between the left DLPFC and left LING and PHG regions in Spatializers compared to Verbalizers during the Object task. Regions shown in blue indicate stronger connectivity between right DLPFC and left PHG in Verbalizers compared to Spatializers during the Object task. The statistical thresholds were corrected to p 〈 .05 at cluster level with voxel-wise p 〈 0.01, using AlphaSim (B) PPI beta estimates of the brain regions coupling with left or right DLPFC. Error bars represent the standard error of the means. DLFPC, dorsolateral frontopolar cortex; FPC, frontopolar cortex; STS, Superior Temporal Sulcus; LING; Lingual Gyrus; PHG; parahippocampal gyrus.

Table 2. Psychophysiological interaction (PPI) results with seed regions (left or right DLPFC)

Seed	Region	L/R	MNI coordinates			Size	z-score
			X	Y	Z		
left DLPFC	Spatializers > Verbalizers in the Word task						
	FPC	R	18	54	26	119	3.18
	Spatializers > Verbalizers in the Object task						
	LING	L	-24	-62	-4	71	3.62
	PHG	L	-26	-38	-8	26	3.43
right DLPFC	Verbalizers > Spatializers in the Object task						
	PHG	L	-22	-36	-12	29	3.06
			-18	-44	-4	22	2.64

Note: FPC, frontopolar cortex; LING; Lingual Gyrus; PHG/FG; parahippocampal/fusiform gyrus.

and left PHG regions with regard to the Object Stroop effect. Conversely, functional coupling increased between the right DLPFC and PHG for Verbalizers compared to Spatializers during the Word task (shown in blue within Figure 5A)

Discussion

This study aimed to identify differences between Verbalizers and Spatializers using a spatial Stroop paradigm of object-spatial and word-spatial tasks, in which object and word stimuli functioned as targets and the spatial location of the stimuli served as a common distracter. This experimental design allowed us to investigate differences in the two different conflict situations by the following comparisons: (1) In the Word task, one group (Verbalizers) that had both a high preference for the target (i.e., words) and a low preference for the distracter was compared to the other group (Spatializers) that had the opposite preference pattern; (2) In the Object task, Verbalizers, who had a low preference for the distracter, were compared to Spatializers who had a high preference for the distracter, while both groups had the same level of the preference for the target (i.e., objects).

Although we expected Verbalizers and Spatializers to show different behavioral

responses, our behavioral results showed that the Stroop effect from the Word and Object tasks were not different between the two groups. Previous studies focusing on how cognitive style is related with an individual's cognitive ability have frequently reported that better behavioral response performances were positively associated with a preference for the task-related information (Cui et al., 2007; Hsu, Kraemer, Oliver, Schlichting, & Thompson-Schill, 2011; Kozhevnikov et al., 2005; Li et al., 2011; Shin & Kim, 2015; Vannucci, Mazzoni, Chiorri, & Cioli, 2008). However, consistent with our results, other studies revealed that cognitive style was not associated with behavioral performance but rather with observed differences in neural activities suggesting that different strategies or neural efficiencies are associated with preferred cognitive style (Kraemer et al., 2009; Motes et al., 2008). Therefore, in the following discussion we focused on whether the observed behavioral performances may be interpreted based on different usages of neural resources for both the Word and Object tasks.

For the Spatializers, we predicted enhanced neural activities in the task-related regions due to unfavorable task demands in the Word task, in which they had to not only focus on the non-preferred verbal stimulus (i.e., target), but also inhibit the preferred spatial location information (i.e., distracter). As predicted,

Spatializers showed more activation in the task-related regions including the right frontopolar cortex (FPC) and right superior temporal sulcus (STS).

