Memory of others' disclosures is consolidated during rest and associated with providing support: neural and linguistic evidence

Eleanor Collier & Meghan L. Meyer
Dartmouth College
Department of Psychological and Brain Sciences

Corresponding Author:

Meghan L. Meyer
Dartmouth College
HB 6207 Moore Hall
Hanover, NH 03755
Phone: 603-646-3181
Meghan.L.Meyer@Dartmouth.Edu

Abstract

Social scientists have documented the power of being heard: Disclosing emotional experiences to others promotes mental and physical health. Yet, far less is known about how listeners digest the sensitive information people share with them. We combined brain imaging and text analysis methods with a naturalistic emotional disclosure paradigm to assess how listeners form memories of others' disclosures. Neural and linguistic evidence support the hypothesis that listeners consolidate memories for others' disclosures during rest *after listening* and that their ability to do so facilitates subsequently providing the speakers with support. In Study 1, brain imaging methods showed that functional connectivity between the dorsomedial subsystem (dMPFC) of the default network and frontoparietal control network (FPCN) increased during rest after listening to others' disclosures and predicted subsequent memory for their experiences. Moreover, graph analytic methods demonstrated that the left anterior temporal lobe (ATL) may function as a connector hub between these two networks when consolidating memory for disclosures. In Study 2, linguistic analyses revealed other-focused thought increased during rest after listening to others' disclosures, and predicted not only memory for the information disclosed, but also whether listeners supported the speakers the next day. Collectively, these findings point to the important role of memory consolidation during rest in helping listeners respond supportively to others' disclosures. In our increasingly busy lives, pausing to briefly rest may not only help us care for ourselves, but also help us care for others.

Key words: disclosure, social cognition, memory, default network, social support

Think about the first person you talk to in trying times. What makes this person good at responding to your difficult emotions? There are likely a number of reasons, but chances are that when you disclose your struggles, they form a clear *memory* of your experiences. They may even refer back to your experiences when they check in with you later. In contrast, if you disclosed your experiences to someone today and they forgot about them by tomorrow, you probably would not seek support from them again.

Remembering other people's disclosures is one of the most crucial—yet under-researched—social skills. Without it, we would have a difficult time maintaining close relationships or responding intelligently to others' struggles. Yet, virtually all studies on memory for other people have focused on how we recognize faces (Bruce & Young, 1986; Clark, Maisog, & Haxby, 1998; Mitchell, Macrae, & Banaji, 2004), learn to associate faces with names, personality traits, and social roles (Meyer, Davachi, Ochsner, & Lieberman, 2019; Tsukiura, Suzuki, Shigemune, & Mochizuki-Kawai, 2008; Wang et al., 2017), or recall our own autobiographical memories of social experiences (Meyer, Williams, & Eisenberger, 2015; Speer & Delgado, 2019; Spreng & Mar, 2012) . While remembering this type of basic social information certainly matters, it only scratches the surface of interpersonal learning and memory. How we consolidate the nuanced information we glean from others' disclosures to us remains largely overlooked. Here, we ask: (i) How do 'listeners' form memories of 'disclosers' (i.e., the individuals sharing their experiences)? And (ii) does skill in this domain help listeners interact supportively with disclosers?

Two bodies of research, when taken in conjunction, suggest that engaging the brain's default network during rest may help listeners create memories of disclosers'

experiences. First, memory research finds that functional connectivity between brain regions during rest periods following encoding (“post-encoding rest”) is associated with memory consolidation, or the process by which new information becomes solidified in memory (Murty, Tompary, Adcock, & Davachi, 2017; Peigneux et al., 2006; Tambini, Ketz, & Davachi, 2010). Of particular relevance here, consolidating basic facts about people (i.e., others’ faces, traits, and jobs) is associated with post-encoding resting state connectivity between default network regions (Meyer et al., 2019). Second, the default network is implicated in listening during communication. For example, listening to others share their personal experiences (Zaki, Weber, Bolger, & Ochsner, 2009) or tell an entertaining story (Baldassano et al., 2017; Simony et al., 2016; Zadbood, Chen, Leong, Norman, & Hasson, 2017) preferentially engages the default network. Given these past findings, we predict that the default network may be associated with consolidating information about disclosers’ experiences *during rest following listening*.

If the default network is associated with consolidating information about disclosers’ experiences during post-encoding rest, there are multiple ways in which the network may accomplish this feat. The default network can be further divided into three subsystems (Andrews-Hanna, Reidler, Sepulcre, Poulin, & Buckner, 2010): a midline core subsystem associated with self-referential processing (Denny, Kober, Wager, & Ochsner, 2012; Gusnard, Akbudak, Shulman, & Raichle, 2001; Lieberman, Straccia, Meyer, Du, & Tan, 2019); a medial temporal lobe (MTL) subsystem associated with remembering and imagining mental scenes (Schacter Daniel L. & Addis Donna Rose, 2009; Squire & Zola-Morgan, 1991); and a dorsomedial (dMPFC) subsystem associated with thinking about other people and social interactions (Mitchell et al., 2004; Saxe &

Kanwisher, 2003; Van Overwalle & Baetens, 2009; Wagner, Kelley, Haxby, & Heatherton, 2016). While each of these subsystems may be important to consolidating different facets of social information, the dorsomedial subsystem—given its sensitivity to thinking about others and social interactions—may be particularly key. Moreover, the dMPFC subsystem might facilitate consolidation on its own (i.e., greater connectivity within regions of the dMPFC subsystem) or by communicating with other brain networks (i.e., greater connectivity between the dMPFC subsystem and other networks). There is a growing appreciation that brain networks do not operate in silos, but rather work together with other networks to process information (Bressler & Menon, 2010; Ryali et al., 2016; Uddin, Supekar, Ryali, & Menon, 2011). Interestingly, the default network and frontoparietal control network (FPCN) increase in tandem to sustain social information processing in the absence of social stimuli (e.g., during a working memory delay period; (Meyer, Spunt, Berkman, Taylor, & Lieberman, 2012; Meyer, Taylor, & Lieberman, 2015), pointing to the possibility that they may work together to consolidate social information during rest as well. Collectively, a network neuroscience framework suggests that listeners' default network, particularly the dorsomedial subsystem, may partner with other brain systems, particularly the frontoparietal control network, to learn about disclosers during rest. Our first goal was to test these possibilities, to determine whether and how listeners may use their default network to consolidate information about disclosers' experiences.

Moving beyond *how* listeners consolidate information about disclosers' experiences, we next sought to answer *why* doing so matters for real-world social behavior. A large body of research has shown that disclosures benefit the discloser's

own health and wellbeing (Kelley, Lumley, & Leisen, 1997; Pennebaker, Kiecolt-Glaser, & Glaser, 1988), and that disclosers benefit the most when listeners respond supportively (Goldstein, Vezich, & Shapiro, 2014; Gramling et al., 2016; Lun, Kesebir, & Oishi, 2008). In fact, even listeners' health may be improved by connecting with disclosers (Inagaki & Eisenberger, 2016; Inagaki & Orehek, 2017). Thus, identifying factors that promote supportive responding on the part of listeners is critical. So far, work on this topic largely focuses on how empathy for another person's experiences leads to immediate helping behavior or helping intentions toward that person (Coke, Batson, & McDavis, 1978; Dovidio, Allen, & Schroeder, 1990; Masten, Morelli, & Eisenberger, 2011; Mathur, Harada, Lipke, & Chiao, 2010; Oswald, 1996; Schroeder, Dovidio, Sibicky, Matthews, & Allen, 1988). Yet in real life, supportive behavior often operates on longer timescales; and as noted above, if a friend forgot about your struggles from yesterday, they would not be very helpful today. However, only a single study has considered the potential role of memory in support-giving, finding that remembering one's own past helping behavior increases the intention to help others in the future (Gaesser & Schacter, 2014). It remains unknown whether our memory for other people's experiences (rather than our own) predicts actual subsequent helping (rather than an intention to help). To fill this gap, we tested whether listeners' memory for disclosers' experiences corresponds with subsequently providing disclosers support.

