Roles of the Default Mode Network in Different Aspects of Self-representation When Remembering Social Autobiographical Memories

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Abstract

■ Autobiographical memory (AM) is episodic memory for personally experienced events, in which self-representation is more important than that in laboratory-based memory. Theoretically, self-representation in a social context is categorized as the interpersonal self (IS) referred to in a social interaction with a person or the social-valued self (SS) based on the reputation of the self in the surrounding society. Although functional neuroimaging studies have demonstrated the involvement of the default mode network (DMN) in self-representation, little is known about how the DMN subsystems contribute differentially to IS-related and SS-related AMs. To elucidate this issue, we used fMRI to scan healthy young adults during the recollection of AMs. We performed multivariate pattern analysis (MVPA) and assessed functional connectivity in the DMN subsystems: the midline core, medial temporal lobe (MTL), and dorsomedial pFC (dmPFC) subsystems. The study yielded two main sets of findings. First, MVPA revealed that all DMN subsystems showed significant classification accuracy between IS-related and nonsocial-self-related AMs, and IS-related functional connectivity of the midline core regions with the retrosplenial cortex of the MTL subsystem and the dmPFC of the dmPFC subsystem was significant. Second, MVPA significantly distinguished between SS-related and nonsocial-self-related AMs in the midline core and dmPFC subsystems but not in the MTL subsystem, and SS-related functional connectivity with the midline core regions was significant in the temporal pole and TPJ of the dmPFC subsystem. Thus, dissociable neural mechanisms in the DMN could contribute to different aspects of self-representation in social AMs. ■

INTRODUCTION

Autobiographical memory is a form of episodic memories for personally experienced events, in which self-representation is more important than that in laboratory-based episodic memory (for a review, see Conway & Pleydell-Pearce, 2000). In a theoretical framework, self-representation in a social context is categorized as the interpersonal self (IS), which is generated during social interaction with another person, or the social-valued self (SS), which is based on the reputation of the self in the surrounding society (for a review, see Sugiura, 2013). There is functional neuroimaging evidence that the default mode network (DMN) contributes to the retrieval of autobiographical memories (for reviews, see Andrews-Hanna, Saxe, & Yarkoni, 2014; Buckner, Andrews-Hanna, & Schacter, 2008) as well as the processing of the self and self-related stimuli (for reviews, see Sui & Humphreys, 2017; Andrews-Hanna, Smallwood, & Spreng, 2014; Qin & Northoff, 2011). However, little is known about how the DMN subsystems contribute to different aspects of the self-related information in social autobiographical memories. The present fMRI study investigated how different types of self-related information are represented in the DMN subsystems during the retrieval of social autobiographical memories.

Cognitive neuroscience studies have consistently reported that the DMN contributes to the processing of autobiographical memories (for reviews, see Andrews-Hanna, Saxe, et al., 2014; Buckner et al., 2008) and self-related information (for reviews, see Sui & Humphreys, 2017; Andrews-Hanna, Smallwood, et al., 2014; Qin & Northoff, 2011) and is categorized into three subsystems: the midline core system, the medial temporal lobe (MTL) subsystem, and the dorsomedial pFC (dmPFC) subsystem (for reviews, see Andrews-Hanna, Smallwood, et al., 2014; Andrews-Hanna, 2012). The midline core system, which includes the rostromedial pFC (rmPFC), posterior cingulate cortex (PCC), superior frontal sulcus (SFS), posterior inferior parietal lobule (pIPL), and right rostral STS (rSTS; Chen et al., 2020), is associated with self-referential processes and acts as the network hub, as it is functionally connected with all subsystems (for reviews, see Andrews-Hanna, Smallwood, et al., 2014; Andrews-Hanna, 2012). The MTL subsystem, which includes the MTL, ventral pIPL, and retrosplenial cortex (RSC)/ventral PCC (Chen et al., 2020), contributes to detailed autobiographical memory and spatial imagery processes (Wen, Mitchell,

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& Duncan, 2020) as well as scene construction in memory and simulation of future events (for a review, see Andrews-Hanna, Smallwood, et al., 2014). The dmPFC subsystem, which includes the dmPFC, inferior frontal gyrus, posterior dorsolateral pFC, lateral temporal cortex (LTC), TPJ, and temporal pole (TP; Chen et al., 2020), plays an important role in theory of mind (ToM) or mentalizing (Wen et al., 2020) and the processing of semantic and conceptual knowledge, including social knowledge (for a review, see Andrews-Hanna, Smallwood, et al., 2014).

The IS-related self-representation is a mindset of awareness that the attention or intentionality of another person is directed at oneself, whereas the SS-related self-representation includes the thought about the social value of oneself or the attribution assigned to oneself (for a review, see Sugiura, 2013). In an fMRI study regarding the IS-related self-representation, univariate activation in the dmPFC subsystem (dmPFC) and functional connectivity between the memory-related hippocampus and the midline core system (rmPFC and PCC) were significant during the encoding of face memories by self-referential processes by imaging a person-to-person relationship (Yamawaki et al., 2017). Another fMRI study related to the IS-related self-representation demonstrated that the intrinsic functional connectivity related to the retrieval of episodic autobiographical memory based on the interpersonal relationship was significant in the midline core system (rmPFC), MTL subsystem (MTL), and dmPFC subsystem (dmPFC and TP; Yang, Bossmann, Schiffhauer, Jordan, & Immordino-Yang, 2013). Regarding the SS-related self-representation, there is functional neuroimaging evidence that the reputation in society includes the formation of meta-representation of oneself, which is involved in the dmPFC subsystem (dmPFC and TPJ), and the cost–benefit analysis of possible actions, which is involved in the midline core system (rmPFC) and striatum (for a review, see Izuma, 2012). In addition, another fMRI study revealed that the midline core system (rmPFC) was involved in the representation of both general (context-independent) and specific (context-dependent) self-concepts (e.g., as a student), whereas the MTL subsystem (RSC) contributed only to the context-dependent self-representation (Martial, Stawarczyk, & D'Argembeau, 2018). Thus, roles of the DMN in the self-representation of IS-related and SS-related autobiographical memories would be differentially modulated by functional networks of the MTL or dmPFC subsystems with the midline core system as the network hub. However, little is known about how the neural mechanisms are dissociable between IS-related and SS-related social autobiographical memories.

In the present study, we investigated how different aspects of self-related information are represented in the DMN subsystems during the retrieval of social autobiographical memory. To elucidate this issue, using an event-related fMRI method, activation in ROIs related to the DMN subsystems was measured when remembering IS-related autobiographical events experienced in an interpersonal relationship with a specific friend or SS-related autobiographical events that included social values such as the reputation of the self in society. Using multivariate pattern analysis (MVPA) and functional connectivity analysis, the neural mechanisms in these social autobiographical memories were compared to those in nonsocial self (NS) autobiographical memories (i.e., events experienced alone). As noted above, there is functional neuroimaging evidence that the midline core, MTL, and dmPFC subsystems in the DMN reflect different functions in the self-representation of autobiographical memory. Thus, the MVPA classifiers for activity patterns in these ROIs were predicted to significantly discriminate among different aspects of self-related information during the retrieval of autobiographical memories. In addition, functional connectivity between the midline core system as the network hub and the MTL/dmPFC subsystems was expected to be modulated by different aspects of self-related information in social autobiographical memories.

METHODS

Participants

Forty-three healthy young adults (18 women and 25 men; mean age = 21.67 [*SD* = 1.60] years), who were recruited from the Kyoto University community, participated in the present study. Using G*Power Version 3.1 (Faul, Erdfelder, Lang, & Buchner, 2007), a priori sample size analysis was performed according to the experimental design employed in the present study. The analysis estimated a total sample size of 36 according to the following parameters: medium effect size (f = 0.25; Cohen, 1988), error probability (α = .05), and power (0.90). To maintain substantial power in the case of missing data because of poor performance, large head motion, and so forth, we recruited 43 participants in the present study. All participants were right-handed, native Japanese-speaking individuals with no clinical history of neurological or psychiatric disease. Their handedness was confirmed by the Japanese version of the Flinders Handedness survey (Okubo, Suzuki, & Nicholls, 2014; Nicholls, Thomas, Loetscher, & Grimshaw, 2013). Participants had normal or corrected-to-normal vision with MRI-compatible glasses. All participants provided informed consent to the protocol, which had been approved by the institutional review board of the Graduate School of Human and Environmental Studies, Kyoto University (30-H-15).

