

The effect of semantic categorization of episodic memory on encoding of subordinate details: An fMRI study*

Darren Sehjung Yi¹⁾

Sanghoon Han^{2),3)}

¹⁾Department of Psychology, New York University,

²⁾Department of Psychology, Yonsei University

³⁾Graduate Program in Cognitive Science, Yonsei University

Grouping episodes into semantically related categories is necessary for better mnemonic structure. However, the effect of grouping on memory of subordinate details was not clearly understood. In an fMRI study, we tested whether attending superordinate during semantic association disrupts or enhances subordinate episodic details. In each cycle of the experiment, five cue words were presented sequentially with two related detail words placed underneath for each cue. Participants were asked whether they could imagine a category that includes the previously shown cue words in each cycle, and their confidence on retrieval was rated. Participants were asked to perform cued recall tests on presented detail words after the session. Behavioral data showed that reaction times for categorization tasks decreased and confidence levels increased in the third trial of each cycle, thus this trial was considered to be an important insight where a semantic category was believed to be successfully established. Critically, the accuracy of recalling detail words presented immediately prior to third trials was lower than those of followed trials, indicating that subordinate details were disrupted during categorization. General linear model analysis of the trial immediately prior to the completion of categorization, specifically the second trial, revealed significant activation in the temporal gyrus and inferior frontal gyrus, areas of semantic memory networks. Representative Similarity Analysis revealed that the activation patterns of the third trials were more consistent than those of the second trials in the temporal gyrus, inferior frontal gyrus, and hippocampus. Our research demonstrates that semantic grouping can cause memories of subordinate details to fade, suggesting that semantic retrieval during categorization affects the quality of related episodic memory.

Key words : semantic categorization, episodic memory, representative similarity analysis

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† Corresponding author: Sanghoon Han, Department of Psychology, Graduate Program in Cognitive Science, Yonsei University 50 Yonsei-Ro Seodaemun-Gu, Seoul Korea 03722

Research areas: Episodic memory, Brain cognitive science, E-mail: sanghoon.han@yonsei.ac.kr

Introduction

Human memory is an ambivalent process, firm yet volatile, effective yet limited; such characteristics require us to employ strategies for optimal memory utilization, and the clustering or categorization of memories may be one such strategy. For instance, chunking is known as an effective strategy for better mnemonic performance. Since Chase and Simon demonstrated that chunking of information improves the encoding and recall of long-term memories of chess players in 1973, a number of similar studies have been performed, including that of Gobet et al. (2001), who stated that associations among elements in the same chunk are strong, while those among elements in different chunks are weak. Episodic clustering of memory into semantically related categories have also been known as an effective and necessary strategy for creating and maintaining a better mnemonic structure (Koenig et al., 2005). The effects and usefulness of semantic and episodic information processing have been examined and confirmed for decades, and categorization is said to be a powerful strategy to acquire environmental information with limited cognitive resources and to produce the most effective estimates of yet unknown information (Anderson, 1991; Collins & Loftus, 1975; Grossman et al., 2002; Koenig et al., 2005; Lambon-Ralph, Lowe & Rogers, 2007; Maguire, white & Brier, 2011; Rajah & Macintosh, 2005; Rosch, 1978; Saumier & Chertkow, 2002; Thompson-Schill, 2003; Tunney, Fernie & Astle, 2010).

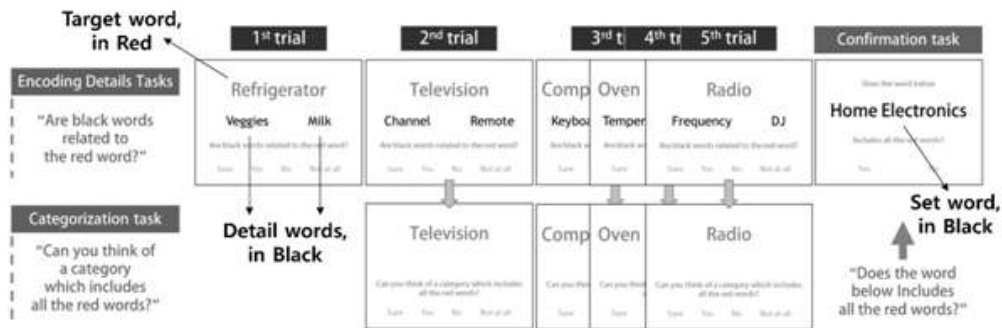
Categorization is not only considered as a level identification process of given information based on the nature of a hierarchical structure embedded in a category, but also a representation of a probability of exemplars in mind-matching given information; the choice of which relies on the amount of resources required to encode the given information when a category is selected (Anderson, 1991; Ashby & Alfonso-Reese 1995; Kruschke, 1992; Love, Medin, & Gureckis, 2004; Pothos & Chater, 2002). Some previous studies also suggest that a categorization of episodic memories establishes a better mnemonic structure and lead to improved memory for episodic details, as categorization process involves both deeper level of processing and chunking of information, which has been easily accepted for decades. Indeed, Craik and Lockhart in 1972 found that deeper processing of given stimuli leads to more concrete memory traces and vice versa decades ago, and a related study by Craik and Tulving in 1975 found that the encoded words were remembered more accurately when assigned to a semantically defined category than when only surface features of the words were investigated. Although a number of researchers have studied the effect of categorization, most studies

were explicitly designed to focus on the categorization of information under a superordinate category, with little or no interest in the influence of categorization on the subordinate details. To our best knowledge, our study is the first empirical research that addresses how categorization impacts episodic details related to the information that is being processed.

In terms of subordinate information, it is not implausible that the categorization of episodic memories will cause disruption of the details of episodic memory, as less informative detailed memories would be crowded out when cognitive resources are demanded for more representative information; especially when one needs to create a category rather than choose from a limited number of existing ones. The aim of the present study was to investigate such disruptions by testing the effect of semantic categorization on episodic details of memory. We instated a new paradigm for our research that requires the encoding and retention of episodic details while ongoing categorization of superordinates. Rule-based categorization was employed in our paradigm, a process in which a test object is evaluated with regard to a set of rules representing category membership criteria (Bruner, Goodnow & Austin, 1956). Such a process requires executive resources to maintain active criteria in working memory, which must be updated to track the results of each criterial evaluation (Grossman et al., 2002).

The level of effort invested during the experiment, which might influence usage of cognitive resources in our study testing the effect of semantic categorization (Jansma, Ramsey, de Zwart, van Gelderen & Duyn, 2007), was accounted for in our experimental design; our experiment demanded escalated levels of effort on each step during semantic categorization of given stimuli as a participant proceed through the task, while keeping the difficulty of encoding subordinate details constant. (see Fig 1).

For neural analyses, we examined whether an overlap in neural function between semantic categorization and keeping of episodic memory details would cause a disruption of the encoding of episodic details, as these two cognitive functions may compete against each other for the limited amount of cognitive resources. We targeted the regions involved in processing both episodic and semantic memories such as temporal and frontal cortices and hippocampi (Badre & Wagner, 2002; Daselaar et al, 2002; Hugdahl et al., 1999; Manns, Clark, & Squire, 2002; Rajah & McIntosh, 2005; Wagner, Bunge & Badre, 2004). Representational similarity analysis (RSA) with searchlight in addition to conventional general linear model (GLM) analysis was applied to achieve more sensitive measurements, as RSA sensitively examines consistency in the patterns of neural activity rather than



(Fig 1) Experimental Procedure. Control sessions involved the same procedure as in the test sessions but different stimuli

the intensity of the activation (Kriegeskorte, Goebel & Bandettini, 2006; Kriegeskorte, Mur & Bandettini, 2008). Hypothesizing that progression of categorization toward completion would show stronger pattern similarity, we sought to identify distinguishable pattern consistencies regarding the process with RSA, while GLM analysis was used to investigate the level of effort involved in processing episodic details, which was not expected to differ throughout the experiment.