To answer these open questions, we developed a new experimental paradigm that involved listening to others share information, resting, and subsequent memory assessments. Specifically, participants alternated between i) listening to someone share information about a personal experience (i.e., watching YouTube videos in which

patients with cystic fibrosis share their experience of dealing with their disease), ii) listening to someone share information that pertained to the same subject matter, but devoid of personal experiences with it (i.e., watching videos from the online educational organization Khan Academy, in which teachers describe the science behind the patients' disease) and iii) resting for several minutes at a time. Next, participants completed a surprise memory test for the information they encoded.

To test whether and how default network connectivity during post-encoding rest consolidates emotional disclosures, in Study 1, participants completed the rest and encoding portions of the paradigm while undergoing functional magnetic resonance imaging (fMRI) and completed the surprise memory test outside of the scanner. To test whether memory for the emotional disclosures predicts subsequent support-giving, in Study 2, participants completed our paradigm over the internet and then the next day were re-contacted with the option to provide support to disclosers. Participants in Study 2 also provided written descriptions of their thoughts across the rest periods. This allowed us to additionally unpack, through linguistic analyses, the post-encoding cognitive processes in listeners during rest that facilitates their memory for disclosers' experiences. Collectively, our multimethod approach provides novel insight into how listeners form memories of disclosers' experiences and how such memory relates to subsequent support-giving.

Study 1

Methods

Participants

Forty right-handed participants (26 females; mean age in years = 29, SD = 11) were recruited from Dartmouth College, New Hampshire and surrounding towns. Participants were paid \$20 per hour or awarded course credit for completing the experiment. Of these participants, 65% were Caucasian, 23% Asian, 8% Hispanic, and 4% mixed/other. Participants provided informed consent in accordance with the Dartmouth College Institutional Review Board (IRB).

Procedures

Participants first completed a functional magnetic resonance imaging (fMRI) session. Upon beginning the experiment, participants were scanned during a six-minute “baseline rest” scan (Figure 1) in order to determine baseline levels of functional connectivity between our regions-of-interest (ROIs). Participants were told that they would see a blank screen and during this time they could rest or mind-wander, but should remain awake. After this baseline rest scan, participants were scanned while watching eight approximately four-minute videos, four of which comprised a block of “patient videos” and four of which comprised a block of “science videos.” Disclosure has been defined as the process of sharing our experiences of events with others (Cosby, 2003; Collins & Miller, 1994; Tamir & Mitchell, 2012). Thus, to assess how people consolidate others’ disclosures, in the patient videos, YouTube vloggers with the terminal illness cystic fibrosis (CF) described their experience with the disease. In the science videos, a Khan Academy teacher delivered lessons on the science behind CF (e.g., its symptoms). In this way, the science videos covered the same broad subject matter as the patient videos (i.e., cystic fibrosis), but did not involve disclosures about the subjective experience of cystic fibrosis. Video order within blocks was randomized,

and the order of patient and science blocks were counterbalanced across subjects. Each block of four videos was followed by another six-minute rest scan (“post-patient rest” and “post-science rest,” respectively).

After the scan session, we tested participants’ memory of the videos with a surprise free recall test in a quiet testing room. Participants were given a laptop on which they viewed a picture of each video along with its title and were asked to type everything they could remember from that video. After data collection, their responses were scored for the number of distinct, correct facts recalled (see Supplementary Materials, “Memory Test Scoring”).

Figure 1. Brain imaging paradigm. Participants first completed a baseline resting state scan. Next participants listened to patients with cystic fibrosis (CF) share their experience of dealing with their disease and, separately, teachers explain the science behind CF (order counterbalanced across participants). Each condition was followed by a post-encoding resting state scan.

fMRI Acquisition

Scanning was performed on a Siemens Trio 3T. Functional images were acquired using an EPI gradient-echo sequence (2.5 x 2.5 x 2.5 mm voxels, TR = 1000 ms, TE = 30 ms, 2.5 mm slice thickness, FOV = 24 cm, matrix = 96 × 96, flip angle = 59°; multiband acceleration factor = 4). A T2-weighted structural image was acquired coplanar with the functional images (0.9 x 0.9 x 0.9 mm voxels, TR = 2300 ms, TE = 2.32 ms, 0.9 mm slice thickness, FOV = 24 cm, matrix = 256 × 256, flip angle = 8°).

fMRI Data Preprocessing

All functional and anatomical images were reoriented in SPM12 (Wellcome Department of Imaging Neuroscience, London) to set the origin to the anterior commissure and the horizontal (y) axis parallel to the AC-PC line. Anatomical images were skull-stripped using the Brain Extraction Tool (BET) in FSL (FMRIB Software Library; Oxford University, Oxford, UK). For the creation of nuisance regressors, white matter and cerebrospinal fluid masks were generated from each anatomical image using FSL's FMRIB's Automated Segmentation Tool.

Preprocessing of functional data was carried out in FSL and was consistent with past approaches to studying functional connectivity during rest and memory consolidation (Meyer et al., 2019; Tambini et al., 2010). First, each EPI volume underwent the following preprocessing steps: removal of low-frequency noise below 0.009 Hz with a high-pass filter, motion correction using FMRIB's Linear Image Registration Tool (MCFLIRT), skull-stripping using BET, spatial smoothing with a 6mm radius, and registration to the anatomical image using Boundary-Based Registration

(BBR). Second, nuisance variables were prepared for use as regressors in a generalized linear model (GLM). These included the six standard motion parameters and their derivatives, as well as the signal extracted from white matter and cerebrospinal fluid regions. In order to correct for extreme motion, additional nuisance variables were generated for global signal regression (the average brain signal) and motion scrubbing (volumes with framewise displacement > 0.2mm). Past work has demonstrated this to be the most effective way of removing motion artifacts (Power et al., 2014). Finally, all nuisance variables were regressed out of the data in a GLM, using a high-pass filter to remove any frequencies in the regressors below 0.009 Hz.

Brain Networks

For our functional connectivity analyses, we used the canonical brain networks defined by Yeo et al. (2011). Consistent with prior work, extremely small clusters (fewer than five voxels) were excluded from analysis (Meyer, Hershfield, Waytz, Mildner, & Tamir, 2019). The Yeo et al. (2011) parcellation generates three default network subsystems that map onto known functional dissociations (Andrews-Hanna et al., 2010): a midline core, associated with self-referential processing (medial prefrontal cortex, posterior cingulate/precuneus, posterior inferior parietal lobule; (Denny et al., 2012; Gusnard et al., 2001; Lieberman et al., 2019); a medial temporal lobe subsystem (MTL), associated with remembering and imagining mental scenes (hippocampal formation, retrosplenial cortex, posterior inferior parietal lobule (Schacter Daniel L. & Addis Donna Rose, 2009; Squire & Zola-Morgan, 1991); and a dorsomedial subsystem (dMPFC), associated with thinking about others and social interactions (dorsomedial prefrontal cortex, temporoparietal junction, temporal poles, inferior frontal gyrus (Mitchell

et al., 2004; Saxe & Kanwisher, 2003; Van Overwalle & Baetens, 2009; Wagner et al., 2016).

The parcellation also generates regions for the frontoparietal control network (FPCN), dorsal attention network (DAN), and ventral attention network (VAN), systems key to cognitive control, attention, and emotion processing (Cabeza & Nyberg, 2000; Dosenbach et al., 2007; Nummenmaa et al., 2012; Nummenmaa et al., 2014). We therefore also included these networks in our analyses to assess whether and how default network subsystems may increase functional connectivity with other, large-scale brain networks throughout our experimental conditions. The frontoparietal control network was further divided into two subsystems based on a 2018 meta-analysis by Dixon et al. (Dixon et al., 2018), suggesting this network is comprised of two dissociable subsystems: one associated with the regulation of internally directed attention, shown to preferentially connect to the default network (posterior middle frontal gyrus, right lateral prefrontal cortex, anterior inferior parietal lobule, anterior middle temporal gyrus, pre-supplementary motor area); and another associated with the regulation of externally directed attention (anterior and posterior inferior frontal sulcus, posterior intraparietal lobule, posterior middle frontal gyrus), shown to preferentially connect to the dorsal attention network. To stay consistent with the naming conventions of Dixon et al. (2018), we refer to these networks as FPCN_A and FPCN_B, respectively.