The data from 11 participants were excluded from behavioral and fMRI analyses because three of them moved their head more than 2 mm during fMRI scanning, seven remembered less than seven autobiographical scenarios in one category explained below, and one was incidentally found to have pathological changes in brain structures. Thus, 32 participants (14 women and 18 men; mean age = 21.72 [*SD* = 1.55] years) in total were included in the analyses. All participants underwent four psychological tests, namely, NEO-Five Factor Inventory (Shimonaka, Nakazato, Gondo, & Takayama, 2002; Costa & McCrae, 1992), Autism Quotient (Wakabayashi, Tojo, Baron-Cohen, & Wheelwright, 2004; Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001), Self-Consciousness Scale (Sugawara, 1984; Fenigstein, Scheier, & Buss, 1975), and Rosenberg Self-Esteem Scale (Mimura & Griffiths, 2007; Rosenberg, 1965). However, none of these tests were included in the behavioral and fMRI analyses.

Stimuli

Procedures of the Pilot Study for Selecting Scenarios

In the present fMRI experiment, we needed 50 scenarios of autobiographical memories in each condition of IS, SS, and NS. To prepare these scenarios, we prepared 180 candidate Japanese sentences describing hypothetical scenarios of autobiographical memory. These scenarios were divided into three categories: (1) IS-related scenarios describing episodes experienced with a close friend (e.g., "I had a quarrel with my friend"), (2) SS-related scenarios describing episodes related to the social reputations of each participant in society (e.g., "I succeeded in a basketball game"), and (3) NS-related scenarios describing episodes experienced alone without any social situations ("I cooked my dinner alone"). All sentences were written in past tense and composed of 10–14 Japanese characters.

To select scenarios employed in the fMRI experiment, these scenarios were evaluated by 21 participants (10 women and 11 men; mean age = 21.5 years, range = 18–35 years) who did not participate in the fMRI experiment. Among these 21 participants, the data from two were excluded from the analyses because one was older than the mean age + 2 *SD*s and another showed only the "Remember" response to all autobiographical scenarios that she or he had experienced. Thus, we analyzed the data from 19 participants (10 women and 9 men; mean age = 20.8 years, range = 18–24 years) when selecting scenarios to be included in the fMRI experiment. In the evaluation of autobiographical scenarios, the stimulus presentation and recording of participants' responses were controlled by a Windows PC. All participants were instructed to indicate whether they had experienced these scenarios of autobiographical memory. In the retrieval of autobiographical memory, participants were randomly presented with individual hypothetical scenarios of autobiographical memory and were instructed to indicate whether they experienced the events described in each scenario within approximately 10 years. If participants remembered the specific autobiographical event along with detailed temporal and spatial contexts, they selected the R (Remember) response. If participants remembered their autobiographical event without detailed contextual information or had a feeling of knowing for a given scenario, the K (Know) response was chosen. The N (New) response was recorded when they had never experienced the autobiographical event described in each scenario. Each scenario was visually presented on the PC monitor for 5.5 sec, and then a visual fixation cross was presented for 0.5 sec as the ISI.

After the retrieval of autobiographical memories, participants were instructed to rate their subjective feelings of the emotional intensity of each event ("arousal"), emotional valence of each event ("valence"), to what extent they paid attention toward the specific person in each event ("attention toward the specific person"), and to what extent they paid attention toward their own reputation according to other persons in each event ("attention toward own reputation"). In these ratings, participants were randomly presented with 180 individual scenarios on the computer monitor with each scenario presented for 5.5 sec followed by a visual fixation cross presented for 0.5 sec as the ISI. Participants were instructed to evaluate each autobiographical event using an 8-point scale. Each evaluation was rated in individual runs, and the participants' responses were recorded by pressing a key from 1 to 8. These runs for ratings were counterbalanced among participants. However, the ratings of "arousal" and "valence" and the ratings of "attention toward the specific person" and "attention toward own reputation" were not ordered consecutively. For the scenarios that participants had never experienced (N response), participants were instructed to rate the scenario by imagining the events.

Results of the Pilot Study for Selecting Scenarios

Using the results of these ratings, we selected 50 scenarios for each scenario category to use in the fMRI experiment. First, we excluded scenarios in which no participant remembered a related autobiographical memory (N response) and in which no participant showed the R response. In addition, scenarios in which more than 10 participants showed the N response were also removed from the candidates. Second, we excluded the IS-related scenarios in which mean rating scores of "attention toward the specific person" were numerically rated lower for the IS-related scenarios than the SS-related scenarios, or those of "attention toward own reputation" were numerically rated higher for the IS-related scenarios than the SS-related scenarios. Third, when mean rating scores of "attention toward own reputation" were rated numerically lower for the SS-related scenarios than the IS-related scenarios or when mean rating scores of "attention toward the specific person" were rated numerically higher for the SS-related scenarios than the IS-related scenarios, the SS-related scenarios were excluded from the stimulus lists. Fourth, we selected the same number of the NS-related scenarios to match those of the IS-related and SS-related scenarios according to the criteria in which more participants showed the R response and fewer participants showed the N response. Finally, 50 sentences from each scenario category were chosen so that the mean "valence" scores were similarly distributed from 1 to 7 in all scenario categories.

To confirm that the subjective ratings for scenarios were selected appropriately for IS, SS, and NS from the candidate sentences, the rating scores and number of characters in autobiographical scenarios were analyzed by one-way ANOVA with a factor of Scenario Category (IS, SS, NS). The ANOVAs for rating scores revealed a significant effect of Scenario Category on "arousal," $F(2, 147) = 101.36, p < .001, \eta^2 = .58$; "valence," $F(2, 147) = 6.44, p = .002, \eta^2 = .08$; "attention toward the specific person," $F(2, 147) = 575.74, p < .001, \eta^2 = .89$; and "attention toward own reputation," $F(2, 147) = 318.30, p < .001, \eta^2 = .81$. In the ANOVA for the number of characters, however, an effect of Scenario Category was not significant, $F(2, 147) = 0.68, p = .509, \eta^2 = .01$. In post hoc tests, we used the Bonferroni method in all analyses. The rating scores of "arousal" were significantly higher in IS and SS than in NS ($p < .001$). Post hoc tests for the "valence" rating scores showed that scores in NS were significantly higher than in SS ($p < .001$), whereas there was no significant difference in scores between IS and SS ($p = .429$) and between IS and NS ($p = .113$). In the rating scores of "attention toward the specific person," scores in IS were significantly higher than those in SS and NS, and scores in SS were significantly higher than those in NS ($p < .001$ for all comparisons). The rating scores of "attention toward own reputation" were significantly higher in SS than in IS and NS and were significantly higher in IS than in NS ($p < .001$ for all comparisons).

Experimental Procedures

All participants performed both retrieval and rating tasks of autobiographical memories and were scanned only during the retrieval task. In the autobiographical memory retrieval task, we employed an event-related fMRI design. Before fMRI scanning, participants were fully familiarized with the experimental procedures by examples of autobiographical memory scenarios, which were not used in the real experiment, and then we confirmed that all participants completely understood the procedures in the autobiographical memory retrieval task.

Examples of the autobiographical memory retrieval task are illustrated in Figure 1. In the retrieval task, participants were randomly presented with 150 individual hypothetical scenarios of autobiographical memory (50 scenarios in each scenario category: IS, SS, and NS) and were instructed to remember their own autobiographical memories related to the hypothetical scenarios. Events were internally recalled regarding autobiographical memories experienced in the past 10 years. If participants remembered their autobiographical memory with vivid temporal and spatial contexts, they were instructed to choose the R response. If participants felt that they had experienced the autobiographical event described in the scenario but could not remember detailed contextual information, they were instructed to choose the K response. When participants judged that the event described in a scenario was not experienced in their lives, the N response was chosen. Each scenario was visually presented for 5.5 sec, and then a visual fixation cross was presented as the ISI of a variable duration (0.5–6.5 sec). The stimulus presentation and recording of behavioral responses were controlled by MATLAB scripts (www.mathworks.com) on a Windows PC. All stimuli were visually presented on an MRI-compatible display (Nordic Neuro Lab, Inc.), and participants viewed the stimuli with a mirror attached to the head coil of the MRI scanner. Behavioral responses during fMRI scanning were recorded by four buttons, which were a part of the eight-button optic fiber response device (Current Designs, Inc.) composed of two boxes, each with four buttons. Among the four buttons assigned to the right hand, three buttons corresponding to the index finger, the middle finger, and the ring finger were used in the present study.