First, the FPC has been well known as a key neural substrate for the higher-level cognitive functions, such as decision making (Koechlin & Hyafil, 2007), reasoning (Christoff & Gabrieli, 2000; Green, Kraemer, Fugelsang, Gray, & Dunbar, 2010), task switching at a endogenous or contextual level (Kim, Johnson, Cilles, & Gold, 2011; Rogers, Andrews, Grasby, Brooks, & Robbins, 2000), and manipulation of integrative information (Badre & Wagner, 2004; Bunge, Wendelken, Badre, & Wagner, 2005; Kim, Kroger, Calhoun, & Clark, 2015). Several neuroimaging studies consistently suggest that the FPC is involved in task sub-goal processing during Stroop-like tasks by way of maintaining or monitoring incompatible task rules (Brass, Zysset, & von Cramon, 2001; Braver & Bongiolatti, 2002). Hence, FPC activations observed in Spatializers during the Word task appear to be associated with increased demand of higher-level control due to the fact that these participants have higher preferences for the distracter (i.e., spatial information) compared to the target (i.e., verbal information), whereas Verbalizers have higher preferences for the target compared to the distracter.

Consistent with this result, the PPI results showed that functional coupling between the left dorsolateral prefrontal cortex (DLPFC) and right FPC during the Word task of Spatializers was stronger than that of Verbalizers. The DLPFC region, an a priori defined seed volume for the PPI analyses, has been known to play a fundamental role in cognitive control at the response level (Botvinick, 2008; Egner & Hirsch, 2005; Kim et al., 2011). Specifically, with respect to functional connectivity between the DLPFC and FPC, Nagel et al. (2011) reported enhanced connectivity when higher cognitive effort was demanded, such as increased difficulty in the N-back task (e.g., 3-back minus 1-back). Therefore, higher functional connectivity between the DLPFC and FPC in Spatializers may be interpreted as Spatializers requiring higher-level control through functional coupling between the FPC and DLPFC in order to regulate higher response-conflict due to their relatively higher preferences for distracters compared to targets.

Second, the right STS appears to play a supportive role in Spatializer's verbal processing in a compensatory processing manner. According to a previous meta-analysis on the right hemisphere's role in language processing, right language regions are involved in higher-level verbal functions, such as contextual verbal processing (Vigneau et al., 2011). Additionally, van Ettinger-Veenstra et al. (2010) found that neural activation in the right posterior temporal

cortex was correlated with better performance during a dichotic listening task, indicating a supportive role of the right temporal region in verbal processing. This result has been supported by developmental studies, as well as lesion studies. For instance, research suggests that the right temporal region subserves the left temporal region language function during childhood and early adolescence until the left language areas completely develop (Boatman et al., 1999; Hertz-Pannier et al., 2002). In addition, lesion studies have found that patients who incurred damage to the left language regions were able to recover their lost language ability because of the compensating system of the right hemisphere, including the STS and frontal regions (Gold & Kertesz, 2000; Thiel et al., 2006). Therefore, our results could be interpreted that Spatializers might require additional neural resources in these regions in order to control for non-preferred word processing.

Given that the behavior results between the two groups were not different, greater activations in the right FPC and STS for Spatializers may contribute to their successful behavioral performance in the Word task. In other words, Spatializers might use additional neural resources required both for higher-level control and for verbal compensation processing in order to successfully perform the Word task. This finding suggests that neural efficiency may vary with

individual preference for cognitive style.

Our interpretation regarding the relationship between cognitive style and cortical activation is consistent with previous findings, particularly those studies that used a Stroop task similar to that in the current task (Buzzell et al., 2013; Shin & Kim, 2015). Specifically, Shin & Kim (2015) employed the color-word Stroop task, in which verbal information was presented as distracter, and observed a neural conflict adaptation effect in several task-related regions, such as the left DLPFC, fusiform gyrus, and precuneus, where activity was positively correlated with verbal preference scores. In another behavioral study, the Stroop effect increased by the existence of preferred but task-unrelated information, demonstrating that cognitive style is closely related with control processes for conflict resolution (Buzzell et al., 2013). Moreover, several previous studies using other cognitive task paradigms have shown that task performance is processed more effectively as preferences for the task-related information types increase (Li et al., 2011; Motes et al., 2008). For example, Motes et al. (2008) demonstrated that object-visualizers used lesser neural resources than spatial-visualizers in task-related regions during the object-processing task, although both groups showed equivalent behavioral performances. They suggested that higher preferences for object processing is associated

with more efficient use of object resources, resulting in less neural activity.