Methods

Ethics

This study was reviewed and approved by Departmental Research Committee for Research Ethics (DRCRE) of the Department of Psychology (Approval number: 201208-13-02). Written informed consent was obtained from participants prior to the study, in a manner approved by DRCRE.

Participants

Eighteen healthy college students (10 males, 8 females), a number to yield significant power as known in the literature (Desmond & Glover, 2002; Friston, 2009; Kriegeskorte, Mur & Bandettini, 2008; Pajula & Tohka, 2016), participated in our study for monetary compensation (\$30). All participants were screened for any conditions that can be affected by the magnet (e.g., cardiac pace

maker, metallic skeletal implants, dental works, tattoos with metallic ink, pregnancy, etc.) prior to the experiment.

Experimental Tasks & Procedures

For the experiment, participants were scanned while completing given tasks in a total of four sessions, alternating between experimental and control sessions. To evaluate whether attending superordinate for semantic categorization disrupts or enhances subordinate episodic details, we designed experimental sessions consisting of four sets of five trials that included an *Encoding detail words task* and a *Categorization task* in each trial, as well as a single *Confirmation task* after the fifth trial. Prior to the scanning, participants repeatedly completed practice sessions which involved the same procedure to the experimental sessions, until they were familiarized with the tasks. Participants were told that they would be tested on every word presented on the screen after the completion of the scanning runs.

The detailed procedure for the experimental sessions is as follows: in the *Encoding detail words task*, a red-colored target word with two black-colored detail words beneath it appeared at the center of the screen and participants were asked, "Are the black words related to the red word?" Participants were expected to respond to each question by choosing one among "Sure", "Yes", "No", or "Not at all" by pressing buttons on a button box, respectively, within a response time of 6000 ms, way longer than expected response time, to ensure enough time to have apparent neural pattern changes which will be used in later analyses. The *Encoding detail words task* was followed by a *Categorization task* in every trial, except for the first trial which did not include presentation of a target word. In the *Categorization task*, the two detail words from the *Encoding detail words task* disappeared, and participants answered the question "Can you think of a category that includes all the red words?" The response choices and time frame were the same as in the *Encoding detail words task*. The fifth trial of the *Encoding detail words task* and the *Categorization task* was followed by a *Confirmation task*, in which participants were presented with a previously unseen set word in black and asked "Does the word below Includes all the red words?" This set word had equal chance of being random or the correct category for all the target words presented in the five trials and participants were expected to answer either "Yes" or "No" by pressing buttons on a buttonbox within a time frame of 6000 ms. The choices appeared synchronously with the question and remained on the screen for 6000 ms in all

tasks (*Encoding detail words task*, *Categorization task*, and *Confirmation task*) of every trial. In control sessions, target words in a set were not semantically related to each other, nor were set words related to target words; however, detail words were presented in the same manner as in the experimental sessions. In the post-scan cued recall test outside of the scanner, set words from the experiment were presented in random order on a computer screen in red, and participants typed as many associated detail words as they could remember in a box provided underneath the target word on the screen, in a self-paced manner.

The presented stimuli were common Korean nouns. Each target word (presented in red in the *Categorization task*) was associated with two detail words that were presented simultaneously on the screen (presented in black in the *Encoding detail words task*). A set word presented in black in the *Confirmation task* was either associated with five target words or chosen randomly. The experimental runs were designed in a way that participants were to assume the five target words belonged to a single category, while the presenting order of the target words in a set was randomly chosen. A set word appeared after the fifth trial, which was either the “single” category that participants assumed the five target words were under or randomly chosen word, by the same chance (For a full list of stimuli, please refer to Appendix A).

Verifying our methods and anticipated results, we conducted another behavioral experiment that included more difficult Categorization tasks which is expected to delay categorization completion (Refer to Results for more details and finding.)

fMRI Data Acquisition & Data Analyses

Functional imaging was conducted on a 3T Siemens MAGNETOM Trio, A Tim System MRI scanner, and functional data was acquired using a gradient-echo planar pulse sequence (repetition time = 2000 msec, TE = 30 msec, 3 x 3 x 3 mm resolution, 33 axial slices tilted 30° from the AC-PC plane, no gap, interleaved collection). Stimuli were presented on MRI-compatible goggles, and responses were collected with a MRI-compatible button box with four buttons.

The fMRI data were analyzed using the GLM with SPM8 (Wellcome Department of Cognitive Neurology, London, U.K.) and RSA scripts with searchlight capability written in-house, based on Kriegeskorte, Mur, and Bandettini (2008) and Kriegeskorte, Goebel, and Bandettini (2006). The slice acquisition timing was corrected by resampling all slices relative to the middle slice in temporal order.

The functional images were realigned to correct for head movements, spatially normalized to the Montreal Neurological Institute (MNI) template provided with SPM8, then resampled into 3-mm cubes, followed by spatial smoothing with a 8-mm full-width, half-maximum isotropic Gaussian kernel. For GLM analyses, volumes were treated as temporally correlated time series and modeled by convolving canonical hemodynamic response function (HRF) and its temporal derivative, with delta function marking the onset of each trial. The resulting hemodynamic functions were used as covariates in a general linear model along with a basis set of cosine functions used to high-pass filter the data and covariates representing session effects. Least-square parameter estimates of the best-fitting synthetic HRF for each condition of interest (averaged across scans) were used in pair-wise contrasts and were stored as separate images for each subject, then checked against the null hypothesis with one-tailed t-tests to determine whether effects of subjects were random at the group level. The single trial analysis (STA) which considers every trial of interest as a separate regressor, was applied with SPM8 for RSA for inter-trial comparisons of embedded neural pattern consistencies in order to reveal additional meaningful information that was unobservable by collapsing data to a mean (Pernet, Sajda & Rousselet, 2011). A beta estimate for each trial was collected voxel-by-voxel over the whole brain using a 3 x 3 x 3 voxel searchlight, and then the data was sorted according to the type of tasks involved. Inter-trial cross-correlation of the data was calculated for each subject and pair-wise contrasted at the group level with two-tailed t-tests. Resulting p-values of t-tests for each voxel were saved into a separate image for each contrast.

Each experimental trial was treated as an event of zero duration in the general linear model (GLM). All four runs were concatenated for conventional GLM analysis while considering the session effect from each run, and GLMs for the *Categorization tasks* and *Encoding details tasks* of the experimental trials were modeled separately in both experimental and control runs. Regressors 1 to 5 were the *Categorization tasks* of the first to fifth trials of the experimental runs, and 6 to 10 were the *Encoding detail words tasks* of the trials in the same order. Regressors 11 to 20 were the tasks in the trials of control runs. The *confirmation tasks* were excluded from the analyses and regarded as noise signal since the tasks were included to verify that participants completed categorization with the given red words. For RSA, every trial, regardless of experimental conditions, was modeled separately for STA, and the region-of-interest (ROI) was defined according to automated anatomical labeling (AAL) (Tzourio-Mazoyer et al., 2002) based on prior studies on semantic networks (Badre & Wagner, 2002; Daselaar et al., 2002; Grossman et al., 2002; Hugdahl et al., 1999; Raposo, A., Moss, H. E.,

Stamatakis, E. A., & Tyler, L. K., 2006; Wagner, Bunge & Badre, 2004). Thresholds were set to $p < 0.001$ for GLM analysis and $p < 0.05$ for RSA, unless otherwise specified in the context.