Immediately after the retrieval task, participants evaluated the autobiographical events outside the fMRI scanner. The presentation of all stimuli was controlled by MATLAB scripts (www.mathworks.com) on a Windows PC, and behavioral responses in each participant were recorded on a keyboard. In the evaluation tasks, participants were visually presented with the 150 hypothetical scenarios of autobiographical events from the retrieval task and instructed to rate their subjective feelings of the

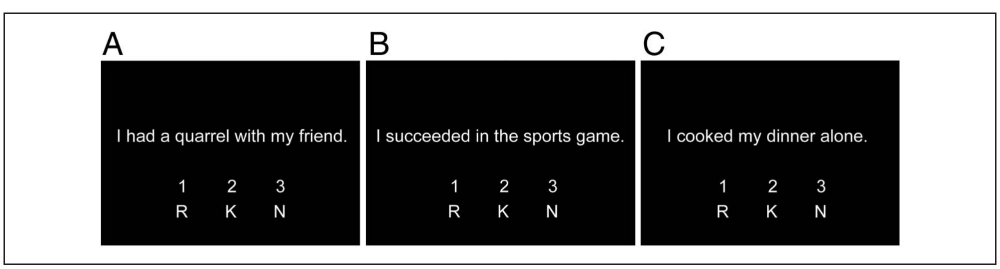

Figure 1. An example of stimuli during the autobiographical memory retrieval with fMRI scanning. Participants were instructed to internally remember their own autobiographical memories within the past 10 years related to hypothetical scenarios. (A) An example stimulus in the IS condition. (B) An example stimulus in the SS condition. (C) An example stimulus in the NS condition. Participants were instructed to judge whether their autobiographical memories were internally remembered with vivid temporal and spatial contexts (R = remember), were internally remembered with unclear contexts (K = know), or were not experienced in their lives (N = new). All scenarios were presented in Japanese. English is used here for illustration purposes only.

emotional intensity of each event ("arousal"), emotional valence of each event ("valence"), importance of each event ("personal significance"), to what extent they paid attention toward the specific person in each event ("attention toward the specific person"), to what extent they paid attention toward their own reputation according to other persons in each event ("attention toward own reputation"), and what impact each event had on their self-esteem ("impact on self-esteem"). In these rating tasks, participants were randomly presented with 150 individual scenarios, including 50 IS-related, 50 SS-related, and 50 NS-related scenarios, and were instructed to rate their subjective feelings for each scenario on an 8-point scale. Each scenario was presented for 5.5 sec, followed by an ISI of a visual fixation cross, which was presented for 0.5 sec. Each evaluation was performed in one run, and participants' responses were recorded by pressing a key from 1 to 8. The six runs for ratings were counterbalanced among participants. However, the ratings of "arousal" and "valence" and the ratings of "attention toward the specific person" and "attention toward own reputation" were not ordered consecutively. In the scenarios that participants showed the R or K responses, subjective feelings for each event were rated according to their memories. The scenarios that participants had never experienced (N response) were rated by imagining the events. In the present study, however, the rating scores for events only with the R responses were included in analyses.

MRI Data Acquisition

All MRI data were collected using a Siemens MAGNETOM Verio 3-T MRI scanner at the Institute for the Future of Human Society, Kyoto University. The noise during fMRI scanning was reduced with earplugs, and head motion was minimized by foam pads. First, three-directional T1-weighted images were taken to localize the subsequent functional and structural images. Second, functional images were collected during the retrieval of autobiographical memories by the multiband gradient-echo EPI sequence, which is sensitive to BOLD contrasts (repetition time = 2000 msec, echo time = 49.4 msec, flip angle = 75°, field of view = 22.4 × 22.4 cm, matrix size = 112 × 112, 72 horizontal slices, slice thickness/gap = 2.0/0 mm, multiband factor = 4). Finally, high-resolution T1-weighted structural images were collected by magnetization prepared rapid gradient echo (repetition time = 2250 msec, echo time = 3.51 msec, field of view = 25.6 × 25.6 cm, matrix size = 256 × 256, 208 horizontal slices, slice thickness/gap = 1.0/0 mm).

fMRI Data Analysis

Preprocessing

To preprocess MRI data, we employed SPM12 (www.fil.ion.ucl.ac.uk/spm/software/spm12/) implemented in MATLAB. In the preprocessing of functional images, first, the initial four volumes were discarded to prevent an initial dip, and then six parameters of head motion were generated from a series of the remaining functional images. Second, a high-resolution T1-weighted structural image was coregistered to the first volume of functional images after removing the initial four volumes. Third, parameters that fit anatomical space of the structural images to the tissue probability map in the Montreal Neurological Institute template were estimated in each participant, and the parameters were applied to all functional images (resampled resolution = 2.0 × 2.0 × 2.0 mm). Finally, these spatially normalized functional images were spatially smoothed with a Gaussian kernel of FWHM = 6 mm. These functional images after preprocessing were used for the univariate and functional connectivity analyses. In MVPA, functional images without spatial smoothing were analyzed.

ROI Definition

In the present study, we analyzed activity and functional connectivity patterns in ROIs of the DMN subsystems. ROIs reflecting the three subsystems of the DMN were defined by a previous study (Chen et al., 2020), from which the original data are available publicly (www.rfmri.org/RuminationfMRIData). This previous study defined 24 anatomical regions according to Yeo et al.'s 17-network parcellation (Yeo et al., 2011) and categorized these regions into the midline core system, MTL subsystem, and dmPFC subsystem, composing the DMN. We created ROI masks related to the three DMN subsystems by combining regions categorized into the same subsystems. Three-dimensional images of ROI masks in the present study are shown in Figure 2.

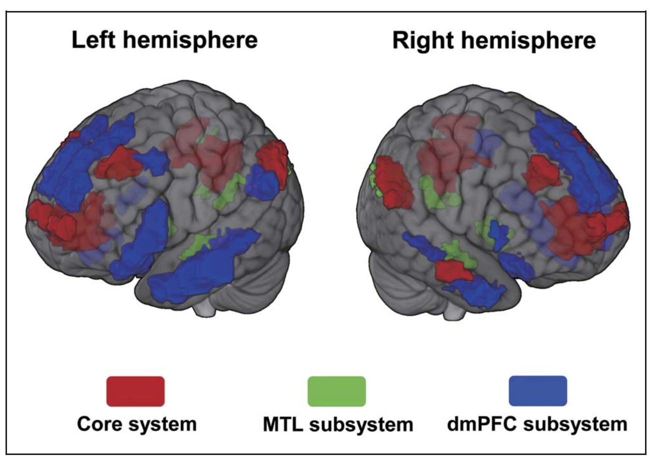

Figure 2. ROIs reflecting three subsystems in the DMN. Red regions correspond to the midline core system, green regions correspond to the MTL subsystem, and blue regions correspond to the dmPFC subsystem. These ROIs were created based on the definition in a previous study (Chen et al., 2020).

Univariate Analysis

After preprocessing, using SPM12, all functional images were statistically analyzed by two steps: at the individual level (fixed effect) and at the group level (random effect). In the individual-level analyses, activation related to each trial was modeled by convolving a vector of onsets with a canonical hemodynamic response function (HRF) in the context of the general linear model (GLM), in which the timing of participants' responses to each scenario were defined as the onset with an event duration of 0 sec. In the first model at the individual level, trials during the retrieval of autobiographical memory were divided into three retrieval conditions (R, K, N) according to responses from each participant, and vectors of onset in each retrieval condition were included as the time of participants' responses to each scenario in the model. The onset of trials with "no response" was set as the time of stimulus presentation in the model. In addition, confounding factors (head motion and magnetic field drift) were included in this model. Activation related to the retrieval of detailed memories was identified by a t contrast of R versus K, and the contrast was computed in each participant. This t contrast was acquired in each participant. In the second model at the individual level, trials during the retrieval of autobiographical memory were divided into nine conditions defined by two factors of scenario category (IS, SS, NS) and retrieval performance (R, K, N), and vectors of onset in each condition (IS-R, IS-K, IS-N, SS-R, SS-K, SS-N, NS-R, NS-K, NS-N) were included as the time of participants' responses to each scenario in this model. In trials with "no response," the time of stimulus presentation was set as an onset in the model. In addition, this model included six regressors of confounding factors (head motion and magnetic field drift). Activation related to the retrieval of detailed memories in the IS-related scenarios was identified by a t contrast of IS-R versus NS-R, whereas that in the SS-related scenarios was identified by a t contrast of SS-R versus NS-R. These t contrasts were acquired in each participant.