Since there was no difference between the groups in preference for the target of the Object task, we would expect the observed results to be related to the difference between preferences for the distracter (i.e., spatial information). In other words, Spatializers would be expected to show greater activation during the Object task in order to control for the preferred spatial distracter than Verbalizers. However, contrary to our expectation, Verbalizers showed greater activation in the two left inferior occipito-temporal regions, lingual gyrus (LING), and parahippocampal/fusiform gyrus (PHG/FG) in the Object task. This raises the possibility that Verbalizers use a different strategy for processing object targets.

Specifically, the LING is involved in early visual processing (Haxby et al., 1991; Zeki et al., 1991). In particular, this region was involved in some aspects of visual processing when participants were required to make a stimulus-specific response, such as object naming. (Humphreys, Riddoch, & Price, 1997; Moore & Price, 1999; Price, Devlin, Moore, Morton, & Laird, 2005; Price, Moore, Humphreys, Frackowiak, & Friston, 1996). For instance, Moore & Price (1999) and Price et al. (1996) reported increased activation in the LING when participants were required to name familiar

objects relative to simply viewing them. Additionally, lesion studies have demonstrated that patients with damage to the LING show impairment in their ability to name objects, whereas their ability to recognize those objects remains intact (Beauvois & Saillant, 1985; Damasio & Damasio, 1983). Hence, greater activation in the LING could be an evidence that Verbalizers might employ an object-naming strategy in order to assist in controlling over conflict between targets and distracters used in the Object task.

The left PHG/FG has been implicated in many studies as an important region involved in semantic processing (Binder et al., 1997; Binder, Desai, Graves, & Conant, 2009; Simons, Koutstaal, Prince, Wagner, & Schacter, 2003; Vandenberghe, Price, Wise, Josephs, & Frackowiak, 1996). Considering that the left LING (in close proximity to the left PHG/FG) may be involved in object-naming processes of the Verbalizers as suggested above, the Verbalizer's PHG/FG activations during the Object task might represent semantic processing associated with the meaning of arrow directions converted from the object information (i.e., arrows) via object-naming. In order words, those who prefer to convert objects into verbal information may highly involve the left PHG/FG for additional semantic processing in order to respond to the non-preferred object target.

The idea that Verbalizers may use a strategy for converting relatively non-preferred object information into preferred verbal code in order to efficiently process non-preferred nonverbal targets is consistent with previous studies that consider an individual`s cognitive strategies for modality-specific processing (Kraemer et al., 2009; 2014). For example, Kraemer et al. (2009) suggested a hypothesis in which one tends to mentally convert information into one's own preferred modality when an incoming stimulus is presented in a non-preferred modality. To confirm their conversion hypothesis, Kraemer et al. (2014) conducted a follow-up study using repetitive transcranial magnetic stimulation (rTMS) and demonstrated that after stimulation of the left supramarginal gyrus, the magnitude of impaired performance that required verbal naming strategies could be predicted by the individual`s verbal cognitive scores, but not by their visual cognitive style. Supporting this hypothesis, the current findings of greater activations in the two left inferior occipito-temporal regions, which are associated with naming and semantic processing, suggest that individuals with preferences for verbal cognitive style tend to use a strategy for converting nonverbal information into the verbal representations. Indeed, Spatializers showed no significant activation or deactivation in the left LING and left PHG/FG compared to baseline,

whereas Verbalizers showed significant activation in left PHG/FG and the left LING. These results are also consistent with the interpretation that Verbalizers might use an additional strategy for converting an object into a verbal code during the Object task.