In addition to these networks, we also examined the role of the hippocampus during our experimental conditions. This included left and right anatomical hippocampal ROIs (based on AAL definitions in WakeForest PickAtlas (Maldjian et al, 2003), as well as two functionally defined hippocampal ROIs. One functionally defined hippocampal

ROI was based on the Neurosynth association test map for the term “consolidation” (Supplementary Figure 1). Inclusion of this ROI allowed us to assess whether our data aligns with past (non-social) memory research implicating hippocampal-cortical connectivity in memory consolidation (Burgess N. et al., 1997; Ji & Wilson, 2007; Tambini et al., 2010). This ROI was constrained to only include regions within the anatomical bilateral hippocampus using SPM’s tool MarsBaR (Brett, Anton, Valabregue, Poline, & Others, 2002). The other functionally defined ROI was an 8mm sphere centered at MNI coordinates (-24 -20 -18), based on two studies that examined autobiographical memory and mentalizing (Rabin et al., 2010; Spreng & Grady, 2010). This hippocampal region has previously been found to connect with regions associated with mentalizing during rest (Spreng & Mar, 2012).

Functional Connectivity and Graph-Based Network Analyses

Computing connectivity. ROIs were registered to MNI space, then to each subject’s anatomical image, using FSL’s FLIRT tool. After preprocessing the BOLD data, average BOLD timecourses were extracted from ROIs using fslmeants. The pairwise connectivity between ROIs was found by computing the Pearson correlation between BOLD time courses for each ROI pair. These Pearson correlations were then fisher-z transformed to allow for statistical comparisons of connectivity between conditions. Within-network connectivity was calculated by averaging across correlation coefficients for each ROI pair in a given network. Between-network connectivity was calculated by averaging across correlation coefficients for each between-network ROI pair.

Figure 2. Brain networks used in functional connectivity analyses.

Condition comparisons. Our primary goal for Study 1 was to assess whether and how the default network may be associated with consolidating disclosures during rest following listening. In order to find connectivity that was preferentially elevated for this rest period, relative to all other conditions, we ran linear mixed-effect models using R's lme4 package (Bates, Mächler, Bolker, & Walker, 2015). For a given within- or between-network comparison, the model evaluated connectivity as a function of block, and controlled for multiple within-subjects measures by including a random intercept for each participant. Connectivity during post-patient rest was compared to the average connectivity during all other conditions (i.e., all other rest and video watching conditions) using a sum contrast. For connectivity that was found to be preferentially enhanced

during post-patient rest, we also ran follow-up sum contrasts comparing post-patient rest vs. each other rest condition (baseline rest and post-science rest), to ensure that our functional connectivity results were not simply driven by idiosyncrasies during video encoding (as opposed to our primary interest in changes during rest). Because we had specific predictions of enhanced connectivity during post-patient rest, these follow-up analyses were one-tailed.

Graph-Based Network Analyses. For network pairs with elevated between-network functional connectivity during post-patient rest, we used graph-based network analyses to investigate whether particular ROIs helped bridge the two networks during post-patient rest. Because follow-up, between-network functional connectivity analyses showed dMPFC-FPCN_A connectivity was greater during post-patient rest vs. baseline and post-science rest (see Results section), we only performed graph analyses on resting state scans with these regions. Network analyses were carried out in BRAPH (Mijalkov et al., 2017) on the weighted undirected graph of a given network pair, with negative correlations between ROIs set to zero. A predefined community structure was established, with each network assigned to a separate community. Linear mixed effects models with sum contrasts were used to test for greater participation during post-patient rest relative to baseline rest and post-science rest. Because we had specific predictions of enhanced participation during post-patient rest, these follow-up analyses were one-tailed.

For every rest period we computed each ROI's participation coefficient, which indicates the extent to which one ROI *preferentially* connects to ROIs outside of its own community. Unlike between-network functional connectivity, which represents how

strongly on average ROIs in one network connect with ROIs in another network, the participation coefficient of a given ROI represents the *proportion* of its connections to ROIs outside its network vs. ROIs within its own network (for the participation coefficient formula, see Supplementary Materials, “Participation Coefficient”). ROIs with high participation coefficients can be considered “connector hubs” and are likely to facilitate integration between networks (Guimera & Amaral, 2005; Guimera et al., 2007). Thus, the participation coefficient provides a more nuanced measure of how two networks connect than functional connectivity does, and can be used to identify individual ROIs critical to cross-network integration.

We tested ROI participation at 1) the network level of analysis and 2) the ROI level of analysis. At the network level of analysis, we averaged across all ROIs in a given network to compute the mean participation of ROIs in that network. This resulted in two distinct values: the mean participation of dMPFC ROIs (preferential connection with FPCN_A ROIs), and the mean participation of FPCN_A ROIs (preferential connection with dMPFC ROIs). Note that these two measures are not redundant, as the participation of dMPFC ROIs depends partly on within-dMPFC connections, while the participation of FPCN_A ROIs depends partly on within-FPCN_A connections (thus it would be possible for one network to have high mean participation and the other to have low mean participation). At the ROI level of analysis, we used each ROI’s individual participation coefficient (preferential connection with ROIs in the opposite network) as the unit of analysis.

Memory performance. Finally, to evaluate whether default network functional connectivity during rest after listening may facilitate consolidation of disclosures, we

assessed the relationship between individual differences in connectivity during rest and subsequent memory of the videos. We computed the Pearson correlation between connectivity and graph-based participation results that was found to be preferentially enhanced during post-patient rest and the number of patient facts recalled. Because we had specific predictions of a positive correlation between connectivity and memory, these analyses were one-tailed. To assess the specificity of observed memory correlations, we also assessed whether similar patterns emerged during post-science rest and the number of science facts recalled.

To generate memory scores, the number of pieces of information recalled was summed across all videos, separately within each video block. A recalled piece of information was only counted if it was both *distinct* (non-redundant with other pieces of information recalled) and *correct*. For the patient videos, pieces of information were additionally limited to memory of patients' *experiences* (as opposed to perceptions of the patient unrelated to what they disclosed, such as patients' physical features or participants' opinions about the patient). For examples of memory scoring, see Supplementary Materials, "Memory Test Scoring." Although participants recalled more facts about the patients' experiences ($M = 25.4$, $SD = 12.5$) than the science of cystic fibrosis ($M = 18.2$, $SD = 11.0$; $t(39) = 3.66$, $p < 0.001$), these two indices of memory were significantly correlated ($r = 0.45$, $p = 0.004$), indicating that they tapped into similar, though not fully redundant, aspects of memory.

Results

Functional Connectivity Results.

The primary goal of Study 1 was to identify brain networks that may help consolidate information about others' disclosures during subsequent rest. Networks that specifically aid in this process should connect most strongly during the rest period following patients' disclosures, or "post-patient rest." Using a linear mixed model with sum contrasts, we tested for within- and between- network connectivity that was preferentially increased during post-patient rest, relative to our other conditions. Only connectivity between the *dMPFC subsystem* of the default network and the *FPCN_A subsystem* was preferentially elevated during post-patient rest ($t(156)=3.24$, $p=0.001$, $\beta=0.17$, $SE=0.05$; Figure 3A). This comparison survives Bonferroni correction for the number of network comparisons made ($p<.002$). The follow-up contrast assessing whether functional connectivity between these regions during post-patient rest was significantly greater than baseline and post-science rest was significant ($t(78)=1.77$, $p=.041$, $\beta=0.12$, $SE=0.07$).