In the group-level analysis, activation related to the retrieval of autobiographical memory with contextual details was identified by a one-sample t test for t contrasts of R versus K acquired in each participant. To identify the retrieval-related activation of social autobiographical memories, which are related to both IS-related and SS-related autobiographical memories, the results of R versus K were inclusively masked by t contrasts of IS-R versus NS-R and SS-R versus NS-R ($p < .05$). This procedure yielded an activation map fulfilling significant activation reflecting the retrieval of detailed autobiographical memories and significantly greater activation in IS and SS than in NS. In this analysis, the statistical thresholds at the voxel level were set at $p < .001$ and corrected for multiple comparisons with a minimum cluster size of 20 contiguous voxels in the midline core ROI of the DMN (FWE-corrected $p < .05$).

MVPA

Multivariate activity patterns in each DMN ROI were analyzed by Pattern Recognition for Neuroimaging Toolbox (PRoNTo) Version 2.1 (Schrouff et al., 2013) implemented in MATLAB. In this analysis, we investigated whether social autobiographical memories in IS and SS, compared to autobiographical memories in NS, are differentially represented by multivariate activity patterns in three DMN ROIs (the midline core system, MTL subsystem, and dmPFC subsystem).

Before MVPA by PRoNTo, trial-by-trial activity at the time of the participants' responses to each scenario was estimated for individual participants by new GLMs in SPM12 (Mumford, Davis, & Poldrack, 2014; Mumford, Turner, Ashby, & Poldrack, 2012; Rissman, Gazzaley, & D'Esposito, 2004). This model convolved onset vectors with a canonical HRF and included a regressor for a specific trial and regressors for all the other trials. In addition, six parameters reflecting head motion and magnetic field drift were also included in this model as confounding factors. With these procedures, a new map of beta estimates was generated for the whole brain in all individual trials, and trial-by-trial beta images were applied to MVPA.

In the MVPA classification analysis, first, a whole-brain mask image was created for each participant after excluding voxels without beta values, and the classification of activity patterns was statistically analyzed by PRoNTo in the whole-brain mask image. Second, the features were extracted from all voxels in each DMN ROI and were centered by the mean of training data for individual voxels (mean centering). Two patterns of binary classification (IS-R vs. NS-R, SS-R vs. NS-R) were computed by support vector machine classifiers with a linear kernel in each DMN ROI. The cross-validation was performed with a k-fold cross-validation procedure ($k = 2$), in which half of the trials were allotted to training and the other half were allotted to testing. Third, mean balanced accuracy (BA) was computed for all DMN ROIs in each participant, and the mean BA values for each ROI were analyzed by one-tailed one-sample t tests, which assessed whether the multivariate activity patterns in the ROI significantly distinguished between two conditions above the chance level (50%). Significant results in the one-sample t tests were verified by 10,000 times permutation tests, in which labels of the two conditions to be classified were randomly swapped. This manipulation yielded a null distribution, in which two conditions to be classified were not significantly represented by multivariate activity patterns in the ROI.

Functional Connectivity Analysis

To investigate interacting mechanisms among the three DMN subsystems during the retrieval of social autobiographical memories, we conducted functional connectivity analysis by a generalized form of context-dependent psychophysiological interactions (gPPI), which improved model fit, specificity to true-negative findings, and sensitivity to true-positive findings in both simulated data models and empirical event-related fMRI data sets (McLaren, Ries, Xu, & Johnson, 2012). In the prior manipulation of the fMRI data at the individual level, a new GLM was constructed. This model included nine conditions defined by two factors of Scenario category (IS, SS, NS) and Retrieval performance (R, K, N), and vectors of onset in each condition (IS-R, IS-K, IS-N, SS-R, SS-K, SS-N, NS-R, NS-K, NS-N) were set as the time at which participants responded to each scenario in the model. The event duration for each onset was defined as 0 sec. The vectors of trials with no response were convolved with this model by setting the onset time at that of stimulus presentation. In addition, six regressors of confounding factors (head motion and magnetic field drift) were included in the model. In this model, seed regions in each participant were defined as volumes of interest consisting of spheres with a 4-mm radius around the peak voxels, which were individually identified in each ROI mask (Chen et al., 2020) of regions reflecting significant activation in the univariate analysis.

In the individual-level analysis of gPPI, the gPPI toolbox (www.nitrc.org/projects/gppi) was used to construct two models for each participant with three sets of columns including (1) condition regressors formed by convolving a vector of condition-related onsets with a canonical HRF, (2) BOLD signals deconvolved from the seed region, and (3) PPI regressors as an interaction between (1) and (2). Thus, the first model consisted of the following nine regressors: four condition regressors of three retrieval (R, K, N) and no-response conditions, BOLD signals of each seed region, and four PPI regressors of three retrieval (R, K, N) and no-response conditions. In the second model, the gPPI toolbox generated a model with 21 regressors, which included 10 condition regressors of nine experimental (IS-R, IS-K, IS-N, SS-R, SS-K, SS-N, NS-R, NS-K, NS-N) and no-response conditions, BOLD signals of each seed region, and 10 PPI regressors of nine experimental (IS-R, IS-K, IS-N, SS-R, SS-K, SS-N, NS-R, NS-K, NS-N) and no-response conditions. The confounding factors of six regressors (head motion and magnetic field drift) were also convolved with these models. The models in each seed region were estimated for each participant, and the linear contrasts were calculated in each model. Regions showing a significant effect of the PPI regressor contrasts were considered to be functionally connected with seed regions at the statistical threshold. The PPI regressor contrasts extracted from these models were applied to the group-level analysis.

In the group-level analysis, we explored regions in the three DMN subsystems showing significant functional connectivity with seed regions in the midline core system of the DMN. In this analysis, first, we conducted one-sample t tests for PPI regressor contrasts of R, IS-R versus NS-R, SS-R versus NS-R, IS-R versus SS-R, and SS-R versus IS-R, which were identified in the first and second models of the individual-level analysis. Second, regions that showed significant functional connectivity with seed regions during the retrieval of IS-related memories were analyzed by the PPI regressor t contrasts of R masked inclusively with two PPI regressor t contrasts of IS-R versus NS-R and IS-R versus SS-R ($p < .05$). This procedure enabled us to identify regions reflecting significant functional connectivity with the midline core system of the DMN only in the retrieval of IS-related autobiographical memories, compared to that of SS-related and NS-related autobiographical memories. Third, regions that were functionally connected with seed regions during the retrieval of SS-related autobiographical memories were analyzed by the PPI regressor t contrasts of R masked inclusively with two PPI regressor t contrasts of SS-R versus NS-R and SS-R versus IS-R ($p < .05$). This procedure yielded a map showing significant functional connectivity with the midline core system of the DMN only in the retrieval of SS-related autobiographical memories, compared to that of IS-related and NS-related autobiographical memories. In these functional connectivity analyses, the statistical thresholds at the voxel level were set at $p < .001$ and corrected for multiple comparisons with a minimum cluster size of 3 contiguous voxels in each DMN ROI of the midline core system, MTL subsystem, and dmPFC subsystem (FWE-corrected $p < .05$). Anatomical labels of regions identified in the univariate and functional connectivity analyses were adopted from ROIs in a previous study (Chen et al., 2020).

RESULTS

Behavioral Results

Table 1 summarizes the number of trials and RTs of participants during the retrieval of autobiographical memories and the rating scores for scenarios of remembered autobiographical memories. The mean numbers of trials for the R responses in each scenario category were 22.53 (*SD* = 8.86, range = 8–40) in IS, 17.13 (*SD* = 6.75, range = 7–34) in SS, and 30.09 (*SD* = 8.46, range = 11–45) in NS, and those for the K responses were 14.47 (*SD* = 7.22, range = 1–29) in IS, 18.44 (*SD* = 4.95, range = 6–28) in SS, and 11.25 (*SD* = 6.64, range = 0–27) in NS. The results confirmed that enough trials with the R responses were retained in the analyses of behavioral and fMRI data.