Additionally, the PPI results for the Object task show that Spatializers had higher connectivity of the left PHG/FG with the left DLPFC relative to Verbalizers, while Verbalizers showed stronger connectivity of the same PHG/FG region with the right DLPFC. This hemispheric asymmetry of functional connectivity has been also observed in previous studies. Specifically, functional connectivity of the task-related regions with the left hemispheric control regions was more specialized for verbal processing (Bokde, Tagamets, Friedman, & Horwitz, 2001; Horwitz, Rumsey, & Donohue, 1998), and the connectivity of those with right hemispheric control regions were more specific to spatial processing (McIntosh et al., 1994). Therefore, observed hemispheric asymmetry in the functional connectivity between Verbalizers and Spatializers during the Object task may reflect individual differences in their information processing according to preferred cognitive styles.

Taken together, the current study found that Verbalizers and Spatializers showed different activation patterns in the Word and Object tasks. These results suggest that individuals

appear to use different strategies for cognitive control processes according to their preferences for the types of information by way of controlling for non-preferred information and/or converting information to their preferred types.

References

Badre, D., & Wagner, A. D. (2004). Selection, integration, and conflict monitoring; assessing the nature and generality of prefrontal cognitive control mechanisms. *Neuron, 41*, 473-487.

Beauvois, M.-F., & Saillant, B. (1985). Optic aphasia for colours and colour agnosia: A distinction between visual and visuo-verbal impairments in the processing of colours. *Cognitive Neuropsychology, 2*, 1-48.

Binder, J. R., Desai, R. H., Graves, W. W., & Conant, L. L. (2009). Where is the semantic system? A critical review and meta-analysis of 120 functional neuroimaging studies. *Cerebral Cortex, 19*, 2767-2796.

Binder, J. R., Frost, J. A., Hammeke, T. A., Cox, R. W., Rao, S. M., & Prieto, T. (1997). Human brain language areas identified by functional magnetic resonance imaging. *Journal of Neuroscience, 17*, 353-362.

Blazhenkova, O., & Kozhevnikov, M. (2009). The new object-spatial-verbal cognitive style model: Theory and measurement. *Applied Cognitive Psychology, 23*, 638-663.

Boatman, D., Freeman, J., Vining, E., Pulsifer, M., Miglioretti, D., Minahan, R., . . . McKhann, G. (1999). Language recovery after left hemispherectomy in children with late-onset seizures. *Annals of Neurology, 46*, 579-586.

Bokde, A. L., Tagamets, M. A., Friedman, R. B., & Horwitz, B. (2001). Functional interactions of the inferior frontal cortex during the processing of words and word-like stimuli. *Neuron, 30*, 609-617.

Botvinick, M. M. (2008). Hierarchical models of behavior and prefrontal function. *Trends in Cognitive Sciences, 12*, 201-208.

Brass, M., Zysset, S., & von Cramon, D. Y. (2001). The inhibition of imitative response tendencies. *Neuroimage, 14*, 1416-1423.

Braver, T. S., & Bongiolatti, S. R. (2002). The role of frontopolar cortex in subgoal processing during working memory. *Neuroimage, 15*, 523-536.

Bunge, S. A., Wendelken, C., Badre, D., & Wagner, A. D. (2005). Analogical reasoning and prefrontal cortex: evidence for separable retrieval and integration mechanisms. *Cerebral Cortex, 15*, 239-249.

Buzzell, G. A., Roberts, D. M., Baldwin, C. L., & McDonald, C. G. (2013). An electrophysiological correlate of conflict processing in an auditory spatial Stroop task: the effect of individual differences in navigational style. *International Journal of Psychophysiology, 90*, 265-271.

Christoff, K., & Gabrieli, J. D. E. (2000). The

frontopolar cortex and human cognition: Evidence for a rostrocaudal hierarchical organization within the human prefrontal cortex. *Psychobiology, 28,* 168-186.

Cui, X., Jeter, C. B., Yang, D. N., Montague, P. R., & Eagleman, D. M. (2007). Vividness of mental imagery: Individual variability can be measured objectively. *Vision Research, 47,* 474-478.