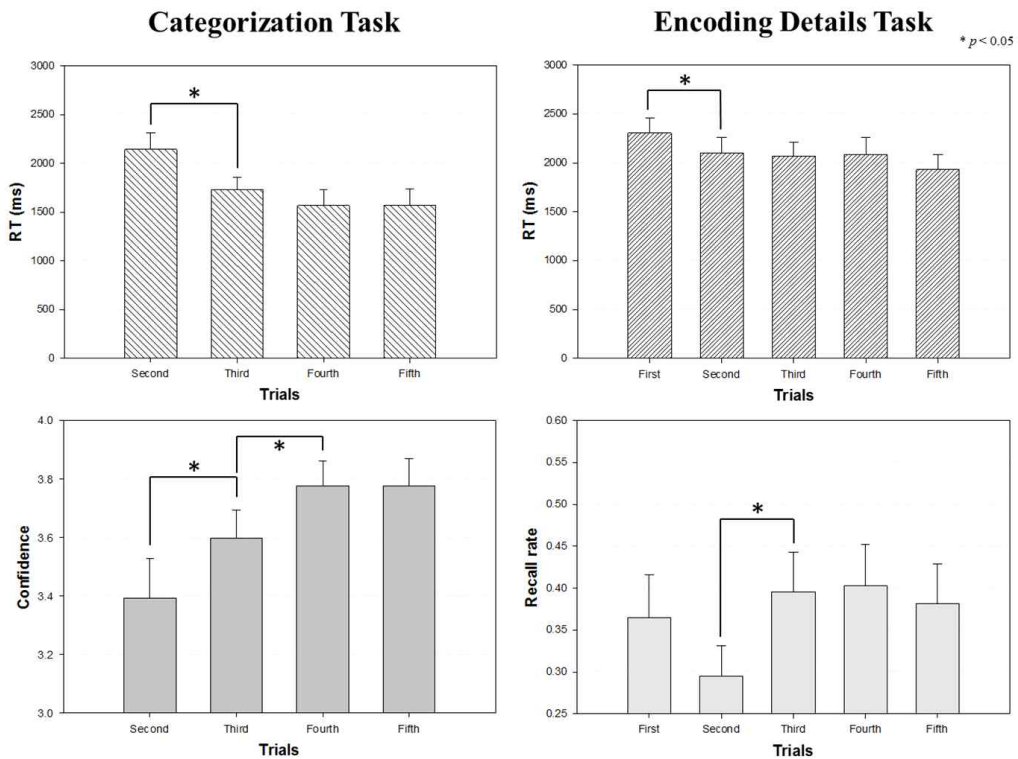
Results

Behavioral Results

We focused on gradual behavioral change as participants progressively categorized red words from one trial to another. We analyzed the reaction times (RTs) and rated confidence in *Categorization tasks*, and RTs and recall rates from cued recalled test of *Encoding details tasks*. The time point of categorization completion was assumed when significant changes were simultaneously observed in RTs and confidence ratings of *Categorization tasks*, and the effect of categorization on subordinate details was evaluated by examining the recall rates of *Encoding details tasks* around the assumed time point.

For analysis, confidence rates were converted into numerical values, with “Sure” being represented with a 4 and “Not at all” being 1. Confidence ratings and RTs of *Encoding details tasks* were not considered for analysis, as both are more associated with episodic memory formed in *Encoding details tasks* rather than sequential categorization. In *Categorization tasks*, pair-wise t-tests between trials in sequential order revealed that RT significantly decreased from second trials ($M = 2142.54$ ms) to third trials ($M = 1727.38$ ms), $t(17) = 3.52$, $p = .003$, while no significant difference was found between third and fourth ($M = 1567.38$ ms) trials, $t(17) = 1.51$, $p = .15$, or fourth and fifth trials ($M = 1570.42$ ms), $t(17) = -0.04$, $p = .97$. In opposition to the observed decrease in RT, confidence ratings increased from second ($M = 3.39$) to third trials ($M = 3.60$), $t(17) = -2.38$, $p = .02$, as well as from third to fourth trials ($M = 3.78$), $t(17) = -2.38$, $p < .001$, but stayed the same from fourth to fifth trials ($M = 3.78$), $t(17) = 0$, $p = 1$. Considering the differences found in both RTs and confidence ratings, we postulate that categorization is successfully established while progressing from second to third trials. In the *Encoding details tasks*, RT only decreased significantly between the first ($M = 2305.77$ ms) and second trials ($M = 2102.06$ ms), $t(17) = 2.49$, $p = .02$, and did not show a significant decrease from second to third ($M = 2072.13$ ms), $t(17) = 0.36$, $p = .72$, third to fourth ($M = 2085.06$ ms), $t(17) = -0.12$, $p = .90$, or fourth to fifth trials ($M = 1928.83$ ms), $t(17) = 1.68$, $p = .11$.

To assess whether episodic details were enhanced or disrupted by the categorization process, we examined recall rates of words presented in *Encoding details tasks*. The recall rates “dipped” prior to third trials, as a marginally significant decrease in recall rate from the first ($M = .36$) to second trials ($M = .30$) was found, $t(17) = 1.87, p = .08$, while recall rate significantly increased from the second to third trials ($M = .40$), $t(17) = -3.07, p = .007$. No significant change was found either from the third to fourth ($M = .40$), $t(17) = -0.19, p = .89$, or fourth to fifth trials ($M = .38$), $t(17) = 0.68, p = .50$. These results can be explained as a consequence of categorization completion during the *Categorization tasks*; red words being fully organized into a common superordinate category somewhere between the second and third trials might be the cause of the disruption in recall rates (see Fig 2).



(Fig 2) Behavioral results from the main experiment. Rated confidence of each trial in *Categorization task* (top left), RT of each trial in *Categorization task* (bottom left), recall rates of episodic details in *Encoding details task* (top right), and RT of each trial in *Encoding details task*. Error bars indicate standard error.

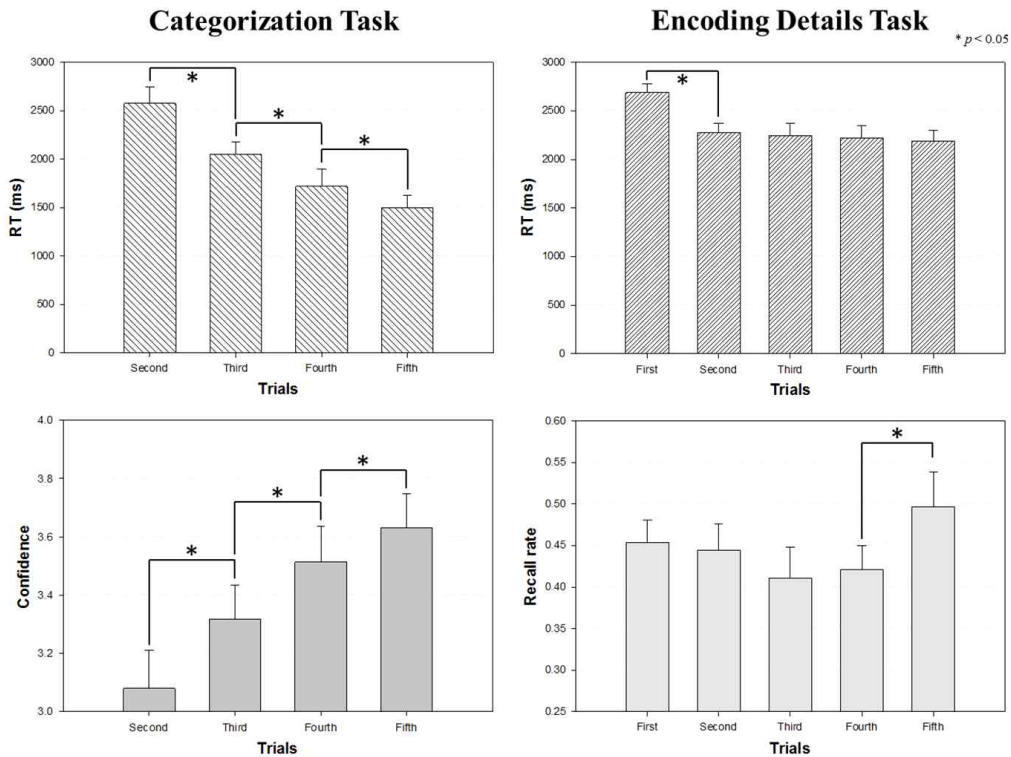
Although our hypothesis was supported by experimental results, further investigation on factors involved in the resulting phenomenon were needed to make sure that the results found in specific time periods was actually occurred due to the factors we suspected. We conducted a behavioral validation experiment by manipulating the difficulties in the *Categorization tasks*, moving forward the temporal position of categorization completion. If the disruption of episodic details prior to the moment of categorization is valid, then shifting the time point of categorization completion will also change the temporal position of the disruption.