A one-way repeated-measures ANOVA with a factor of Scenario Category (IS, SS, NS) was performed for RTs in trials for the R response. This ANOVA showed a significant effect of Scenario Category, $F(2, 62) = 42.79, p < .001, \eta^2 = .58$, in which post hoc tests by the Bonferroni method showed that RTs in trials for the R response were significantly longer in IS and SS than in NS ($p < .001$ for both comparisons). The ANOVA for RTs in trials for the K response showed a significant effect of Scenario Category, $F(2, 60) = 11.31, p < .001, \eta^2 = .27$, in which post hoc tests by the Bonferroni method showed significantly longer RTs in IS than in SS and NS ($p < .001$ for both comparisons).

Table 1. Behavioral Results

	IS (SD)	*SS (SD)*	*NS (SD)*
Number of R trials	22.53 (8.86)	17.13 (6.75)	30.09 (8.46)
Number of K trials	14.47 (7.22)	18.44 (4.95)	11.25 (6.64)
RTs (msec) in R trials	2872.83 (594.88)	2942.51 (558.28)	2464.44 (608.68)
RTs (msec) in K trials	3580.57 (573.39)	3291.31 (563.75)	3284.02 (624.43)
Rating scores in R trials			
Arousal	5.01 (0.76)	5.47 (0.82)	3.00 (0.66)
Valence	5.23 (0.48)	4.87 (0.61)	5.21 (0.46)
Personal significance	5.06 (0.78)	5.07 (0.90)	3.48 (1.07)
Attention toward the specific person	6.09 (0.96)	4.94 (1.11)	2.19 (0.76)
Attention toward own reputation	4.62 (0.86)	6.05 (0.71)	2.43 (0.89)
Impact on self-esteem	4.59 (0.92)	5.74 (0.85)	2.90 (1.00)

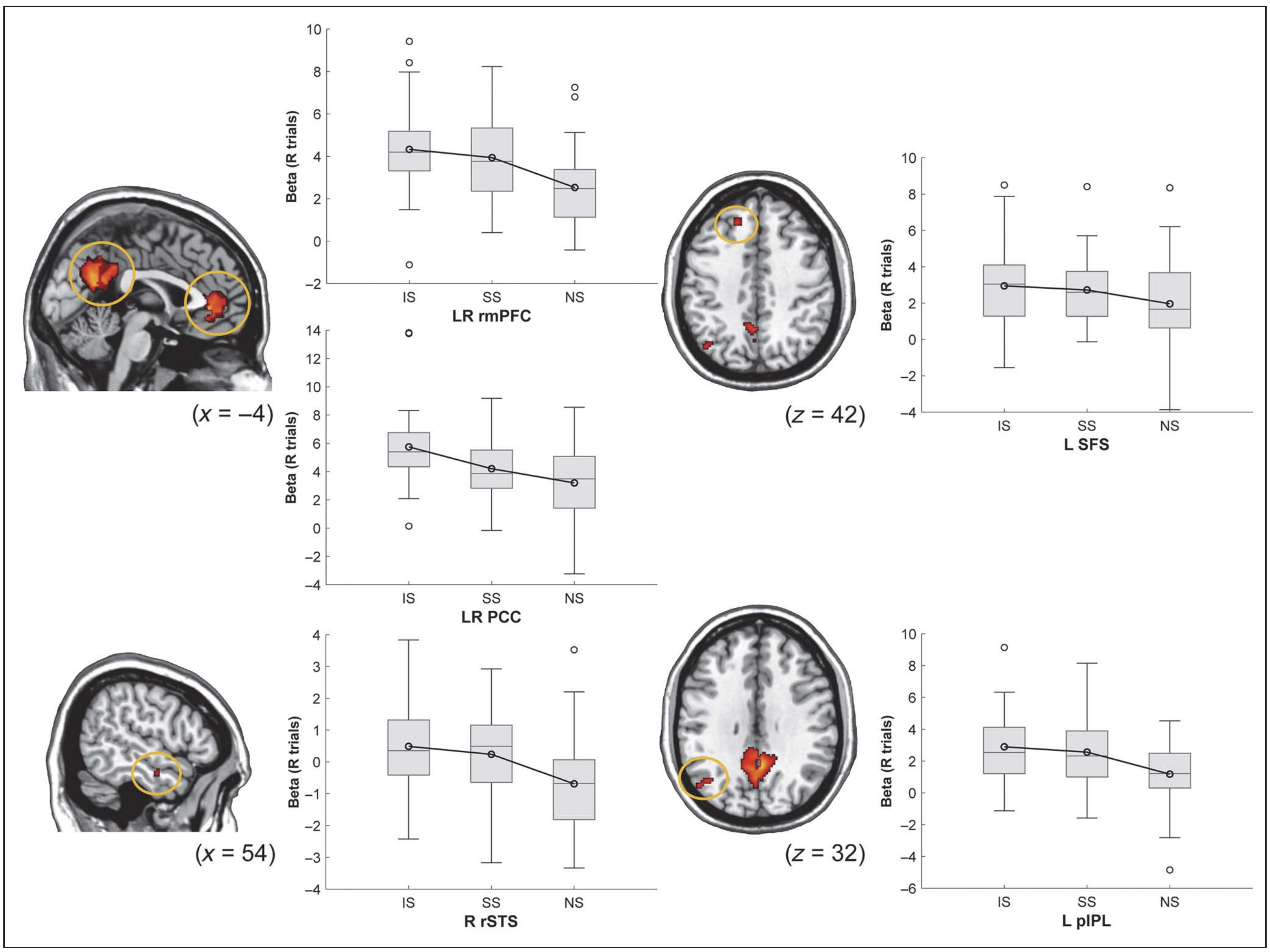

Figure 3. Results of the univariate analysis ($p < .001$, FWE-corrected for multiple comparisons, $p < .05$). Significant activation was identified commonly between contrasts of IS versus NS and SS versus NS in the R response trials. Beta estimates in boxplots and mean values (polygonal lines) were extracted from peak voxels showing significant activation. L = left; R = right.

Table 2. Significant Activation in the Midline Core System of the DMN When Remembering Social Autobiographical Memories

		MNI Coordinates				
Region	*L/R*	*x*	*y*	*z*	*T Score*	*k*
rmPFC	LR	−2	36	0	11.39	635
SFS	L	−18	34	42	6.88	44
rSTS	R	54	−6	−20	6.00	27
PCC	LR	−6	−58	22	14.85	1024
pIPL	L	−38	−64	32	7.36	102

L = left; R = right; MNI = Montreal Neurological Institute; k = cluster size.

The RT results for the R response suggest that more detailed information could be remembered in social autobiographical memories than in nonsocial autobiographical memories. In addition, the retrieval of social autobiographical memories could be harder than that of nonsocial autobiographical memories.

Rating scores in the evaluation task were analyzed by one-way ANOVAs with a factor of Scenario Category. The ANOVA on "arousal" scores showed a significant effect of Scenario Category, $F(2, 62) = 191.94$, $p < .001$, $\eta^2 = .86$, in which scores in SS were significantly higher than those in IS ($p = .003$) and NS ($p < .001$), and scores in IS were significantly higher than those in NS ($p < .001$). In the ANOVA on "valence" scores, we found a significant effect of Scenario Category, $F(2, 62) = 5.17$, $p = .008$, $\eta^2 = .14$, and post hoc tests by the Bonferroni method showed significantly higher scores in IS than in SS ($p = .02$) and NS ($p = .03$). In the ANOVA on "personal significance" scores, we found a significant effect of Scenario Category, $F(2, 62) = 49.80$, $p < .001$, $\eta^2 = .62$, in which scores in IS and SS were significantly higher than those in NS ($p < .001$ for both comparisons). The ANOVA on scores of "attention toward the specific person" showed a significant effect of Scenario Category, $F(2, 62) = 219.18$, $p < .001$, $\eta^2 = .88$, and the difference in rating scores was significant among all categories of IS, SS, and NS ($p < .001$ for all comparisons). In the ANOVA on scores of "attention toward own reputation," an effect of scenario category was significant, $F(2, 62) = 250.93$, $p < .001$, $\eta^2 = .89$; the scores were significantly different among all categories (IS, SS, and NS; $p < .001$ for all comparisons). In the ANOVA on the "impact on self-esteem" scores, we found a significant effect of Scenario Category, $F(2, 62) = 137.32$, $p < .001$, $\eta^2 = .82$; the scores were significantly different among all categories (IS, SS, and NS; $p < .001$ for all comparisons).

fMRI Results

Univariate Analysis

In the univariate analysis, we found significantly greater activation in the DMN midline core system during the retrieval of social autobiographical memories with contextual details (IS-R and SS-R) than during the retrieval of nonsocial autobiographical memories (NS-R). As illustrated in Figure 3, this analysis demonstrated significant activation in the bilateral rmPFC and PCC, left SFS and pIPL, and right rSTS. Detailed results are summarized in Table 2.