Damasio, A. R., & Damasio, H. (1983). The anatomic basis of pure alexia. *Neurology, 33,* 1573-1583.

Egner, T., & Hirsch, J. (2005). The neural correlates and functional integration of cognitive control in a Stroop task. *Neuroimage, 24,* 539-547.

Friston, K. J., Buechel, C., Fink, G. R., Morris, J., Rolls, E., & Dolan, R. J. (1997). Psychophysiological and modulatory interactions in neuroimaging. *Neuroimage, 6,* 218-229.

Gitelman, D. R., Penny, W. D., Ashburner, J., & Friston, K. J. (2003). Modeling regional and psychophysiologic interactions in fMRI: the importance of hemodynamic deconvolution. *Neuroimage, 19,* 200-207.

Gold, B. T., & Kertesz, A. (2000). Right hemisphere semantic processing of visual words in an aphasic patient: an fMRI study. *Brain and Language, 73,* 456-465.

Green, A. E., Kraemer, D. J., Fugelsang, J. A., Gray, J. R., & Dunbar, K. N. (2010). Connecting long distance: semantic distance in analogical reasoning modulates frontopolar

cortex activity. *Cerebral Cortex, 20,* 70-76.

Haas, B. W., Omura, K., Amin, Z., Constable, R. T., & Canli, T. (2006). Functional connectivity with the anterior cingulate is associated with extraversion during the emotional Stroop task. *Social Neurosciences, 1,* 16-24.

Harrison, B. J., Shaw, M., Yucel, M., Purcell, R., Brewer, W. J., Strother, S. C., . . . Pantelis, C. (2005). Functional connectivity during Stroop task performance. *Neuroimage, 24,* 181-191.

Haxby, J. V., Grady, C. L., Horwitz, B., Ungerleider, L. G., Mishkin, M., Carson, R. E., . . . Rapoport, S. I. (1991). Dissociation of object and spatial visual processing pathways in human extrastriate cortex. *Proceedings of the National Academy of Sciences, 88,* 1621-1625.

Hertz-Pannier, L., Chiron, C., Jambaque, I., Renaux-Kieffer, V., Van de Moortele, P. F., Delalande, O., . . . Le Bihan, D. (2002). Late plasticity for language in a child's non-dominant hemisphere - A pre- and post-surgery fMRI study. *Brain, 125,* 361-372.

Horwitz, B., Rumsey, J. M., & Donohue, B. C. (1998). Functional connectivity of the angular gyrus in normal reading and dyslexia. *Proceedings of the National Academy of Sciences, 95,* 8939-8944.

Hsu, N. S., Kraemer, D. J., Oliver, R. T., Schlichting, M. L., & Thompson-Schill, S. L. (2011). Color, context, and cognitive style:

variations in color knowledge retrieval as a function of task and subject variables. *Journal of Cognitive Neuroscience, 23*, 2544-2557.

Humphreys, G. W., Riddoch, M. J., & Price, C. J. (1997). Top-down processes in object identification: Evidence from experimental psychology, neuropsychology and functional anatomy. *Philosophical Transactions of the Royal Society of London Series B-Biological Sciences, 352*, 1275-1282.

Kemmotsu, N., Villalobos, M. E., Gaffrey, M. S., Courchesne, E., & Muller, R. A. (2005). Activity and functional connectivity of inferior frontal cortex associated with response conflict. *Cognitive Brain Research, 24*, 335-342.

Kim, C., Johnson, N. F., Cilles, S. E., & Gold, B. T. (2011). Common and distinct mechanisms of cognitive flexibility in prefrontal cortex. *Journal of Neuroscience, 31*, 4771-4779.

Kim, C., Kroger, J. K., Calhoun, V. D., & Clark, V. P. (2015). The role of the frontopolar cortex in manipulation of integrated information in working memory. *Neuroscience Letters, 595*, 25-29.

Koechlin, E., & Hyafil, A. (2007). Anterior prefrontal function and the limits of human decision-making. *Science, 318*, 594-598.

