Constructive Retrieval and Episodic Memory: Cognitive and Neural Evidence

A dissertation presented

by

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Abstract

Research over the past decade has indicated striking overlap in the cognitive and neural processes that support remembering the past and imagining the future. An experimental tool, the episodic specificity induction, was initially developed and examined to dissociate contributions of constructive episodic retrieval to these tasks in young and older adults from non-episodic contributions like narrative description and semantic memory. Having established the efficacy of the tool, the first two dissertation papers extend the induction approach to other cognitive tasks where little empirical attention has been given but where kernels of evidence suggest a role for constructive episodic retrieval. Social means-end problem solving, or generating steps from an identified problem to a solution, was affected by the specificity induction (Paper 1), as was divergent creative thinking, or generating new ideas by combining diverse types of information (Paper 2). Performance on non-episodic tasks (e.g., typical object associations, convergent word riddles) did not show induction-related differences. With the cognitive signature of the specificity induction identified, the neural signature of the tool was examined with fMRI. Following the specificity induction relative to a control, greater neural activity was observed in key brain regions previously linked to constructive episodic retrieval, including the anterior hippocampus and inferior parietal lobule, when participants imagined future events relative to comparing and defining words (Paper 3). The body of work strengthens our theoretical understanding of the boundary conditions of episodic memory, and could have functional
implications for populations characterized by overgeneralized memory, such as aging, depression, and posttraumatic stress disorder.
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Introduction

A surge of research in the past decade has focused on how remembering the past and imagining the future engage similar cognitive and neural processes (for reviews, see Schacter et al., 2012; Szpunar, 2010; Szpunar, Spreng, & Schacter, 2014). The line of inquiry initially began in the 1980s with evidence from amnesic patient K.C. whom was impaired at both recalling past personal episodes and imagining personal future episodes (Tulving, 1985), and was later extended by other research groups (e.g., Atance & O’Neill, 2001; Klein, Loftus, & Kihlstrom, 2002; Okuda et al., 2003). More recently, Schacter and Addis (2007, 2009) put forth the constructive episodic simulation hypothesis to explain cognitive and neural commonalities in remembering and imagining. The hypothesis is supported by cognitive data showing similarities in the content contained in remembered and imagined events, and by neural data showing overlap in the activity within particular brain regions implicated for both tasks (referred to as the core network by Buckner & Carroll, 2007; Schacter, Addis, & Buckner, 2007; for a recent meta-analysis, see Benoit & Schacter, 2015). A central tenet of the hypothesis is that elements of episodic memories – those for personal events situated in particular times and places (Tulving, 1983, 2002) – are retrieved and recombined to create novel future events. The constructive nature of memory (Bartlett, 1932; Schacter, 2012; Schacter, Norman, & Koutstaal, 1998) allows for flexibility in remembering and imagining, in that event constructions are not static representations like those from a camera but involve dynamic and active mental scenario building using the currency of past experiences.

The three papers of the dissertation are situated in this theoretical framework. First, background research from cognitive and neural studies most pertinent to the dissertation and outstanding issues that emerge from such work will be presented. Then, the motivation for each
paper of the dissertation will be presented, followed by the contents of each paper. The
dissertation will close with a discussion of how each paper addresses outstanding issues, as well
as the implications and future directions for the research program.