MVPA

MVPA was used to investigate whether multivariate activity patterns in the DMN ROIs differentiated IS- and SS-related autobiographical memories from NS-related autobiographical memories above the chance level (50%). In this analysis of the midline core system, one-tailed one-sample t tests on the BA values from individual participants demonstrated that multivariate activity patterns in this ROI significantly differentiated between IS-R and NS-R [mean BA = 0.71: $t(31) = 10.03$, $p < .001$, $d = 1.77$] and between SS-R and NS-R [mean BA = 0.62: $t(31) = 5.47$, $p < .001$, $d = 0.97$]. One-tailed one-sample t tests on the BA values in the MTL subsystem were significant in only IS-R versus NS-R [mean BA = 0.57: $t(31) = 4.27$, $p < .001$, $d = 0.75$], but not SS-R versus NS-R [mean BA = 0.52: $t(31) = 1.44$, $p = .080$, $d = 0.25$]. In the analysis of activity patterns in the dmPFC subsystem, we found significant BA values in both IS-R versus NS-R [mean BA = 0.62: $t(31) = 6.73$, $p < .001$, $d = 1.19$] and SS-R versus NS-R [mean BA = 0.60: $t(31) = 4.88$, $p < .001$, $d = 0.86$]. These results are illustrated in Figure 4.

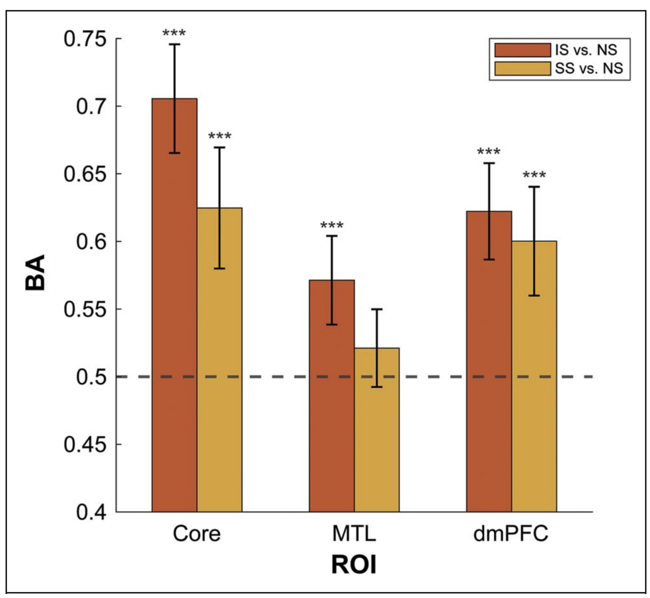

Figure 4. Results of the MVPA classification analysis. Multivariate classification accuracy (BA) for scenario categories of autobiographical memory in each ROI reflecting the DMN subsystems. Error bars represent the 95% confidence interval, and the dotted line represents chance-level classification accuracy (50%). Core refers to the midline core system; MTL refers to the MTL subsystem; dmPFC refers to the dmPFC subsystem. ***Significant results according to one-sample t tests ($p < .001$).

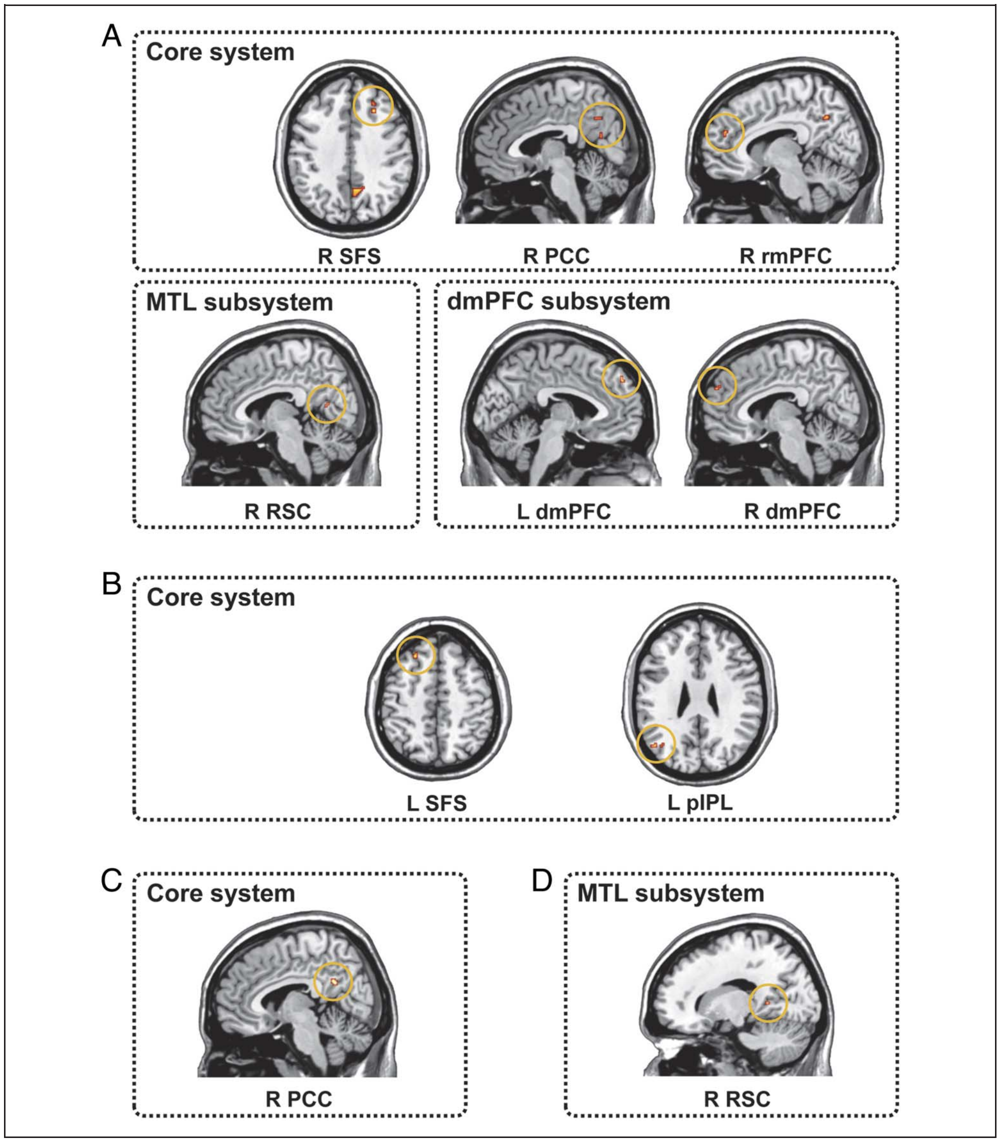

Figure 5. Results of the functional connectivity analysis during the retrieval of IS-related autobiographical memory. Regions showing significant functional connectivity were identified by the PPI regressor *t* contrasts of R masked inclusively with the PPI regressor *t* contrasts of IS-R versus NS-R and IS-R versus SS-R. (A) Functional connectivity with the rmPFC seed. (B) Functional connectivity with the rSTS seed. (C) Functional connectivity with the PCC seed. (D) Functional connectivity with the SFS seed. L = left; R = right.

Functional Connectivity Analysis

In the functional connectivity analysis, we investigated the functional connectivity of seed regions in the midline core system with three subsystems of the DMN in the retrieval of IS-related and SS-related autobiographical memories. In the retrieval of IS-related autobiographical memories, which were analyzed by the PPI regressor *t* contrasts of R masked inclusively with the PPI regressor *t* contrasts of IS-R versus NS-R and IS-R versus SS-R, significant functional connectivity within the midline core system was identified in widespread regions, including the rmPFC, PCC, SFS, and pIPL. In addition, seed region in the rmPFC showed significant functional connectivity with the RSC in the MTL subsystem and with the dmPFC in the dmPFC subsystem. Activity in the SFS seed region was also functionally connected with that in the RSC. In the retrieval of SS-related autobiographical memories, which were analyzed by the PPI regressor *t* contrasts of R masked inclusively with the PPI regressor *t* contrasts of SS-R versus NS-R and SS-R versus IS-R, the PCC and rSTS seeds in the midline core system showed significant functional connectivity with the PCC and rSTS in the midline core system and with the LTC-TP and TPJ in the dmPFC subsystem. Significant functional connectivity with the pIPL seed region was also found in the pIPL in the midline core system. However, functional connectivity with seed regions in the midline core system was not identified in any regions in the MTL subsystem. These functional connectivity results are illustrated in Figures 5 and 6, and detailed results of the functional connectivity analysis are shown in Table 3.