Kozhevnikov, M. (2007). Cognitive styles in the context of modern psychology: toward an integrated framework of cognitive style. *Psychological Bulletin, 133*, 464.

Kozhevnikov, M., Kosslyn, S., & Shephard, J. (2005). Spatial versus object visualizers: a new characterization of visual cognitive style. *Memory & Cognition, 33*, 710-726.

Kraemer, D. J., Hamilton, R. H., Messing, S. B., Desantis, J. H., & Thompson-Schill, S. L. (2014). Cognitive style, cortical stimulation, and the conversion hypothesis. *Frontiers in Human Neuroscience, 8*, 15.

Kraemer, D. J., Rosenberg, L. M., & Thompson-Schill, S. L. (2009). The neural correlates of visual and verbal cognitive styles. *Journal of Neuroscience, 29*, 3792-3798.

Kriegeskorte, N., Simmons, W. K., Bellgowan, P. S., & Baker, C. I. (2009). Circular analysis in systems neuroscience: the dangers of double dipping. *Nature Neuroscience, 12*, 535-540.

Li, S., Gong, D., Jia, S., Zhang, W., & Ma, Y. (2011). Object and spatial visualizers have different object-processing patterns: behavioral and ERP evidence. *Neuroreport, 22*, 860-864.

McIntosh, A. R., Grady, C. L., Ungerleider, L. G., Haxby, J. V., Rapoport, S. I., & Horwitz, B. (1994). Network analysis of cortical visual pathways mapped with PET. *Journal of Neuroscience, 14*, 655-666.

Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience, 24*, 167-202.

Moore, C. J., & Price, C. J. (1999). Three distinct ventral occipitotemporal regions for reading and object naming. *Neuroimage, 10*, 181-192.

Motes, M. A., Malach, R., & Kozhevnikov, M. (2008). Object-processing neural efficiency

differentiates object from spatial visualizers. *Neuroreport, 19*, 1727-1731.

Nagel, I. E., Preuschhof, C., Li, S.-C., Nyberg, L., Bäckman, L., Lindenberger, U., & Heekeren, H. R. (2011). Load modulation of BOLD response and connectivity predicts working memory performance in younger and older adults. *Journal of Cognitive Neuroscience, 23*, 2030-2045.

Niendam, T. A., Laird, A. R., Ray, K. L., Dean, Y. M., Glahn, D. C., & Carter, C. S. (2012). Meta-analytic evidence for a superordinate cognitive control network subserving diverse executive functions. *Cognitive, Affective, & Behavioral Neuroscience, 12*, 241-268.

Price, C. J., Devlin, J. T., Moore, C. J., Morton, C., & Laird, A. R. (2005). Meta-analyses of object naming: Effect of baseline. *Human Brain Mapping, 25*, 70-82.

Price, C. J., Moore, C. J., Humphreys, G. W., Frackowiak, R. S. J., & Friston, K. J. (1996). The neural regions sustaining object recognition and naming. *Proceedings of the Royal Society of London B: Biological Sciences, 263*, 1501-1507.

Rogers, R. D., Andrews, T. C., Grasby, P. M., Brooks, D. J., & Robbins, T. W. (2000). Contrasting cortical and subcortical activations produced by attentional-set shifting and reversal learning in humans. *Journal of Cognitive Neuroscience, 12*, 142-162.

Shin, G., & Kim, C. (2013). Individual differences in performance on working memory tasks according to object, spatial, and verbal cognitive styles. *The Korean Journal of Cognitive and Biological Psychology, 25*, 539-563.

Shin, G., & Kim, C. (2015). Neural correlates of cognitive style and flexible cognitive control. *Neuroimage, 113*, 78-85.

Simons, J. S., Koutstaal, W., Prince, S., Wagner, A. D., & Schacter, D. L. (2003). Neural mechanisms of visual object priming: evidence for perceptual and semantic distinctions in fusiform cortex. *Neuroimage, 19*, 613-626.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18*, 643.