Nineteen undergraduate students (6 males, 13 females) participated in our study for either course credit or monetary compensation. Experimental tasks and procedures were identical to the fMRI experiment, except for the word stimuli; 9 target words and 18 detail words used in the experimental sessions were replaced (22.5% of total words). Target words in 75% of total sets were replaced with the new target words that group detail words on divergent criteria while still being categorized under the original set words, in order to increase the difficulty of the *Categorization task* (For a full list of stimuli, please refer to Appendix B).

Results were analyzed in the same manner as in the first experiment. Pair-wise t-tests between sequential trials of the *Categorization tasks* showed that RT significantly decreased from second ($M = 2576.28$ ms) to third trials ($M = 2048.08$ ms), $t(18) = 5.30$, $p < .001$, third to fourth trials ($M = 1720.64$ ms), $t(18) = 3.22$, $p = .005$, and fourth to fifth trials ($M = 1496.49$ ms), $t(18) = 2.14$, $p = .05$. Meanwhile, confidence ratings increased significantly from second ($M = 3.08$) to third trials ($M = 3.32$), $t(18) = -2.36$, $p = .03$, third to fourth trials ($M = 3.51$), $t(18) = -2.70$, $p = .01$, and fourth to fifth trials ($M = 3.63$), $t(18) = -2.96$, $p = .008$. Behavioral changes from one trial to the next were similar to the direction of results from the main experiment, but a significant decrease of RT and an increase of confidence were found in every sequential comparison of trials. Based on these new results, we posit that categorization was completed in the last trial, due to increased difficulty of the *Categorization task* compared to our prior experiment. In the *Encoding details tasks*, a significant decrease in RT was found only from first ($M = 2789.01$ ms) to second trials ($M = 2335.13$ ms), $t(18) = 6.54$, $p < .001$. No significant difference was found either from second to third trials ($M = 2447.22$ ms), $t(18) = -1.12$, $p = .28$, third to fourth ($M = 2359.54$ ms), $t(18) = -0.97$, $p = .35$, or fourth to fifth trials ($M = 2185.97$ ms), $t(18) = 1.07$, $p = .30$. Subsequent analysis of recall rates from cued recall tests for words presented in the *Encoding details tasks* showed significant increases from fourth ($M = 0.42$) to fifth trials ($M = 0.50$), $t(18) = -2.17$, $p = .04$,

immediately prior to the point where categorization was assumed to be established. No significant change was found either from first ($M = 0.45$) to second ($M = 0.44$), $t(18) = 0.28$, $p = .78$, second to third ($M = 0.41$), $t(18) = .64$, $p = .53$, and third to fourth trials, $t(18) = 0.24$, $p = .81$. Similar to our results from our first experiment, the recall rate of detail words “dipped” in the trial prior to the assumed point where categorization is established in *Categorization tasks*, namely the fourth trial in the current experiment. These results are similar to the results of our first experiment, providing supports for our view that the low performance of episodic encoding is due to the disruption caused by successful semantic categorization of events (See Fig 3).

Considering the results from both the *Categorization tasks* and *Encoding details tasks* of the first experiment and similar results from the validation experiment, we emphasize the change to and from third trials of the main experiment in the fMRI results.



(Fig 3) Behavioral results from the validation experiment. Rated confidence of each trial in *Categorization task* (top left), RT of each trial in *Categorization task* (bottom left), recall rates of episodic details in *Encoding details task* (top right), and RT of each trial in *Encoding details task*. Error bars indicate standard error.

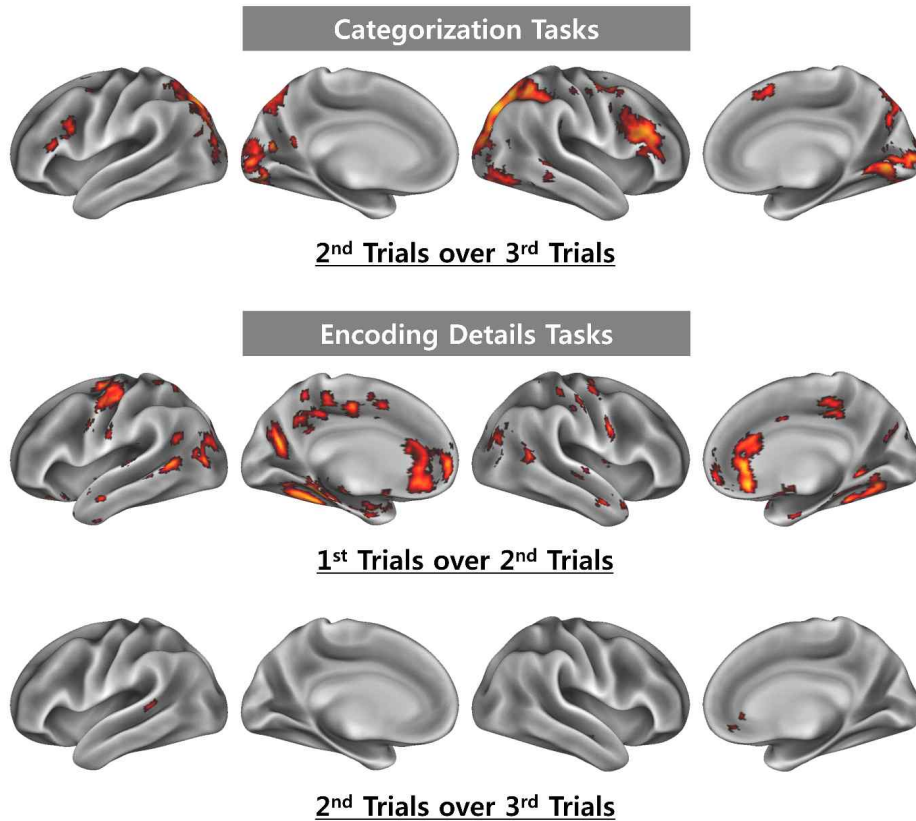
fMRI Results

General Linear Model Analysis

Regions of the semantic network (Badre & Wagner, 2002; Grossman et al., 2002; Raposo, Moss, Stamatakis, & Tyler, 2006; Wagner, Bunge & Badre, 2004) based on prior studies were the main focus of our study. Considering our findings in behavioral results, we contrasted the neural activities of tasks included in the trials in sequential order as we did in the behavioral analyses (i.e., tasks in first trials vs. tasks in second trials, so on), while focusing on the time period between the second and third trials as the possible moment of successful categorization. Changes of neural activations in target regions in each trial were consistent with the behavioral results. Following our hypothesis of categorization, the GLM analysis showed a gradual decrease in the activation of regions up to the assumed time point of categorization completion, reflecting the change in effort invested in the process to this cognitive achievement (Jansma, Ramsey, de Zwart, van Gelderen & Duyn, 2007).