DISCUSSION

Two sets of main findings emerged from the present study. First, in the retrieval of IS-related autobiographical memories experienced in interpersonal relationships,

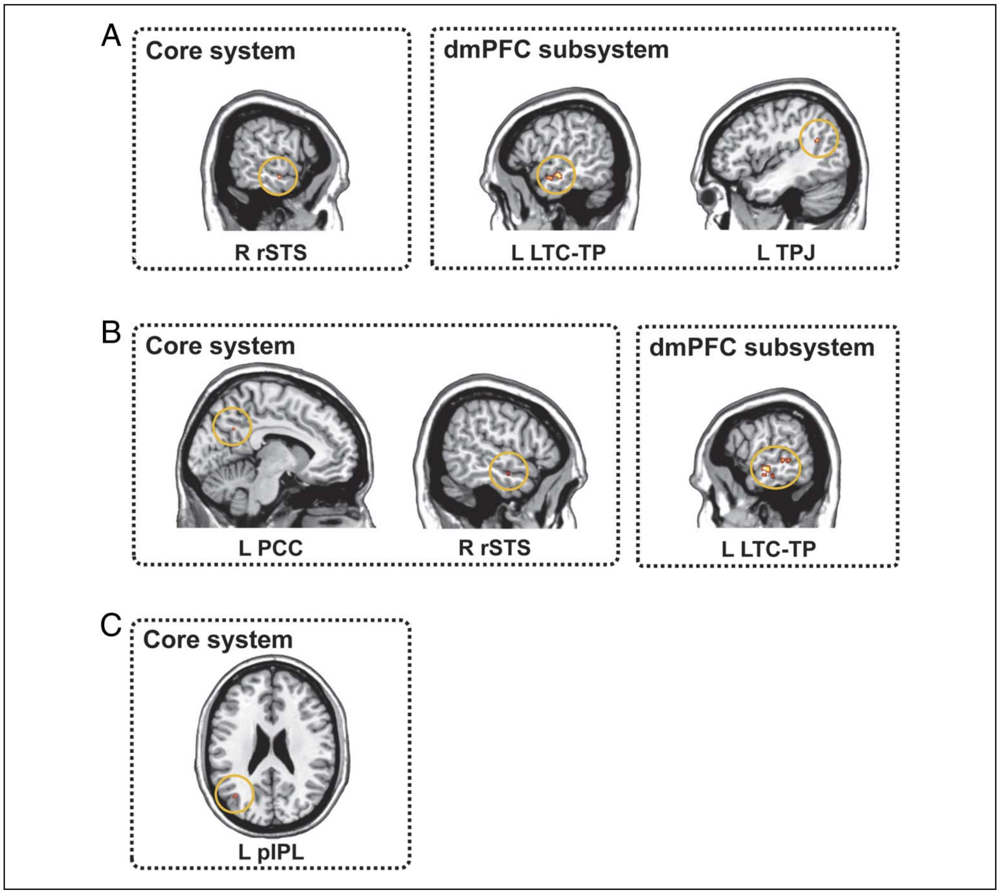

Figure 6. Results of the functional connectivity analysis during the retrieval of SS-related autobiographical memory. Regions showing significant functional connectivity were identified by the PPI regressor *t* contrasts of R masked inclusively with the PPI regressor *t* contrasts of SS-R versus NS-R and SS-R versus IS-R. (A) Functional connectivity with the rSTS seed. (B) Functional connectivity with the PCC seed. (C) Functional connectivity with the pIPL seed. L = left; R = right.

multivariate activity patterns in all subsystems of the DMN significantly distinguished between IS and NS, and functional connectivity was significant in the midline core system (rmPFC, SFS, rSTS, and pIPL seeds) with both MTL (RSC) and dmPFC (dmPFC) subsystems. These findings suggest that, in the retrieval of autobiographical memories experienced in interpersonal relationships, an interaction between the dmPFC subsystem and the midline core system reflects the mentalizing process toward a personally close person, and an interaction between the MTL subsystem and the midline core system contributes to the processing of spatial contexts with different visual perspectives. Second, in the retrieval of SS-related autobiographical memories reflecting one's own reputation in surrounding society, MVPA showed significant classification accuracies of SS versus NS in the midline core system and dmPFC subsystem but not in the MTL subsystem. In addition, trial-by-trial activity in the midline core system (rSTS, PCC, and pIPL seeds) was functionally connected with that in the dmPFC subsystem (LTC-TP and TPJ). However, functional connectivity between the midline core and MTL subsystems was not significant in SS-related autobiographical memory. These findings suggest that an interaction between the dmPFC subsystem and the midline core system is involved in self-representation generated from social knowledge and social value about oneself during the retrieval of autobiographical memories. These two sets of results are discussed in each section below.

Neural Mechanisms Underlying the Processing of Self-representation Based on Interpersonal Relationships in Autobiographical Memory

The first set of findings was that multivariate activity patterns in the DMN subsystems (midline core system, MTL subsystem, and dmPFC subsystem) significantly distinguished between the recollection of IS-related and NS-related autobiographical memories, and significant IS-related functional connectivity with regions in the midline core system (rmPFC, SFS, rSTS, and pIPL) was identified in regions of both the MTL (RSC) and dmPFC (dmPFC) subsystems. These findings suggest that self-representation referred to in IS-related autobiographical memory is involved in the dmPFC, which is related to ToM or mentalizing processes in interpersonal interactions, and the MTL, which is related to the retrieval of autobiographical memory with context-rich spatial information.

Multivariate activity patterns in the dmPFC subsystem and functional connectivity patterns of the midline core system with the dmPFC would reflect ToM or mentalizing processes toward a personally close person during the retrieval of autobiographical memories experienced in interpersonal interactions. Functional neuroimaging

Table 3. Regions and MNI Coordinates Showing Significant Functional Connectivity within the DMN When Remembering Social Autobiographical Memories

	Target ROIs in IS			*Target ROIs in SS*		
Seed Region	*Core*	*MTL*	*dmPFC*	*Core*	*MTL*	*dmPFC*
LR rmPFC	(R SFS: 26, 28, 38)	(R RSC: 6, −60, 12)	(L dmPFC: −4, 50, 42)	–	–	–
	(R SFS: 24, 38, 42)					
	(R rmPFC: 8, 48, 22)					
	(LR PCC: 0, −44, 26)		(R dmPFC: 6, 56, 30)			
	(R PCC: 14, −48, 34)					
	(R PCC: 4, −62, 20)					
R rSTS	(L SFS: −24, 30, 50)	–	–	(R rSTS: 62, −10, −16)	–	(L LTC-TP: −56, −12, −12)
	(L pIPL: −48, −68, 34)					(L LTC-TP: −56, 0, −16)
	(L pIPL: −38, −66, 28)					(L TPJ: −44, −54, 24)
LR PCC	(R PCC: 6, −52, 26)	–	–	(L PCC: −8, −58, 32)	–	(L LTC-TP: −60, −14, −10)
						(L LTC-TP: −60, −32, 0)
				(R rSTS: 56, −6, −18)		(L LTC-TP: −62, −38, 2)
						(L LTC-TP: −58, −22, −16)
L SFS	–	(R RSC: 16, −48, 6)	–	–	–	–
L pIPL	–	–	–	(L pIPL: −38, −66, 24)	–	–

studies have consistently demonstrated the importance of the dmPFC in ToM or mentalizing of others' mental states (for reviews, see Molenberghs, Johnson, Henry, & Mattingley, 2016; Li, Mai, & Liu, 2014; Schurz, Radua, Aichhorn, Richlan, & Perner, 2014; Denny, Kober, Wager, & Ochsner, 2012; Van Overwalle, 2009; Van Overwalle & Baetens, 2009). For example, one fMRI study reported that the dmPFC and dorsolateral pFC showed greater activation in a social context of interpersonal relationships derived from cooperation or competition, in which understanding others' mental states is needed (Lee, Ahn, Kwon, & Kim, 2018). In another fMRI study, significant empathy-related activity was observed in the dmPFC subsystem, including the dmPFC/ACC, inferior frontal gyrus, TPJ, and anterior insular cortex (Tholen, Trautwein, Böckler, Singer, & Kanske, 2020). Thus, the dmPFC subsystem could contribute to the representation of self-related information, which refers to mentalizing or empathy toward personally close persons in individual autobiographical events.