Given that dMPFC-FPCN_A connectivity increased during post-patient rest, we next tested whether the gain in connectivity between these networks was associated with better memory for the patients' experiences. If so, this would be consistent with the idea that communication between these networks after listening to disclosers facilitates memory for them. Indeed, dMPFC-FPCN_A connectivity during post-patient rest (vs. baseline rest) correlated with the number of distinct, correct facts recalled from the patient videos ($r=0.36$, $p=0.02$; Figure 2B). In contrast, dMPFC-FPCN_A connectivity during rest after the Kahn academy videos, or "post-science rest" (vs. baseline rest) did not significantly correlate with the number of facts recalled from the science videos ($r=0.22$, $p=0.17$), though it should be noted that these two correlations with memory are

not significantly different from one another ($z=1.04$, $p=0.15$). Previous work has shown that the dMPFC subsystem plays a role in interpreting other people (Mitchell et al., 2004; Saxe & Kanwisher, 2003; Van Overwalle & Baetens, 2009; Wagner et al., 2016), while the FPCN_A subsystem helps regulate and sustain internal reflection (Dixon et al., 2018). It is possible that the integration of these two processes in the brain, i.e. *sustaining reflection about others* during post-encoding rest aids in subsequent recollection of others' experiences.

It is also noteworthy that while dMPFC-FPCN_A connectivity was highest during *post-patient rest*, as noted above it was significantly lower during the *patient videos* ($t(156)=-6.53$, $p<0.001$). Thus, the dMPFC subsystem's partnership with the FPCN_A may be more important for sustaining social information processing during post-encoding rest, rather than during encoding itself. In contrast, *within-network* dMPFC subsystem connectivity was greater during patient video encoding ($M=0.26$, $SD=0.03$) vs. science video encoding ($M=0.23$, $SD=0.03$, $t(39)=6.40$, $p<0.001$). This result is consistent with past research showing that the dMPFC subsystem is preferentially associated with social vs. non-social inferences during encoding (Mitchell et al., 2004; Saxe & Kanwisher, 2003; Van Overwalle & Baetens, 2009; Wagner et al., 2016), and survives Bonferroni correction for the number of possible within- and between-network comparisons ($p<.002$). However, neither dMPFC within-system connectivity, nor any of the other network comparisons that significantly varied for encoding conditions, correlated with subsequent memory (r 's <0.14 p 's > 0.39). This further implicates the potential importance of *post-encoding rest periods*, above and beyond encoding, for consolidating information about disclosers' experiences.

Although it was not our main goal, we also looked for connectivity that may help consolidate memory for the science videos. A large body of research has already explored the neural correlates of *non*-social memory consolidation during rest, finding that hippocampal-cortical connectivity plays a critical role (e.g., Murty et al., 2017; Peigneux et al., 2006; Tambini et al., 2010). However, to our knowledge, no studies have done so using stimuli that mimics how students learn in classrooms. Our results showed that none of our hippocampal ROIS, nor any of the Yeo et al. (2011) networks we examined were uniquely elevated during post-science rest (p 's > 0.2). However, during post-science rest (vs. baseline rest), connectivity between the *core subsystem* of the default network and the *hippocampus* ROI defined by the search term 'consolidation' in NeuroSynth correlated with memory for the science videos ($r=0.37$, $p=0.02$, Supplementary Figure 2).

Graph-Based Network Results.

Thus far, our results suggest that dMPFC-FPCN_A between network functional connectivity during post-patient rest is associated with consolidating others' disclosures in memory. To further understand this phenomenon, we next sought to determine which of these regions are particularly strong connector hubs that may help integrate the two networks during post-patient rest. To this end, we used graph-based network analyses on our resting state scans to assess 1) network-level participation (i.e., how much, on average, each ROI in a network preferentially connects with the opposite network) and 2) ROI-specific participation (i.e., how much an ROI preferentially connects with all other ROIs outside its own network).

At the network level of analysis, we found that, on average, regions in the dMPFC subsystem and FPCN_A subsystem demonstrated higher participation during post-patient rest compared to the other rest periods ($t(78)_{\text{FPCNA}}=2.47, p=.016, \beta=0.18, \text{SE}=0.07$; $t(78)_{\text{dMPFC}}=1.95, p=.054, \beta=0.15, \text{SE}=0.08$; Figure 4A&C). Additionally, their participation during post-patient rest (vs. baseline rest) significantly correlated with memory for the patient videos ($r_{\text{dMPFC}}=.30, p=.029$; $r_{\text{FPCNA}}=.41, p=.004$; Figure 4B&D). In contrast, average subsystem participation during post-science rest (vs. baseline rest) did not significantly correlate with memory for the science videos ($r_{\text{FPCNA}}=.19, p=.12$; $r_{\text{dMPFC}}=.23, p=.08$). Moreover, the correlations between 1) participation during post-patient rest and patient memory and 2) participation during post-science rest and science memory were significantly different from one another for FPCN_A participation ($z=1.84, p=0.03$), though not dMPFC subsystem participation ($z=0.62, p=0.27$). Thus, FPCN_A participation with dMPFC subsystem ROIs during post-patient rest is preferentially associated with better memory for patients' disclosures.

At the ROI level of analysis, only the left anterior temporal lobe (ATL) from the dMPFC subsystem showed higher participation across the two networks during post-patient rest relative to the other two rest periods ($t(78)=2.02, p=.047, \beta=0.16, \text{SE}=0.08$; Figure 5A). The left ATL's participation during post-patient rest (vs. baseline rest) also correlated with memory for the patient videos ($r=.33, p=.02$; Figure 5A). In contrast, left ATL participation during post-science rest (vs. baseline rest) did not correlate with memory for the science videos ($r=.19, p=.13$), though it should be noted that these two correlations with memory are not significantly different from each other ($z=1.16, p=0.12$). These ATL findings complement and extend previous work showing this region

is associated with representing and retrieving information about others in memory (Olson, McCoy, Klobusicky & Ross, 2013; Wang et al., 2017).

In summary, Study 1 provides the first insight into the large-scale brain networks that are associated with consolidating *memory for others' disclosures* during rest. We found that dMPFC-FPCN_A between-network functional connectivity preferentially increased during rest after the patient videos and correlated positively with subjects' subsequent memory for the patients' experiences. Graph-based network analyses further demonstrated that this preferential gain in functional connectivity corresponds with greater participation of regions in these networks. The left ATL in particular may help bridge these two networks to consolidate memory for others' disclosures. Critically, although some within- and between-network comparisons statistically varied in response to each encoding condition, no connectivity during video watching related to subsequent memory. These patterns point to the possibility that idle rest after listening, above and beyond listening in the moment, is important for interpersonal learning and memory.

A.

B.

Figure 3. Functional Connectivity results from Study 1. Panel A) shows that dMPFC-FPCNA connectivity was greater during post-patient rest, relative to each other condition. Panel B) shows that greater dMPFC-FPCNA connectivity during post-patient rest (vs. baseline rest) correlates with greater subsequent memory for the patients' experiences.

Figure 4. Network-level participation coefficient results from Study 1. Panel A) shows that average participation of dMPFC ROIs was greater during post-patient rest, relative to each other condition. Panel B) shows that average participation of dMPFC ROIs during post-patient rest (vs. baseline rest) correlates with greater subsequent memory for the patients' experiences. Panels C) and D) show the same pattern of results for average participation of FPCNA ROIs.

Figure 5. ROI-level participation coefficient results from Study 1. Panel A) shows that the left ATL's participation was greater during post-patient rest, relative to each other condition. Panel B) shows that the left ATL's participation during post-patient rest (vs. baseline rest) correlates with greater subsequent memory for the patients' experiences. Panel C) shows the relative participation of all ROIs for post-patient rest vs. baseline

rest and post-patient rest vs. post-science rest. A larger sphere indicates that an ROI had greater participation during post-patient rest relative to the other rest period. Edges between ROIs are based on the weighted undirected graph for post-patient rest.

Study 2

Results from Study 1 suggest that dMPFC-FPCN_A between-network connectivity during rest after listening to disclosures is associated with consolidating information about disclosers' experiences. Given that the dMPFC and FPCN_A are associated with interpreting other people and regulating internal reflection, respectively (Dixon et al., 2018; Mitchell et al., 2004; Saxe & Kanwisher, 2003; Van Overwalle & Baetens, 2009; Wagner et al., 2016), it is possible that listeners reflect on the newly encoded information about disclosers' experiences during subsequent rest in order to learn about them. To test this psychological interpretation more explicitly, in Study 2, a new sample of participants completed the same experimental paradigm used in Study 1 (however without undergoing fMRI). At the end of each rest period, participants were asked to write a journal entry describing what they thought about during the idle period. These journal entries were submitted to a text analysis to assess whether participants preferentially engaged in other-focused thought during post-patient rest, as well as whether this objectively-assessed form of other-focus predicted subsequent memory for the patients.