In *Categorization tasks*, the experimental procedures prompted participants to actively engage in the categorization process, and the level of effort required was anticipated to decrease with trials until the point of categorization completion. When comparing the neural activities of *Categorization tasks* involved in second and third trials, higher activations were observed in the second trial in the bilateral dorsolateral prefrontal cortices (dlPFC) including the bilateral inferior frontal gyri (IFG; BA 45), middle frontal gyrus (MFG; BA 6/8/9/46), right superior frontal gyrus (rSFG; BA 6), and in right superior temporal gyrus (rSTG; BA 22), middle temporal gyrus (rMTG; BA 21/22), inferior temporal gyrus (rITG; BA 20), and bilateral precunei (PrC; BA 7/19/31) and caudate nuclei, while no significant hyperactivity was found in the opposite direction of the comparison. Comparisons of the third to fourth and fourth to fifth trials resulted in no important supra-threshold activation difference. Higher levels of neural activation in the areas of the semantic network found in the analysis implies usage of cognitive resources in the process of semantic categorization and supports our behavioral results in which categorization was postulated to be completed between the second and third trials. (see Fig 4 and Table 1)

For *Encoding details tasks*, the same level of effort for each trial was expected, as in the way that our experiment was designed. We analyzed the results in the same manner as for the *Categorization tasks*, and neural activities of *Encoding details tasks* were in agreement with our expectations. Higher overall activations were found in the first trials compared to second trials but were disregarded as



(Fig 4) GLM results of the experimental tasks. Highlighted regions denote areas of significant difference in neural activity.

those were possibly caused by a novelty effect of the task or stimuli rather than actual neural activity of our interest. Comparison of first to the second trials showed significantly higher activation in the left superior frontal gyrus (LSFG; BA 8/9/10), bilateral inferior frontal gyri (IFG; BA 9/47) and medial frontal gyrus (mFG; BA 6/10/11/25) of the dorsolateral prefrontal cortex (dlPFC), bilateral superior temporal gyri (STG; BA 22/38/39/42) and middle temporal gyrus (mTG; BA 19/21/38/39), bilateral precuneus (PrC; BA 7/31) and parahippocampal gyrus (PHG; BA 19/35/36). The right medial frontal gyrus (rmFG; BA 10) was found to be more activated in the second trials compared to third trials, while the comparison in the opposite direction did not show any significant difference in our ROIs. No significant area was found in the comparison of the third to fourth trials and fourth to fifth trials. Absence of significant difference in neural activity among trials except that caused by the novelty effect supports our assumption that participants invested the same level of effort into the

〈Table 1〉 Whole brain GLM analysis, categorization task

Regions	Lat. ^a	BA ^b	Talairach Coordinates			z-score
			x	y	z	
<i>Categorization tasks,</i>						
<i>SecondtrialsoverThirdtrials</i>						
Superior Frontal Gyrus	R	6	9	13	53	3.48
	L	6	-36	1	48	3.36
		6	-27	5	56	3.28
	R	6	33	-1	53	4.46
		9	50	10	36	3.13
		6	39	1	48	3.98
		6	27	10	45	3.23
		8	50	13	42	3.17
		46	48	23	22	3.99
Inferior Frontal Gyrus	L	45	-48	26	11	3.55
	R	45	48	26	8	3.65
Superior Temporal Gyrus	R	22	65	-41	9	3.43
Middle Temporal Gyrus	R	21	59	-39	0	3.16
		21	65	-45	-4	3.16
		22	56	-33	-3	3.10
Inferior Temporal Gyrus	R	20	48	-54	-14	3.27
Precuneus	L	7	-12	-68	49	4.48
		19	-30	-69	40	4.22
		19	-30	-81	35	4.01
	R	7	15	-71	51	3.40
	R	7	21	-63	34	3.55
		19	27	-75	43	4.20
	31	18	-67	26	3.47	
Caudate Nuclues	L	N/A	-9	-11	-2	3.84
	R	N/A	9	11	0	3.51
Superior Parietal Lobule	L	7	30	-48	48	3.92
		7	-27	-62	54	3.92
	R	7	33	-69	43	4.63
		7	30	-63	51	4.29
Inferior Frontal Lobule	L	40	-36	-48	50	3.25
		40	-39	-43	42	3.18
	R	40	36	-37	41	3.57
		40	33	-51	39	3.54
		40	48	-34	30	3.67

^aLat. = laterality; ^bBA=approximateBrodmannareas

〈Table 2〉 Whole brain GLM analysis, encoding details task

Regions	Lat. ^a	BA ^b	Talairach Coordinates			z-score
			x	y	z	
<i>Encoding Details tasks,</i> SecondtrialsoverThirdtrials						
Medial Temporal Gyrus	R	10	9	42	-11	3.43
Anterior Cingulate	R	32	6	34	-3	3.30

^aLat. = laterality; ^bBA=approximateBrodmannareas

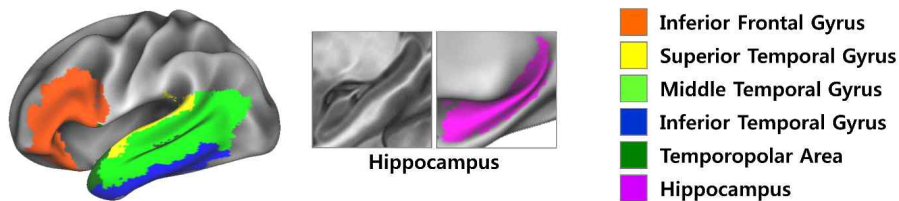
tasks, in spite of the behavioral difference in recall rates of episodic details (see Fig 4 and Table 2).

Neural Pattern Similarities Reflected in Categorization Process

Representational similarity analysis examined pattern consistencies of neural activities elevated by experimental tasks while GLM analysis compared the level of activation. Using RSA, we expected to find a gradual increase in pattern similarity up to the third trials of the *Categorization tasks*, where categorization was believed to be completed according to the behavioral results and GLM results, with no significant increase in trials following successful categorization (See Fig 2 and Fig 4). *Encoding details tasks* were excluded from analysis as we focused on the categorization process rather than encoding of stimuli.

Unlike conventional GLM analysis which implies higher neural activation in certain groups of voxels in a region, RSA with searchlight is more focused on voxel-by-voxel differences in correlation of neural activities in temporal dimension. This allows RSA to attain not only more sensitive measurements than GLM analysis but also spontaneous findings in the whole brain area in pair-wise contrasts.

Commonly known areas of the semantic network and memory processing based on previous studies include the temporal gyri, inferior frontal gyrus, and hippocampi (Badre & Wagner, 2002; Daselaar et



(Fig 5) Regions-of-Interest for RSA. Colored areas denote regions included in the analyses.

〈Table 3〉 Regions-of-Interest for Representational Similarity Analysis

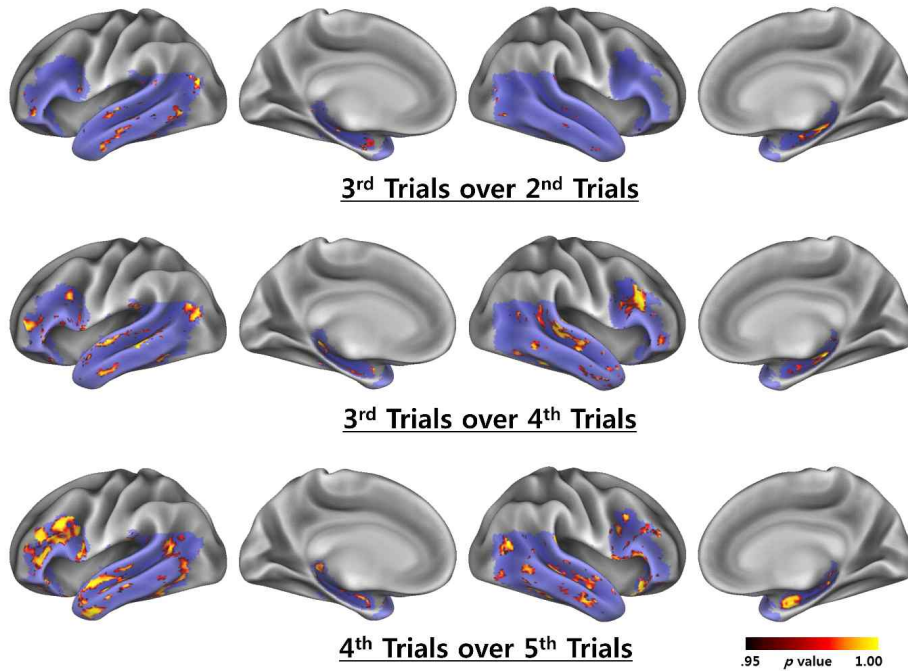
Regions	Laterality	Brodman Area
Inferior Frontal Gyrus	L / R	22
Superior Temporal Gyrus	L / R	21
Middle Temporal Gyrus	L / R	20
Inferior Temporal Gyrus	L / R	38
Temporopolar Area	L / R	44, 45, 47
Hippocampus	L / R	N/A

al, 2002; Hugdahl et al., 1999; Manns, Clark, & Squire, 2002; Rajah & McIntosh, 2005; Wagner, Bunge & Badre, 2004). These areas were selected as our ROIs for the representational similarity analyses (See Table 3 and Figure 4).