In the present study, MVPA demonstrated that multivariate activity patterns in the MTL subsystem significantly distinguished between the retrieval of IS-related and NS-related autobiographical memories. In the functional connectivity analysis, significant functional connectivity with the midline core system was identified in the RSC of the MTL subsystem. These findings are consistent with previous findings showing the contribution of the RSC to the retrieval of context-rich autobiographical memory (Wen et al., 2020) and the perspective taking in spatial domains including memory, prediction, planning, and social cognition (for a review, see Alexander, Place, Starrett, Chrastil, & Nitz, 2023). For example, functional neuroimaging studies have demonstrated that RSC activity is functionally connected with hippocampal activity during the initial retrieval of autobiographical memories from observer perspectives (Iriye & St Jacques, 2020), and the spatial context information in episodic memory is represented by multivariate activity patterns in posterior-medial regions including the RSC/PCC, MTL, and occipital cortex (Robin, Buchsbaum, & Moscovitch, 2018). In addition, another functional neuroimaging study indicated that a posterior part of the RSC contributes to scene perception, whereas an anterior part of this region is important in memory-based scene construction (Silson et al., 2019). Taken together, these results suggest that self-related information referred to in experiences with a personally close person is formed by both mentalizing and spatial context processes with different visual perspectives and is involved in the dmPFC (dmPFC) and MTL (RSC) subsystems correlated with the midline core system as the DMN hub.

Neural Mechanisms Underlying the Processing of Self-representation Based on One's Own Reputation in Autobiographical Memory

The second set of findings was that MVPA significantly distinguished between SS-related and NS-related autobiographical memories by activity patterns in the midline core system and dmPFC subsystem, and activity in the midline core system (rSTS, PCC, and pIPL) showed significant functional connectivity with that in the dmPFC subsystem (LTC-TP and TPJ) during the retrieval of SS-related autobiographical memory. These findings suggest that self-representation referred to in SS-related autobiographical memory is involved in the TP/anterior temporal lobe (ATL), which supports the processing of social knowledge or social concepts, and the TPJ, which supports the processing of social values.

In the dmPFC subsystem, multivariate activity patterns significantly distinguished between SS-related and NS-related autobiographical memory retrieval. In addition, significant functional connectivity between the midline core system and the dmPFC subsystem (TP) was observed in SS-related autobiographical memory retrieval. These findings are consistent with functional neuroimaging studies, in which the TP/ATL contributes to the processing of social knowledge or social concepts (for reviews, see Herlin, Navarro, & Dupont, 2021; Olson, McCoy, Klobusicky, & Ross, 2013; Wong & Gallate, 2012; Olson, Plotzker, & Ezzyat, 2007). For example, an fMRI study demonstrated stimulus-specific sensitivity within the ATL, in which the superior and polar regions were more sensitive to the retrieval of social knowledge than to that of nonsocial knowledge (Skipper, Ross, & Olson, 2011). The ATL specificity was supported by a meta-analysis of functional neuroimaging studies (Hung, Wang, Wang, & Bi, 2020). In addition, another meta-analysis indicated that the ATL regions act as hubs connecting to various modality-specific sensory, motor, and limbic regions in the representation of conceptual knowledge (Rice, Lambon Ralph, & Hoffman, 2015). Thus, the roles of the ATL in the retrieval of SS-related autobiographical memory could reflect self-representation in terms of the conceptual self, which is formed by the knowledge-based reputation of the self in surrounding society.

The present findings of multivariate activity patterns of the dmPFC subsystem and functional connectivity between the midline core system and the TPJ (part of the dmPFC subsystem) could reflect the subjective value of one's own reputation in SS-related autobiographical memory. A previous fMRI study reported that functional connectivity between the medial pFC and the TPJ significantly increased during rest after the encoding of social impression for unfamiliar people (Meyer, Davachi, Ochsner, & Lieberman, 2019). The importance of the TPJ in the processing of social values has also been identified in the judgment of the justice of actions (Yoder & Decety, 2014) and the detection of gender-based occupational prejudice (Proverbio, Orlandi, & Bianchi, 2017). In another fMRI study, self-related thoughts were associated with increased functional connectivity between regions in the midline core system and the TPJ after the cultural priming of collectivism (Knyazev, Merkulova, Savostyanov, Bocharov, & Saprigyn, 2018). Taken together, the information related to one's own reputation in surrounding society could be formed by both social knowledge represented in the ATL and social values represented in the TPJ, and these regions in the dmPFC subsystem could be functionally connected by the midline core system as the DMN hub during the retrieval of SS-related autobiographical memories.

Limitation

There was a potential limitation in the present study. As mentioned above, we recruited only native Japanese-speaking individuals for the fMRI experiment. Previous psychological studies have demonstrated that, in the retrieval of autobiographical memory, European American people recollect specific, self-focused, and emotionally elaborate memories, whereas East Asian people recollect memories focusing on collective activities, general routines, and emotionally neutral events (Wang, 2001, 2004, 2006). The similar trends have also been observed in the laboratory-based experiments (Leger & Gutchess, 2021; Millar, Serbun, Vadalia, & Gutchess, 2013). These findings implicate that the cultural differences have a possible effect on neural mechanisms underlying self-representation in social autobiographical memories. Thus, it remains unclear to what extent the present results are generalized to samples with different cultural backgrounds. Further investigations would be required to clarify it in future studies.

Conclusion

In the present fMRI study, we investigated the roles of the DMN subsystems in the processing of social selves, which are based on interpersonal relationships and one's own reputation in surrounding society, during the retrieval of autobiographical memories. First, during the retrieval of autobiographical memories experienced in interpersonal relationships, multivariate activity patterns in all subsystems of the DMN significantly distinguished between autobiographical events experienced with a close friend and those experienced alone, and significant functional connectivity with the midline core regions of the DMN was identified in regions in the MTL (RSC) and dmPFC (dmPFC) subsystems. Second, during the retrieval of autobiographical memories reflecting social reputations of the self in surrounding society, multivariate activity patterns in the midline core system and dmPFC subsystems showed significant classification accuracies between the social-reputation-based events and the nonsocial events. In addition, trial-by-trial activity in the midline core system (rSTS, PCC, and pIPL seeds) was functionally connected with that in the dmPFC subsystem (LTC-TP and TPJ). Thus, dissociable neural mechanisms in the DMN could contribute to different aspects of self-representation referred to in social autobiographical memories. The IS-related self-representation referred to in experiences with specific persons could be formed by the mentalization of others' mental states involved in the dmPFC (dmPFC subsystem) and the processing of spatial contexts involved in the RSC (MTL subsystem). In addition, the SS-related self-representation related to the social reputation of the self in surrounding society could be formed by the processing of social knowledge involved in the ATL (dmPFC subsystem) and social values involved in the TPJ (dmPFC subsystem).

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Data Availability Statement

Due to a lack of consent of the participants, raw structural and functional MRI data cannot be shared publicly. Sharing of these data would be considered upon reasonable request and only under circumstances where data privacy can be assured.

Author Contributions

Azusa Katsumi: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Resources; Software; Visualization; Writing—Original draft. Saeko Iwata: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Resources; Software. Takashi Tsukiura: Conceptualization; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Software; Supervision; Validation; Visualization; Writing—Original draft; Writing—Review & editing.

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Diversity in Citation Practices

Retrospective analysis of the citations in every article published in this journal from 2010 to 2021 reveals a persistent pattern of gender imbalance: Although the proportions of authorship teams (categorized by estimated gender identification of first author/last author) publishing in the *Journal of Cognitive Neuroscience (JoCN)* during this period were M(an)/M = .407, W(oman)/M = .32, M/W = .115, and W/W = .159, the comparable proportions for the articles that these authorship teams cited were M/M = .549, W/M = .257, M/W = .109, and W/W = .085 (Postle and Fulvio, *JoCN*, 34:1, pp. 1–3). Consequently, *JoCN* encourages all authors to consider gender balance explicitly when selecting which articles to cite and gives them the opportunity to report their article's gender citation balance. The authors of this article report its proportions of citations by gender category to be M/M = .413, W/M = .326, M/W = .13, and W/W = .13.

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