In Study 2, we also tested whether listeners' memory for disclosers' experiences predicts whether and how well listeners subsequently provide them with support. To this end, participants in Study 2 were provided the option to write the patients a

supportive message. Critically, participants did not receive additional payment if they chose to write a letter, to help ensure that only prosocial motivation drove the decision. These messages were then assessed by a new set of participants, who rated them for their supportiveness. We were therefore able to test whether memory for disclosers' experiences is associated with deciding to provide support, and if so, whether it additionally related to the effectiveness of support-giving.

Methods

Participants

Participants (N=197; 106 female; mean age in years = 36.96, SD = 10.53) recruited online from Amazon's Mechanical Turk (MTurk) completed Study 2 for monetary payment (\$6/hour). Of these participants, 85% were Caucasian, 4% African American, 4% Asian, 2% Hispanic, and 5% mixed/other. Participants provided informed consent in accordance with the Dartmouth College Institutional Review Board (IRB).

Online Task

Day one. Upon beginning the experiment, participants completed the same paradigm used in Study 1, with a few differences. To facilitate engagement online, but without changing the overall length of the experiment, rest blocks were slightly shorter (four minutes rather than six), and the video blocks were slightly longer (six videos rather than four). Participants completed the experiment in the Inquisit 5 Player application, which ensured that participants could not do other tasks on their computers during the videos or rest periods as it locks users into the Inquisit screen. Compliance during rest periods was further ensured by asking attention check questions every

minute plus or minus a random interval; data was discarded for participants who failed more than one attention check (36 participants who are not reflected in our final sample of N=197). After each rest period, participants were additionally asked to free write about all of the thoughts they had during the previous rest period. At the end of the task, participants completed the same surprise memory test used in Study 1, and their responses were later scored for the number of distinct, correct facts recalled.

Day two. On the second day of the experiment, participants had the option to write a message of support to any of the patients they had listened to the day prior. To ensure that choosing to write a message was not driven by interest in monetary reward, participants were not paid extra for choosing to write, nor their time spent doing so. To increase participants' perception that their support could be impactful, they were told that their messages would be delivered to the patients they addressed.

Supporters' messages were scored by an independent sample of MTurk raters (N=28). Raters answered the following four questions for each message, on a scale of zero to one hundred: 1) "Overall, how supportive does the writer seem?" 2) "To what extent does the writer express concern for the difficulties the recipient is facing?" 3) "To what extent does the writer express encouragement (e.g. You can do it)?" 4) "To what extent do you think this message would make the recipient feel better?" Similar questions have been used in past work studying support-giving to evaluate the supportiveness of messages (Inagaki & Eisenberger, 2016). As ratings for these four questions were highly related (Chronbach's $\alpha=0.98$), we averaged across them to generate a single supportiveness score.

Data Analysis

Linguistic analysis of rest thought content. We used the 2015 LIWC (Linguistic Inquiry and Word Count; Pennebaker & Booth, 2015) software to assess the amount of other-focused reflection in participants' free writes. For each subject, we summed the percentages from the LIWC categories that referenced other people and social interaction more generally. This included all non-first-person singular personal pronouns (e.g., 'she'; 'him'; 'they'), nouns that pertain to people (e.g., "girl", "neighbor") and verbs that suggest human interaction (e.g., "talking", "sharing"). We refer to this score in all subsequent analyses as "other-focus."

Condition comparisons. In order to test whether other-focus was uniquely elevated during post-patient rest, we ran a linear mixed-effect model using R's lme4 package (Bates et al., 2015). The model evaluated other-focus as a function of rest block and controlled for multiple within-subjects measures by including a random intercept for each participant. Other-focus during post-patient rest was compared to other-focus during all other rest blocks using a sum contrast.

Memory performance and providing support. To evaluate the relationship between individual differences in other-focus during rest and subsequent memory for the videos, we computed the Pearson correlation between other-focus and number of facts recalled. T-tests were used to compare other-focus and memory across subjects who wrote at least one supportive message and subjects who wrote none. To examine the interactions between all three variables (other-focus, memory, and message writing), we tested for mediation with R's mediation package (Tingley, Yamamoto, Hirose, Keele, & Imai, 2014) using the bias-corrected bootstrap based on 5000 bootstrapped samples. In addition, for the subjects who wrote at least one supportive

message, we computed the Pearson correlation between the supportiveness of their messages and facts recalled from the patient videos.

Participants' memory performance for the patient ($M=15.1$, $SD=9.0$) and science videos ($M=14.8$, $SD=11.5$) were not significantly different from one another ($t(196)=0.57$, $p=0.57$), suggesting that the significant difference between memory scores observed in Study 1 is unlikely a robust finding and mitigates concerns that observed differences may be driven by differences in memory difficulty for the two types of encoding. Nonetheless, as in Study 1, these two indices of memory were significantly correlated ($r=0.71$, $p<0.001$), again indicating that they tap into similar, though not fully redundant, aspects of memory.

Results

Thought Content Preferentially Associated with Rest after Listening to Emotional Disclosures

Our first goal in Study 2 was to test whether other-focused thought during rest after listening to disclosures is associated with better subsequent memory for them. If so, our linguistic measure of other-focus should parallel the neural findings from Study 1 (i.e. increase the most during post-patient rest and correlate with number of patient facts recalled). Indeed, a linear mixed model showed that other-focus was uniquely elevated during post-patient rest ($t(392)=6.28$, $p<0.001$, $\beta=0.26$, $SE=0.04$; Figure 6A). Moreover, other-focus during post-patient rest also correlated with the number of facts recalled from the patient videos ($r=0.20$, $p=0.005$; Supp. Figure A).

The Relationship between Thought Content, Memory, and Supportive Behavior

Our next goal was to assess the relationship between memory for others' emotional disclosures and subsequent supportive behavior. When we compared memory between participants who wrote at least one supportive message ("supporters") and those who did not ("non-supporters"), we found that supporters remembered on average 3.6 more facts from the patient videos ($t(195)=2.95$, $p=0.004$; Supp. Figure 3B). Intriguingly, supporters also engaged in 1.5 times as much other-focused thought during post-patient rest compared to non-supporters ($t(186)=4.18$, $p<0.001$; Supp. Figure 3C). This observation led us to test for mediation, and we indeed found that the relationship between other-focus during post-patient rest and supportive behavior was partially mediated by memory of the patient videos (proportion mediated=11%, CI=2%, 38%; $p=.03$; Figure 6B, Table 1). Finally, among supporters, greater memory for disclosers' experiences also tracked with the supportiveness of their messages. That is, independent raters' assessments of letter supportiveness significantly correlated with supporters' memory for disclosers' experiences ($r=0.24$, $p<0.001$; Supp. Figure 4). Collectively, these results suggest that memory for others' disclosures has a real-world impact on supportive behavior and helps explain the link between the content of our thoughts after listening to disclosers and our decision to subsequently support them.

Figure 6. Results from Study 2. Panel A) shows that other-focused thought content was greatest during post-patient rest, relative to each other rest period. Panel B) shows results from the mediation model demonstrating that memory of patient videos partially explains the relationship between other-focused thoughts during post-patient rest and subsequently choosing to write a supportive message.

	B coefficient	Bias-corrected CI		p-value
		Lower	Upper	
Indirect effect	0.02	0.002	0.04	0.03
Direct effect	0.13	0.06	0.21	<0.001
Total effect	0.15	0.08	0.22	<0.001
Proportion of total effect mediated	0.11	0.02	0.38	0.03

Table 1. Test of mediation with bootstrapped results for other-focus -> memory of patient videos -> decision to provide support.