Comparison of second and third trials revealed higher levels of pattern similarities in the bilateral temporal and inferior frontal gyri, and hippocampi in third trials. The same regions showed higher pattern consistencies in third trials compared to fourth trials and in fourth trials compared to fifth trials. The gradual increase and decrease in pattern similarities surrounding the third trials, the postulated time point of categorization completion, demonstrate that categorization is a unique, multi-level process that involves discriminable patterns of neural activities, and supports our findings from the behavioral and GLM analyses that categorization is established around the third trial.

Although brain regions involved in processing of memory and semantic information were identified by analysis of similarities in activation patterns, it was unclear whether the results were due solely to actual differences in pattern consistencies or were confounded by other factors. The results from pattern similarity analysis can be affected both directly and indirectly by differences in mean levels of neural activation, as the statistical comparisons used in the analysis involved the actual intensity of activations, and such activations are effectively induced by psychological processes involved in the experiment. To corroborate our findings, the GLM analysis was repeated with a very liberal threshold ($p < .1$, uncorrected), identifying the voxels with significant differences in activation magnitudes. The resulted voxels were subtracted from our results of pattern similarity analyses. (See Fig 6).

Significant differences, in almost identical manner to our RSA results on cortical areas, were found in third trials compared to second trials in the bilateral inferior frontal and temporal gyri, and hippocampi. Third trials revealed higher pattern consistencies in the mentioned regions compared to



(Fig 6) RSA results of the categorization task excluding voxels of the GLM results. Highlighted regions denote significant differences in pattern similarities; blue-colored regions denote ROI.

fourth trials, as did fourth trials when compared to fifth trials.

Sequential increases and decreases in pattern consistencies with third trials showing the highest pattern consistencies was found even after removing the voxels responsible for statistical differences in GLM analysis. This result indicates that pattern similarities in the processing of semantic information convey different meanings than those of overall magnitude changes in neural activation. In support of the RSA results, these new results possibly indicate that neural patterns in the categorization process change based on its progress toward completion and are reliably distinguished from neural activation strength, although not completely independent of the fluctuation in neural firing intensities.

Discussion

Grouping of episodic memories into semantically related categories is known to be necessary for

superior mnemonic structure (Koenig et al., 2005). However, the effect of this grouping on subordinate levels of memories has not yet been well researched. Here, we examined whether semantic categorization of superordinates would enhance or disrupt its subordinate details by implementing a new paradigm that requires simultaneous encoding and retention of episodic details while engaging in categorization of superordinates. Employing RSA with searchlight in addition to conventional GLM analysis, we sought to examine not only the level of neural activation of a certain region, but also the pattern similarity with voxel-level sensitivity (Kriegeskorte, Goebel & Bandettini, 2006; Kriegeskorte, Mur & Bandettini, 2008).

The time point of categorization was found to be the third trial according to behavioral results from the *Categorization task* of the fMRI experiment, where simultaneous significant decreases in RT and increases in confidence ratings were found. Evaluation of the effect of categorization on subordinate details was followed by examination of the recall rates during the *Encoding details tasks*, and a significant “dipping” in recall rate was found prior to the assumed time point of categorization. This finding supports our hypothesis that categorization of episodes disrupts subordinate details of episodic memories. To verify the found effect, we also conducted a behavioral validation experiment that had manipulated difficulty of categorization. The new experiment was designed in a way that the point of categorization would be pushed forward along with the temporal position of the disruption on encoding of detail words. The results followed the design that both categorization completion and the time point of encoding disruption were delayed.

Our results are in line with previous fMRI studies that showed increased neural activities during categorization (Grossman et al., 2002; Okada et al., 2000) although comparisons done in our analyses focused on difference in general brain activation associated with categorization. The task in our study borrows ideas from classical and fundamental concepts (Costanzo, 2013; Ungerer & Schmid, 2006) in categorization that semantic information can be ordered into a hierarchy of its features. In the same direction, our study shares a concept with a previous study (Löw et al., 2003) that semantic process involved during categorization of subordinate information into superordinate groups instates specific patterns of brain networks.

The new findings in our study on the effect of categorization of superordinate upon episodic details highlight the loss of memory details, but it does not conflict with well-known previous studies as our research pertains to different levels of mnemonic structures involved in categorization. Unlike conventional categorization experiments dealt with memories of the information being categorized and

discussed how categorization affects information at the same semantic level, we analyzed different level of information; subordinate memories. There is an undeniable possibility that the recall of target words could have been affected by the categorization process; however, this possibility was eliminated in our analysis because the cues presented in the cued recall tests were the target words themselves. Rosch (1978) and Anderson (1991) describe categorization as an optimal sacrifice for conserving as much finite resources as possible, a hypothesis supported by our experiments due to the strong drop of recall rate immediately prior to completion of categorization. The amount of resources invested in a process cannot be independent from the resources allocated to another since the human cognition operates on finite. Therefore, the encoding of episodic details is inevitably affected by the process of categorization.

While our two experiments resulted in support of our hypothesis, there are a number of points to verify before forming a reliable conclusion. First, the continuous increase in confidence rating within the *Categorization task* of the validation experiment may be due to incomplete categorization caused by increased difficulty of the task. We assumed the period of transition from second trials to third trials in the fMRI experiment as the temporal indication of successful categorization, although confidence increased after the third trials. Indeed, confidence can increase after completion of categorization as participants become more confident when a newly presented target word belongs to their subjectively determined categories. This could also be true for the validation experiment, but a chance to explore such a tendency was not available in our new experiment, since categorization was found to be established in the last trial. Second, the result that subsequent cued recall rates of detail words in the validation experiment differed only in sequential comparison of the fourth and fifth trials could be seen as categorization is completed before participants reached the fifth trials. We call the significantly low recall rate prior to the point of categorization a “dip” not only due to the peaking of recall rate after the “dip”, but also because only the fourth trials were found to be significantly different from fifth trials compared to all other trials. If categorization was to be complete prior to the fifth trials and “dip,” in the fourth trials were not to be produced, then significant differences must also be found when fifth trials were compared to other trials, not only fourth trials. Third, continuous decreases in RT in concordance with simultaneous increases in confidence ratings in the *Categorization task* of our validation experiment might conservatively be seen as little vague in its support of the fMRI experiment. Nonetheless, rather than ruling out other factors that might affect our results, we emphasize the finding that the assumed time point of categorization appeared to occur in conjunction

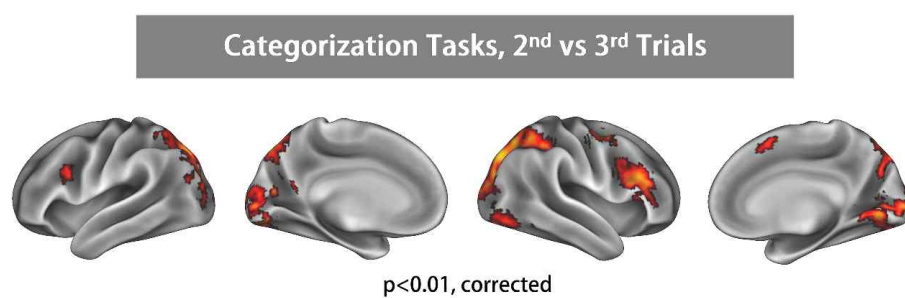
with a disruption in the recall of detail words. The time point was successfully moved forward by increasing the task difficulty, indicating that the effort invested in categorization affects the creation of categorical representation.