Thiel, A., Habedank, B., Herholz, K., Kessler, J., Winhuisen, L., Haupt, W. F., & Heiss, W. D. (2006). From the left to the right: How the brain compensates progressive loss of language function. *Brain and Language, 98*, 57-65.

Vandenberghe, R., Price, C., Wise, R., Josephs, O., & Frackowiak, R. S. (1996). Functional anatomy of a common semantic system for words and pictures. *Nature, 383*, 254-256.

Vannucci, M., Mazzoni, G., Chiorri, C., & Cioli, L. (2008). Object imagery and object identification: object imagers are better at identifying spatially-filtered visual objects. *Cognitive Processing, 9*, 137-143.

Vigneau, M., Beaucousin, V., Herve, P. Y., Jobard, G., Petit, L., Crivello, F., . . . Tzourio-Mazoyer, N. (2011). What is

right-hemisphere contribution to phonological, lexico-semantic, and sentence processing? Insights from a meta-analysis. *Neuroimage, 54*, 577-593.

Zeki, S., Watson, J. D., Lueck, C. J., Friston, K. J., Kennard, C., & Frackowiak, R. S. (1991). A direct demonstration of functional specialization in human visual cortex. *Journal of Neuroscience, 11*, 641-649.

인지적 통제 과정에서 인지양식에 따른
전략 사용의 신경적 증거

서 희 영   김 초 복

경북대학교 심리학과

인지적 통제는 현재의 목표와 관련되는 정보에 주의를 기울이고, 관련 없는 정보를 무시하는 인간의 능력을 포함한다. 이전 연구들에서는 각각의 인지 처리 과정이 특정 정보의 선호 정도에 영향을 받는 것으로 밝혀졌지만, 단일 과제에서 특정 정보의 선호에 의해 두 인지 처리 과정이 어떠한 영향을 받는지에 관해 직접적으로 제시한 증거는 없다. 본 연구는 개인의 선호 인지양식이 과제관련 정보와 과제무관련 정보의 측면에서 인지적 통제 메커니즘에 어떠한 영향을 주는지 알아보고자 한다. 대상-공간-언어 인지양식 설문지의 측정치를 바탕으로, 참가자들을 언어양식 선호집단과 공간양식 선호집단으로 구분하였다. 모든 참가자들은 두 종류의 스트룹 과제를 수행하였다. 언어 과제는 언어 목표자극에 주의를 기울이고 공간 방해자극을 무시하도록 요구하는 과제이고, 대상 과제에서는 대상 목표자극에 주의를 기울이는 동안 공간 방해자극을 무시하도록 요구하였다. 관련 정보를 선호할 때, 그리고 관련 없는 정보를 선호하지 않을 때 더 우수한 수행과 효율적인 신경활성화를 보인 이전 연구 결과들을 바탕으로, 두 과제 모두 공간양식 선호자가 언어양식 선호자에 비해 더 느린 행동 반응과 더 큰 신경 활성화를 보일 것으로 예상하였다. 행동 결과에서 두 과제에서의 스트룹 효과는 집단차를 나타내지 않은 반면, 뇌영상 분석 결과에서는 언어 과제 동안, 언어양식 선호 집단보다 공간양식 선호 집단에서 우측 전두극 피질과 우측 상측두구에서 뇌활동이 증가한 것으로 나타났다. 반면, 대상 과제 동안에 공간양식 선호 집단보다 언어양식 선호 집단에서 좌측 설회와 좌측 해마방/방추상회에서 활성화가 증가한 것으로 나타났다. 뿐만 아니라, 양측 배외측 전전두피질과 과제 관련 영역들과의 기능적 연결성은 두 스트룹 효과에서 집단차를 보였다. 이 결과는 개인의 인지양식 선호에 따라 인지적 통제 과정에서 다양한 전략을 사용하고 있음을 시사한다.

주제어 : 인지적 통제, 인지양식, 공간 스트룹 과제, 신경 효율성, 기능적 자기공명영상