Discussion

Disclosing difficult experiences is a hallmark of interpersonal relationships. Yet, virtually no research to date has examined how listeners digest this information to effectively learn about disclosers' experiences, nor whether the ability to do so helps listeners provide disclosers with support. Across two studies, we identified mechanisms during post-encoding rest that help listeners consolidate information about disclosers' experiences and found that such memory facilitates subsequent supportive behavior. In Study 1, dMPFC-FPCN_A between-network connectivity was uniquely elevated during rest after watching videos of patients' disclosures and correlated with memory for patients' experiences. In addition, graph-based network analyses revealed that regions in these two networks, most notably the left ATL, may help bridge these networks to consolidate memory for others' disclosures. In Study 2, memory for patients' disclosures predicted whether and how well participants supported the patients the next day. Moreover, memory for patients' disclosures partially mediated the relationship between other-focused thought during post-encoding rest and subsequent social support. Collectively, these findings point to the important role of memory consolidation during rest in support provision.

Results from Study 1 provide new insight into the role of dMPFC-FPCN_A connectivity in social learning and memory. Past research has found that both of these networks are associated with maintaining and manipulating high-level social information (e.g., information about people's personality traits) over a very brief delay in working memory (i.e., 6 seconds (Meyer et al., 2012, 2015)). Here, we found that these

networks can sustain communication during longer timescales (i.e., 6 minutes) directly after exposure to new social information, and that doing so predicts subsequent social memory performance. Previous work implicates the dMPFC subsystem in interpreting other people (Dixon et al., 2018; Mitchell et al., 2004; Saxe & Kanwisher, 2003; Van Overwalle & Baetens, 2009; Wagner et al., 2016), and the FPCN_A subsystem in regulating internal reflection (Dixon et al., 2018). Thus, the integration of these two processes during post-encoding rest may help listeners learn about disclosers after interacting with them. Consistent with this interpretation, in Study 2, we found that other-focused thought during the rest period following patients' disclosures correlated with memory for patients' experiences. Interestingly, the primary neural findings in Study 1 were specific to *post-encoding rest*; while there was evidence of greater connectivity for some networks while participants listened to patient videos vs. science videos, it did not relate to subsequent patient memory. These patterns point to the intriguing possibility that idle rest after listening, above and beyond listening in the moment, is important for interpersonal learning and memory.

Graph-based network analyses in Study 1 provide further insight into which and how regions in these two networks help them work together to consolidate memory of disclosures. On average, regions in both the dMPFC subsystem and the FPCN_A subsystem demonstrated higher participation (the extent to which regions can be considered “connector hubs” between networks) during post-patient rest and their participation during post-patient rest correlated with memory for the patient videos. Of these regions, only the left ATL demonstrated significant participation and links to patient memory at the ROI level of analysis. This finding is consistent with past work

showing that the ATL is critical to representing and retrieving information about others in memory (Olson, McCoy, Klobusicky & Ross, 2013; Wang et al., 2017). However, to our knowledge, this is the first study to reveal that the ATL may play an important role in bridging the dMPFC and FPCN_A subsystems to support social learning and memory during post-encoding rest.

Study 1 was also the first to compare consolidation during rest of social vs. nonsocial *naturalistic* stimuli. Both sets of videos present information in a realistic style: the patient videos are real emotional disclosures posted on YouTube, and the science videos are real course material used by students in Khan Academy. Thus, results from Study 1 lend real-world relevance to past experimental findings with high internal validity, but relatively impoverished external validity. In particular, our findings dovetail with past work showing that default network connectivity during post-encoding rest helps consolidate basic facts about people (i.e., recognizing photographs of faces and associating traits and roles with them). Collectively, these results suggest one function of engaging the default network during rest may be to learn about the people we interact with day-to-day (Meyer, 2019; Meyer et al., 2019).

Additionally, results from Study 1 lend real-world relevance to previous work identifying hippocampal-cortical connectivity in nonsocial memory consolidation. Connectivity between the hippocampus and core subsystem of the default network during the rest period following Khan Academy videos correlated with memory for the science facts communicated in these videos. On the one hand, these findings are at odds with past social neuroscience suggestions that the default network's core subsystem is associated with self-referential processing (Denny et al., 2012; Lieberman

et al., 2019). On the other hand, the results align with other memory research implicating connectivity between the hippocampus and the MPFC (a region of the core subsystem) in memory consolidation more broadly (Eichenbaum, 2017; Euston, Gruber, & McNaughton, 2012). For example, hippocampal-MPFC connectivity during rest is associated with updating our knowledge of an unfolding story (van Kesteren, Fernández, Norris, & Hermans, 2010). Future research may reveal whether hippocampal-core subsystem connectivity during post-encoding rest plays a general role in updating previous memories across both self-relevant and non-self-relevant stimuli.

Study 2 builds on the primary neural findings in Study 1 by illuminating the cognitive processes during rest that may aid in consolidating memory of emotional disclosures. Other-focused thought was uniquely elevated during rest after viewing videos of patients' disclosures and correlated positively with subjects' memory for patients' experiences. These findings add to a growing area of research examining the neurocognitive processes associated with providing social support (Inagaki & Eisenberger, 2012, 2016; Inagaki & Orehek, 2017) and open interesting avenues for future investigation. For example, one direction for future research will be to examine whether (and how) memory consolidation during rest could help us learn about and support individuals in our own social networks. Indeed, one study found that greater dMPFC subsystem connectivity during rest corresponded with greater support-giving to a close other during the following month (Inagaki & Meyer, 2019). Although our findings pertained to learning about and providing support to *new* individuals, the ability to remember disclosures may also help us maintain our close social connections. The

results also have interesting implications for provider-patient relationships. Patients overwhelmingly prefer doctors, nurses, and therapists who respond supportively to their disclosures (Miller, 1993; Ong, de Haes, Hoos, & Lammes, 1995; Thompson & Anderson, 1982; von Dietze & Orb, 2000). Our findings implicate brief rest after listening as a possible route to compassionate care.

While our findings provide the first evidence to date on the role of rest in consolidating others' disclosures, they are not without limitations. Most notably, while our two video watching conditions vary in disclosure, they may vary on other dimensions as well, such as valence and interestingness, which could impact our results. In our view, these variables may be intrinsic to disclosures, and thus we chose to not control for them in this first study on consolidation of disclosures during rest. Instead, we chose the science videos as the control condition because they also involve hearing someone talk about cystic fibrosis, just not their personal experience with it. Finally, it is also possible that the science videos were more challenging to comprehend than the patient videos. However, in our large sample in Study 2, participants' science memory performance was not significantly different from their patient memory performance, suggesting any differences in difficulty did not impact memory. Nonetheless, future research may help clarify the combination of ingredients in disclosures that contribute to their consolidation during rest.

In summary, we found that listeners consolidate information shared by disclosers, in part, by increasing dMPFC-FPCN_A connectivity during rest. Moreover, listeners' ability to consolidate information about disclosers' experiences helped them support disclosers in their time of need. These results point to the critical, though

previously overlooked, role of memory consolidation in facilitating supportive relationships. More broadly, the findings suggest that in our increasingly busy lives, taking the time to briefly rest may not only help us care for ourselves, but also help us care for others.