There are also some worth mentioning alternative accounts to argue against: increases in demand of cognitive resources or competitions for general-purpose attentional resources, both of which could lead to poor encoding of details (Craik, Govoni, Naveh-Benjamin & Anderson, 1996; Fernandes & Morris, 2000). It should be noted that the postulated time point of categorization completion was moved to different temporal location in the validation experiment, from just prior to third trial to that of fifth trial, to be specific. Time allocated for two trials in the first experiment would have been too short to show that the working memory is not the primary component, but five trials in the validation experiment seems long enough. Also, if any increase in cognitive demands might lead to poor encoding of the detail words, then there must have been some significant decreases of recall rates in incremental order of trials, but such was not found until immediately prior to the postulated time point of categorization completion. It is also possible that divided attention might be involved in the task, but it should have been the case for all trials, not just for the time period immediately prior to the third or fifth trial. If one needed to keep in mind the previous target words and compare those to the current target word to search for a semantic category, and if the process required general-purpose resources, then it must have happened through the whole experiment procedure, not just at certain time points.

The GLM analysis of brain regions in a semantic network (Badre & Wagner, 2002; Daselaar et al, 2002; Hugdahl et al., 1999; Manns, Clark, & Squire, 2002; Rajah & McIntosh, 2005; Wagner, Bunge & Badre, 2004) for the fMRI experiment yielded results that showed similarities to the behavioral results, and the level of effort required for categorization was expected to be lessened, trial-by-trial, until the moment of successful categorization. As expected, we observed significantly lower neural activation of the bilateral dlPFC and precunei, rSFG, rSTG, rMTG, rITG, and caudate nuclei in third trials compared to second trials, and no significant change in activation was observed after the third trials. Comparisons of third to fourth and fourth to fifth trials did not show important supra-threshold differences in activation. These results support the findings from our behavioral study, in which categorization was possibly completed between second and third trials. In the *Encoding details tasks*, no significant difference in neural activation in each trial was expected, as every trial was supposed to be completed with a similar amount of effort. The analysis concluded as we expected,

except that the overall activation pattern was found to be higher on first trials compared to second trials which was disregarded as a novelty effect of the task or stimuli.

Representational similarity analysis results also supported our hypothesis, in that each level of the categorization process was discriminated from one another. Gradual increases in pattern similarity up to the third trials where categorization was supposedly completed supported our view, indicating that neural activity patterns of voxels were more persistent as participants progressed toward completion of categorization. Subsequent decreases in pattern similarities after the categorization were also observed, indicating that pattern similarities peaked at the moment of successful categorization. We hypothesized that the change of directionality marks a cognitive process takeover as the increase indicates more neural information being cognitively collected, whereas the decrease demonstrates that building of neural similarity is not required anymore and another cognitive process took over. One possible new process would be maintenance of the completed categorization, which does not require any increase in pattern similarity. Ensuring reliability of our sample, we took an extra step to check whether multiple comparisons with our sample could produce unpredicted errors. We corrected our GLM result of comparison between second and third trials to the level that corresponds to very strict FWE corrected $p < 0.01$ (Slotnick, Moo, Segal & Hard, 2003) and compared it to our original results. While some regions did not survive such stringent threshold, most of the regions responsible for semantic processing did, resulting in a pattern seemingly very similar to our original result (See Fig 7 and Table 4). Correction of results could possibly negate the increase of type I error, but it may inflate type II error along the way, so it could miss out significant results rather than add up false findings. With all the mentioned evidences, we argue against the view that our sample is too small or our results are falsely reported by errors.



(Fig 7) Corrected result of the categorization task, 2nd vs 3rd trial. Corrected to the level of $p < 0.01$, seemingly very similar to uncorrected $p < 0.001$.

〈Table 4〉 Whole brain GLM analysis, categorization task, $p < 0.01$, corrected

Regions	Lat. ^a	BA ^b	Talairach Coordinates			z-score
			x	y	z	
<i>Categorization tasks,</i>						
SecondtrialoverThirdtrials,						
$p < 0.01$, corrected						
Superior Frontal Gyrus	L	9	-48	16	24	3.33
	R	6	36	0	53	4.24
		9	39	10	27	3.70
		6	9	14	52	3.59
		6	30	8	47	3.26
Inferior Frontal Gyrus	R	45	48	27	10	3.78
Inferior Temporal Gyrus	R	37	39	-67	-4	3.56
Precuneus	L	19	-30	-62	39	4.54
		19	-30	-83	35	4.32
		7	-18	-67	50	3.99
		R	7	30	-47	49
	31	18	-69	28	3.30	
Superior Parietal Lobule	L	7	-27	-61	56	3.99
		7	-12	-64	58	3.58
	R	7	33	-68	45	4.67
		7	27	-62	50	4.35
Inferior Parietal Lobule	L	40	-36	-50	52	3.27
	R	40	36	-36	43	3.70
		40	33	-53	41	3.67

^aLat. = laterality; ^bBA=approximateBrodmannareas

An extra concern would be potential difference of neural semantic representations among individuals. While some recent studies focused on individual mappings of semantic processing (Huth, Wendy, Griffiths, Theunissen & Jack, 2016), it is consistently found throughout the literature that there are common regions involved in the semantic processing (Badre & Wagner, 2002; Daselaar et al., 2002; Grossman et al., 2002; Hugdahl et al., 1999; Raposo, Moss, Stamatakis & Tyler, 2006; Wagner,

Bunge & Badre, 2004). We set our *a priori* ROI for sensitive analyses based on the consistent findings, thus we can say that our resulted brain representation is not dependent or functionally biased by individual differences of semantic networks. In addition, we are looking for involvement of semantic network during episodic encoding and our findings on underlying neural mechanism of semantic network are consistent with what is found in previous studies in the literature mentioned.

Our study is not without limitations. First, the time period of assumed categorization is relatively broad. A six-second-long *Encoding detail task* was implemented between two *Categorization tasks*, and we presumably define that gap as the time period that includes the moment of categorization. A shorter interval would improve the precision of such a prediction but could also possibly lessen the effect of categorization if the shortened interval is not long enough to ensure the development of categorization. Second, even though we tried to minimize the sensitivity problem by regulating the number of voxels included in a searchlight to a relatively conservative number, RSA with searchlight can be overly sensitive due to the fact that each voxel holds the mean correlation value of included trials' activations. It is also without doubt that morphologies in western and eastern languages are different, but we rather focused on categorization process built upon the meaning of the words than linguistic features in our study. Statistical power and individual differences in semantic processing that are elaborated in the discussion might be extra issues to consider. Lastly, as concerned by reviewers, we treated recruited subjects as a normal sample under usual fMRI criteria, without explicitly conducting neuropsychological test.

Our study tested the effect of semantic categorization on subordinated detail using a new paradigm that engages encoding and retention of details with categorization of superordinate, and both behavioral and neural results identified disruption of episodic details prior to completion of categorization. In spite of the limitations in our experiment, the current results elucidate an unknown effect of categorization on subordinate details.