References

- Andrews-Hanna, J. R., Reidler, J. S., Sepulcre, J., Poulin, R., & Buckner, R. L. (2010). Functional-anatomic fractionation of the brain's default network. *Neuron*, 65(4), 550–562.
- Baldassano, C., Chen, J., Zadbood, A., Pillow, J. W., Hasson, U., & Norman, K. A. (2017). Discovering Event Structure in Continuous Narrative Perception and Memory. *Neuron*, Vol. 95, pp. 709–721.e5.
<https://doi.org/10.1016/j.neuron.2017.06.041>
- Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting Linear Mixed-Effects Models Using lme4. *Journal of Statistical Software*, Vol. 67.
<https://doi.org/10.18637/jss.v067.i01>
- Bressler, S. L., & Menon, V. (2010). Large-scale brain networks in cognition: emerging methods and principles. *Trends in Cognitive Sciences*, 14(6), 277–290.
- Brett, M., Anton, J.-L., Valabregue, R., Poline, J.-B., & Others. (2002). Region of interest analysis using an SPM toolbox. *8th International Conference on Functional Mapping of the Human Brain*, 16, 497. Sendai, Japan.
- Bruce, V., & Young, A. (1986). Understanding face recognition. *British Journal of Psychology*, 77 (Pt 3), 305–327.
- Burgess N., Oapos;Keefe J., Qin Yu-Lin, Mcnaughton Bruce L., Skaggs William E., & Barnes Carol A. (1997). Memory reprocessing in corticocortical and hippocampocortical neuronal ensembles. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, 352(1360), 1525–1533.
- Cabeza, R., & Nyberg, L. (2000). Imaging cognition II: An empirical review of 275 PET and fMRI studies. *Journal of Cognitive Neuroscience*, 12(1), 1–47.
- Clark, V. P., Maisog, J. M., & Haxby, J. V. (1998). fMRI study of face perception and memory using random stimulus sequences. *Journal of Neurophysiology*, 79(6), 3257–3265.
- Collins, N. L., & Miller, L. C. (1994). Self-disclosure and liking: A meta-analytic view. *Psychological Bulletin*, 116(3), 457–475.
- Coke, J. S., Batson, C. D., & McDavis, K. (1978). Empathic mediation of helping: A two-stage model. *Journal of Personality and Social Psychology*, 36(7), 752–766.
- Cozby, P. C. (1973). Self-disclosure: A literature review. *Psychological Bulletin*, 79(2), 73–91.
- Denny, B. T., Kober, H., Wager, T. D., & Ochsner, K. N. (2012). A meta-analysis of functional neuroimaging studies of self- and other judgments reveals a spatial gradient for mentalizing in medial prefrontal cortex. *Journal of Cognitive Neuroscience*, 24(8), 1742–1752.
- Dixon, M. L., De La Vega, A., Mills, C., Andrews-Hanna, J., Spreng, R. N., Cole, M. W., & Christoff, K. (2018). Heterogeneity within the frontoparietal control network and its relationship to the default and dorsal attention networks. *Proceedings of the National Academy of Sciences of the United States of America*, 115(7), E1598–E1607.
- Dosenbach, N. U. F., Fair, D. A., Miezin, F. M., Cohen, A. L., Wenger, K. K., Dosenbach, R. A. T., ... Petersen, S. E. (2007). Distinct brain networks for adaptive and stable task control in humans. *Proceedings of the National Academy of Sciences of the United States of America*, 104(26), 11073–11078.

- Dovidio, J. F., Allen, J. L., & Schroeder, D. A. (1990). Specificity of empathy-induced helping: Evidence for altruistic motivation. *Journal of Personality and Social Psychology*, 59(2), 249–260.
- Eichenbaum, H. (2017). Prefrontal–hippocampal interactions in episodic memory. *Nature Reviews. Neuroscience*, 18, 547.
- Euston, D. R., Gruber, A. J., & McNaughton, B. L. (2012). The role of medial prefrontal cortex in memory and decision making. *Neuron*, 76(6), 1057–1070.
- Gaesser, B., & Schacter, D. L. (2014). Episodic simulation and episodic memory can increase intentions to help others. *Proceedings of the National Academy of Sciences of the United States of America*, 111(12), 4415–4420.
- Goldstein, N. J., Vezich, I. S., & Shapiro, J. R. (2014). Perceived perspective taking: when others walk in our shoes. *Journal of Personality and Social Psychology*, 106(6), 941–960.
- Gramling, R., Stanek, S., Ladwig, S., Gajary-Coots, E., Cimino, J., Anderson, W., ... Unroe, K. T. (2016). Feeling Heard and Understood: A Patient-Reported Quality Measure for the Inpatient Palliative Care Setting. *Journal of Pain and Symptom Management*, 51(2), 150–154.
- Guimera, R. and Amaral, L. A. N. (2005). Cartography of complex networks: modules and universal roles. *Journal of Statistical Mechanics: Theory and Experiment*, 2005(2005), p. P02001.
- Guimera, R., Sales-Pardo, M., Amaral, L. A. N. Classes of complex networks defined by role-to-role connectivity profiles. *Nature Physics*, 3(2007), 63-69.
- Gusnard, D. A., Akbudak, E., Shulman, G. L., & Raichle, M. E. (2001). Medial prefrontal cortex and self-referential mental activity: relation to a default mode of brain function. *Proceedings of the National Academy of Sciences of the United States of America*, 98(7), 4259–4264.
- Inagaki, T. K., & Eisenberger, N. I. (2012). Neural correlates of giving support to a loved one. *Psychosomatic Medicine*, 74(1), 3–7.
- Inagaki, T. K., & Eisenberger, N. I. (2016). Giving support to others reduces sympathetic nervous system-related responses to stress. *Psychophysiology*, 53(4), 427–435.
- Inagaki, T. K., & Meyer, M. L. (2019). Individual differences in resting state connectivity and giving social support: implications for health. *Social Cognitive and Affective Neuroscience*. <https://doi.org/10.1093/scan/nsz052>
- Inagaki, T. K., & Orehek, E. (2017). On the Benefits of Giving Social Support: When, Why, and How Support Providers Gain by Caring for Others. *Current Directions in Psychological Science*, 26(2), 109–113.
- Ji, D., & Wilson, M. A. (2007). Coordinated memory replay in the visual cortex and hippocampus during sleep. *Nature Neuroscience*, 10(1), 100–107.
- Kelley, J. E., Lumley, M. A., & Leisen, J. C. (1997). Health effects of emotional disclosure in rheumatoid arthritis patients. *Health Psychology: Official Journal of the Division of Health Psychology, American Psychological Association*, 16(4), 331–340.
- Lieberman, M. D., Straccia, M. A., Meyer, M. L., Du, M., & Tan, K. M. (2019). Social, self, (situational), and affective processes in medial prefrontal cortex (MPFC): Causal, multivariate, and reverse inference evidence. *Neuroscience and Biobehavioral Reviews*, 99, 311–328.

- Lun, J., Kesebir, S., & Oishi, S. (2008). On Feeling Understood and Feeling Well: The Role of Interdependence. *Journal of Research in Personality*, 42(6), 1623–1628.
- Maldjian, J.A., Laurienti, P.J., Kraft, R.A., Burdette, J.H. (2003). An automated method for neuroanatomic and cytoarchitectonic atlas-based interrogation of fMRI data sets. *Neuroimage* 19, 1233–1239.
- Masten, C. L., Morelli, S. A., & Eisenberger, N. I. (2011). An fMRI investigation of empathy for “social pain” and subsequent prosocial behavior. *NeuroImage*, Vol. 55, pp. 381–388. <https://doi.org/10.1016/j.neuroimage.2010.11.060>
- Mathur, V. A., Harada, T., Lipke, T., & Chiao, J. Y. (2010). Neural basis of extraordinary empathy and altruistic motivation. *NeuroImage*, 51(4), 1468–1475.
- Meyer, M. L., Herschfield, H. E., Waytz, A. G., Mildner, J. N., & Tamir, D. I. (2019). Creative Expertise Is Associated With Transcending the Here and Now. *Journal of Personality and Social Psychology*.
- Meyer, M. L. (2019). Social by Default: Characterizing the Social Functions of the Resting Brain. *Current Directions in Psychological Science*, 0963721419857759.
- Meyer, M. L., Davachi, L., Ochsner, K. N., & Lieberman, M. D. (2019). Evidence That Default Network Connectivity During Rest Consolidates Social Information. *Cerebral Cortex*, 29(5), 1910–1920.
- Meyer, M. L., Spunt, R. P., Berkman, E. T., Taylor, S. E., & Lieberman, M. D. (2012). Evidence for social working memory from a parametric functional MRI study. *Proceedings of the National Academy of Sciences of the United States of America*, 109(6), 1883–1888.
- Meyer, M. L., Taylor, S. E., & Lieberman, M. D. (2015). Social working memory and its distinctive link to social cognitive ability: an fMRI study. *Social Cognitive and Affective Neuroscience*, 10(10), 1338–1347.
- Meyer, M. L., Williams, K. D., & Eisenberger, N. I. (2015). Why social pain can live on: Different neural mechanisms are associated with reliving social and physical pain. *PLOS One* 10(6): e0128294.
- Mijalkov M, Kakaei E, Pereira JB, Westman E, Volpe G, et al. (2017) BRAPH: A graph theory software for the analysis of brain connectivity. *PLOS ONE* 12(8): e0178798.
- Miller, L. (1993). Who Are the Best Psychotherapists? *Psychotherapy in Private Practice*, 12(1), 1–18.
- Mitchell, J. P., Macrae, C. N., & Banaji, M. R. (2004). Encoding-specific effects of social cognition on the neural correlates of subsequent memory. *The Journal of Neuroscience: The Official Journal of the Society for Neuroscience*, 24(21), 4912–4917.
- Murty, V. P., Tompary, A., Adcock, R. A., & Davachi, L. (2017). Selectivity in Postencoding Connectivity with High-Level Visual Cortex Is Associated with Reward-Motivated Memory. *The Journal of Neuroscience: The Official Journal of the Society for Neuroscience*, 37(3), 537–545.
- Nummenmaa, et al (2012). Emotions promote social interaction by synchronizing brain activity across individuals. *Proceedings of the National Academy of Sciences of the United States of America*, 109(24), 9599–9604.
- Nummenmaa, et al. (2014). Emotional speech synchronizes brains across listeners and engages large-scale dynamic brain networks. *NeuroImage*, 102(P2), 498–509.
- Olson IR, McCoy D, Klobusicky E, Ross LA (2013) Social cognition and the anterior

- temporal lobes: a review and theoretical framework. *Social Cognitive and Affective Neuroscience* 8(2):123–133.
- Ong, L. M., de Haes, J. C., Hoos, A. M., & Lammes, F. B. (1995). Doctor-patient communication: a review of the literature. *Social Science & Medicine*, 40(7), 903–918.
- Oswald, P. A. (1996). The effects of cognitive and affective perspective taking on empathic concern and altruistic helping. *The Journal of Social Psychology*, 136(5), 613–623.
- Peigneux, P., Orban, P., Balteau, E., Degueldre, C., Luxen, A., Laureys, S., & Maquet, P. (2006). Offline persistence of memory-related cerebral activity during active wakefulness. *PLoS Biology*, 4(4), e100.
- Pennebaker, J. W., Kiecolt-Glaser, J. K., & Glaser, R. (1988). Disclosure of traumas and immune function: health implications for psychotherapy. *Journal of Consulting and Clinical Psychology*, 56(2), 239–245.
- Power, J. D., Mitra, A., Laumann, T. O., Snyder, A. Z., Schlaggar, B. L., & Petersen, S. E. (2014). Methods to detect, characterize, and remove motion artifact in resting state fMRI. *NeuroImage*, 84, 320–341.
- Rabin, J. S., Gilboa, A., Stuss, D. T., Mar, R. A., Rosenbaum, R. S. (2010). Common and unique neural correlates of autobiographical memory and theory of mind. *Journal of Cognitive Neuroscience*, 22, 1095–1111.
- Ryali, S., Supekar, K., Chen, T., Kochalka, J., Cai, W., Nicholas, J., ... Menon, V. (2016). Temporal Dynamics and Developmental Maturation of Salience, Default and Central-Executive Network Interactions Revealed by Variational Bayes Hidden Markov Modeling. *PLoS Computational Biology*, 12(12), e1005138.
- Saxe, R., & Kanwisher, N. (2003). People thinking about thinking people: The role of the temporo-parietal junction in “theory of mind.” *NeuroImage*, 19(4), 1835–1842.
- Schacter Daniel L., & Addis Donna Rose. (2009). On the nature of medial temporal lobe contributions to the constructive simulation of future events. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, 364(1521), 1245–1253.
- Schroeder, D. A., Dovidio, J. F., Sibicky, M. E., Matthews, L. L., & Allen, J. L. (1988). Empathic concern and helping behavior: Egoism or altruism? *Journal of Experimental Social Psychology*, 24(4), 333–353.
- Simony, E., Honey, C. J., Chen, J., Lositsky, O., Yeshurun, Y., Wiesel, A., & Hasson, U. (2016). Dynamic reconfiguration of the default mode network during narrative comprehension. *Nature Communications*, 7, 12141.
- Speer, M. E., & Delgado, M. R. (2019). The social value of positive autobiographical memory retrieval. *Journal of Experimental Psychology: General*. Advance online publication.
- Spreng, R. N. & Grady, C. (2010). Patterns of brain activity supporting autobiographical memory, prospection and theory-of-mind and their relationship to the default network. *Journal of Cognitive Neuroscience*, 21, 489–510.
- Spreng, R. N. & Mar, R. A. (2012). I remember you: A role for memory in social cognition and the functional neuroanatomy of their interaction. *Brain Research* 1428, 43–50.
- Squire, L. R., & Zola-Morgan, S. (1991). The medial temporal lobe memory system.

- Science*, 253(5026), 1380–1386.
- Tambini, A., Ketz, N., & Davachi, L. (2010). Enhanced brain correlations during rest are related to memory for recent experiences. *Neuron*, 65(2), 280–290.
- Tamir, D.I., Mitchell, J.P. (2012). Disclosing information about the self is intrinsically rewarding. *Proceedings of the National Academy of Sciences*, 109(21), 8038–8043.
- Thompson, J. A., & Anderson, J. L. (1982). Patient preferences and the bedside manner. *Medical Education*, 16(1), 17–21.
- Tingley, D., Yamamoto, T., Hirose, K., Keele, L., & Imai, K. (2014). mediation: RPackage for Causal Mediation Analysis. *Journal of Statistical Software*, Vol. 59. <https://doi.org/10.18637/jss.v059.i05>
- Tsukiura, T., Suzuki, C., Shigemune, Y., & Mochizuki-Kawai, H. (2008). Differential contributions of the anterior temporal and medial temporal lobe to the retrieval of memory for person identity information. *Human Brain Mapping*, 29(12), 1343–1354.
- Uddin, L. Q., Supekar, K. S., Ryali, S., & Menon, V. (2011). Dynamic reconfiguration of structural and functional connectivity across core neurocognitive brain networks with development. *The Journal of Neuroscience: The Official Journal of the Society for Neuroscience*, 31(50), 18578–18589.
- van Kesteren, M. T. R., Fernández, G., Norris, D. G., & Hermans, E. J. (2010). Persistent schema-dependent hippocampal-neocortical connectivity during memory encoding and postencoding rest in humans. *Proceedings of the National Academy of Sciences of the United States of America*, 107(16), 7550–7555.
- Van Overwalle, F., & Baetens, K. (2009). Understanding others' actions and goals by mirror and mentalizing systems: a meta-analysis. *NeuroImage*, 48(3), 564–584.
- von Dietze, E., & Orb, A. (2000). Compassionate care: a moral dimension of nursing *. *Nursing Inquiry*, 7(3), 166–174.
- Wagner, D. D., Kelley, W. M., Haxby, J. V., & Heatherton, T. F. (2016). The Dorsal Medial Prefrontal Cortex Responds Preferentially to Social Interactions during Natural Viewing. *The Journal of Neuroscience: The Official Journal of the Society for Neuroscience*, 36(26), 6917–6925.
- Wang, Y., Collins, J. A., Koski, J., Nugiel, T., Metoki, A., & Olson, I. R. (2017). Dynamic neural architecture for social knowledge retrieval. *Proceedings of the National Academy of Sciences of the United States of America*, 114(16), E3305–E3314.
- Yeo, B. T. T., Krienen, F. M., Sepulcre, J., Sabuncu, M. R., Lashkari, D., Hollinshead, M., ... Buckner, R. L. (2011). The organization of the human cerebral cortex estimated by intrinsic functional connectivity. *Journal of Neurophysiology*, 106(3), 1125–1165.
- Zadbood, A., Chen, J., Leong, Y. C., Norman, K. A., & Hasson, U. (2017). How We Transmit Memories to Other Brains: Constructing Shared Neural Representations Via Communication. *Cerebral Cortex*, 27(10), 4988–5000.
- Zaki, J., Weber, J., Bolger, N., & Ochsner, K. (2009). The neural bases of empathic accuracy. *Proceedings of the National Academy of Sciences of the United States of America*, 106(27), 11382–11387.