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(요 약)

일화 기억의 의미적 범주화가 세부 기억의 부호화에 미치는 영향에 대한 자기공명영상 분석 연구

이 세 중¹⁾

한 상 훈^{2),3)}

¹⁾뉴욕대학교 심리학과

²⁾연세대학교 심리학과, ³⁾연세대학교 인지과학 협동과정

의미적 연관성을 지닌 일화들의 범주화는 기억을 더 효과적으로 구조화하는데 도움이 된다. 그러나 해당 일화의 하위 세부 기억들에 대한 상기한 범주화의 영향은 아직 명확하게 알려져 있지 않다. 본 연구에서는 fMRI 실험을 통해 의미적 범주화가 이루어지는 동안 상위의 일화 기억에 주의를 기울이는 것이 하위 세부 기억의 생성을 방해하는지, 혹은 강화하는지 실험하였다. 참가자들에게 한 사이클 내에서 각각 2개의 하위 단어를 가지고 있는 5개의 목표 단어들 순서대로 제시되었는데, 참가자들은 해당 사이클 내에서 제시된 목표 단어를 포함할 수 있는 범주를 떠올릴 수 있는지 응답한 후 그 범주에 대한 주관적 확신도를 평정하였다. fMRI 내 과정이 끝난 후 참가자들은 스캐너 밖으로 이동하여 제시되었던 단서 단어의 하위 단어들에 대한 단서 회상과제를 수행하였다. 행동 실험 결과 매 사이클의 세 번째 시행에서 범주화 과제의 반응 속도가 감소하였고 동시에 주관적 확신도 수준이 증가하였는데, 이는 해당 시행에서 의미적 범주화가 완성되었음을 의미한다. 주목할 점은 세 번째 시행 바로 직전에 제시되었던 하위 단어들의 회상 정확도가 그 다음 시행 직전에 제시된 단어들에 비해 유의미하게 낮았다는 점이며 이는 범주화가 완성될 때 일화 기억의 하위 세부 요소들이 손상되었음을 의미한다. 일반선형모델을 통한 분석 결과 의미적 범주화가 완성되기 직전의 시행에서 의미적 기억망과 관련이 있는 것으로 알려져 있는 측두회와 하전두회에서 유의미한 활성화가 나타났다. 또한 패턴 유사성 분석 결과 또한 측두회, 하전두회, 해마 영역에서 세 번째 시행 간의 활성화 패턴이 두 번째 시행의 활성화 패턴에 비해 더 일관적인 것으로 나타났다. 본 연구는 의미적 범주화가 하위 세부 일화 기억을 방해할 수 있다는 것을 보여주며, 이러한 범주화가 진행되는 동안 일어나는 의미적 인출 경험이 관련된 일화 기억의 흔적에 질적인 영향을 미칠 수 있음을 시사한다.

주제어 :

Appendix A. Full list of stimuli used in the main experiment.

Experimental Session				Control Session			
Set Word	Target Word	Detail Words		Set Word	Target Word	Detail Words	
가전제품	냉장고	채소	우유	None	카메라	렌즈	필름
	TV	채널	리모컨		필기구	볼펜	지우개
	컴퓨터	키보드	모니터		가을	단풍	낙엽
	오븐	쿠키	온도		집	주택	빌라
	라디오	주파수	디제이		선거	대통령	국회의원
동물	포유류	강아지	원숭이	None	고등학생	수능	입시
	파충류	악어	뱀		홍기	몽둥이	칼
	조류	기러기	비둘기		종이	수첩	이면지
	감각류	가재	게		과일	망고	바나나
병원	근층	사마귀	잠자리	None	화장품	로션	립스틱
	의사	진찰	정진기		화폐	가치	지폐
	분만	신생아	산통		스마트폰	어플	와이파이
	주사	바늘	예방접종		음악	힙합	클래식
	약	감기약	소화제		아이들	댄스	성형
음식	환자	입원	치료	None	직장	진급	상사
	양식	스테이크	피자		추석	송편	보름달
	일식	우동	회		신발	슬리퍼	하이힐
	중식	짜장면	간pong기		인터넷	검색	블로그
	한식	계장	불고기		사무용품	테이프	포스트잇
대학교	멕시코식	칠리	타코	None	시간	종말	미래
	축제	술	공연		악기	바이올린	피아노
	강의	조교	숙제		SNS	싸이월드	트위터
	시험	범위	학점		술	막걸리	와인
	동아리	후배	동기		남극	펭귄	빙하
교통수단	취업	스터디	봉사활동	None	결혼	하객	신랑
	버스	전용도로	관광		방송국	연출	작가
	지하철	노선	역		가구	책상	서랍
	비행기	수하물	연착		종교	힌두교	천주교
	배	바다	항해		시	낭송	운율
학문	택시	요금	기사	None	잠	이불	베게
	물리학	에너지	힘		아프리카	밀림	부족
	생물학	진화	세포		바느질	실	단추
	심리학	우울	정신		건강	비타민	운동
	전자공학	반도체	회로		하늘	구름	해
스포츠	수학	인수분해	도형	None	언어	불어	일어
	축구	피파	잔디		공장	기계	노동
	야구	투수	포수		범죄	법원	범인
	하키	빙판	스케이트		화장실	변기	세면대
	골프	홀	캐디		친척	고모	할머니
	양궁	화살	과녁	폰트	바탕	돋움	

Appendix B. Full list of stimuli used in the validation experiment.

Experimental Session				Control Session			
Set Word	Target Word	Detail Words		Set Word	Target Word	Detail Words	
가전제품	인터넷공유기	랜선	와이파이	None	카메라	렌즈	필름
	라디오	주파수	디제이		필기구	볼펜	지우개
	냉장고	채소	우유		가을	단풍	낙엽
	TV	채널	리모컨		집	주택	빌라
	컴퓨터	키보드	모니터		선거	대통령	국회의원
동물	산짐승	호랑이	늑대	None	고등학생	수능	입시
	갑각류	가재	게		홍기	몽둥이	칼
	파충류	악어	뱀		종이	수첩	이면지
	조류	기러기	비둘기		과일	망고	바나나
	곤충	사마귀	잠자리		화장품	로션	립스틱
병원	약	감기약	소화제	None	화폐	가치	지폐
	신경의학과	뇌	CT		스마트폰	어플	와이파이
	의사	진찰	청진기		음악	힙합	클래식
	주사	바늘	예방접종		아이돌	댄스	성형
	환자	입원	치료		직장	진급	상사
음식	튀김	모듬	치킨	None	추석	송편	보름달
	한식	비빔밥	불고기		신발	슬리퍼	하이힐
	중식	짜장면	간pong기		인터넷	검색	블로그
	절임음식	간장게장	장아찌		사무용품	테이프	포스트잇
	일식	우동	회		시간	종말	미래
대학교	취업	스터디	봉사활동	None	악기	바이올린	피아노
	축제	술	공연		SNS	싸이월드	트위터
	동아리	후배	동기		술	막걸리	와인
	시험	범위	학점		남극	펭귄	빙하
	강의	조교	숙제		결혼	하객	신랑
교통수단	자가용	소형차	카풀	None	방송국	연출	작가
	배	바다	항해		가구	책상	서랍
	지하철	노선	역		종교	힌두교	천주교
	비행기	수하물	연착		시	낭송	운율
	택시	요금	기사		잠	이불	베개
학문	해의학	방사선	스캔	None	아프리카	밀림	부족
	심리학	우울	정신		바느질	실	단추
	수학	인수분해	도형		건강	비타민	운동
	물리학	에너지	힘		하늘	구름	해
	철학	진화	세포		언어	불어	일어
스포츠	중계방송	카메라	해설위원	None	공장	기계	노동
	펜싱	사브르	예페		범죄	법원	범인
	하키	빙판	스케이트		화장실	변기	세면대
	골프	홀	캐디		친척	고모	할머니
	양궁	화살	과녁		폰트	바탕	돋움