**Cognitive Evidence for Memory and Imagination Overlap**

As mentioned, one line of evidence for the constructive episodic simulation hypothesis,
and for commonalities in remembering and imagining more broadly, stems from cognitive
studies that examine the degree of episodic detail contained in memory and imagination
narratives from different populations. A technique referred to as the Autobiographical Interview
(AI; Levine, Svoboda, Hay, Winocur, & Moscovitch, 2002) is used to accomplish this task,
where individuals narrate a personal memory or imagination specific in time and place related to
a cue. Narrative details are segmented into those that are “internal” and “external”. Internal
details refer to the who, what, where, and when elements of the memory or imagination (i.e.,
episodic details), whereas external details refer to fact bits, commentary, and off-topic speech
unrelated to the memory or imagination (i.e., semantic details). Studies have typically found that
individuals from populations characterized by episodic memory deficits show reduced internal
details on both memory and imagination tasks compared with healthy controls. This sort of
pattern on memory and imagination tasks has been documented in cognitive aging (cf. Addis,
Musicaro, Pan, & Schacter, 2010; Addis, Wong, & Schacter, 2008; Cole, Morrison, & Conway,
2013; Rendell et al., 2012; Romero & Moscovitch, 2012), Alzheimer’s disease (Addis, Sacchetti,
Ally, Budson, & Schacter, 2009; El Haj, Antoine, & Kapogiannis, 2015), global temporary
amnesia (Juskenaite et al., 2014), unilateral temporal lobe epilepsy (Lechowicz et al., 2016),
autism (Lind, Williams, Bowler, & Peel, 2014), and various psychopathological conditions
including depression (Addis, Hach, & Tippett, 2016; Williams et al., 1996), schizophrenia
Results from the cognitive literature support the constructive episodic simulation hypothesis because they suggest that episodic memory processes at work for remembering past events are also at work for imagining future events as documented via parallel patterns on the tasks.

Nonetheless, one outstanding issue that has emerged from such work is that non-episodic processes may also contribute to similarities exhibited on memory and imagination. For example, most studies (e.g., Addis et al., 2008) find that individuals who exhibit reduced internal details on memory and imagination also exhibit increased external details, suggesting a reliance on semantic, non-episodic memory processes on both memory and imagination (for related evidence and discussion of this point, see Irish, Addis, Hodges, & Piguet, 2012; Irish & Piolino, 2016; Klein, 2013, 2016; Szpunar et al., 2014). Typically used memory and imagination tasks likewise ask individuals to narrate an event, and to communicate in a way conducive to task guidelines (i.e., be specific in time and place). Non-episodic processes such as narrative style (Adams, Smith, Nyquist, & Perlmutter, 1997; Labouvie-Vief & Blanchard-Fields, 1982; Trunk & Abrams, 2009), communicative goals (Adams et al., 1997; Labouvie-Vief & Blanchard-Fields, 1982; Trunk & Abrams, 2009), and inhibitory control (Arbuckle & Gold, 1993) may thus also contribute to parallels seen on memory and imagination tasks of this sort (for further review, see Schacter, Gaesser, & Addis, 2013). For example, how individuals verbalize a story about their life in the form of a memory or imagination could impact the sorts of details they generate (e.g., focusing on the overall gist versus the many specific details of a narrative), as could the why (e.g., focusing on the meaning versus the actual content of a narrative). Differences in inhibiting off-topic information during open-ended, generative tasks could also contribute to parallels seen
on memory and imagination (e.g., verbalizing every thought that comes to mind versus only those thoughts that are perceived to be task relevant).

In one study that examined non-episodic contributions to memory and imagination, Gaesser, Sacchetti, Addis, and Schacter (2011) had healthy young and older adults look at picture cues of common everyday scenes (e.g., a museum, a park, etc.) and recall a past event related to the picture, imagine a novel future event related to the picture, or just describe the literal contents of the picture. This latter instruction was meant to measure the non-episodic process of descriptive ability – a process that could contribute to narrating remembered and imagined events along with episodic memory processes. Memory and imagination narratives were scored for internal/episodic and external/semantic details using the AI procedure, and picture descriptions were also scored for internal and external details; in this case internal details referred to bits of information individuals described that related to the literal contents of the picture and external details referred to bits of information that were off-topic, repetitive, or unrelated to the actual contents of the picture. Gaesser et al. (2011) found that older adults produced fewer internal details and more external details than young adults on memory, imagination, and description tasks, which suggests that age-related impairments on previous memory and imagination tasks were not due to episodic processes alone. A regression analysis similarly showed that description internal details predicted variance in memory and imagination performance, though age also had a modest but significant effect.

The results are important for the constructive episodic simulation hypothesis because they underscore that non-episodic processes can contribute to observed similarities in remembering and imagining and may even be driving patterns of parallel performance. This is an outstanding issue in the literature; most studies that are concerned with the relationship between
memory and imagination have not measured non-episodic contributions, and assume that
similarities between memory and imagination are due to episodic processes alone. While little
empirical attention has been paid to this distinction, preliminary work from Gaesser et al. (2011)
and from research groups interested in hippocampal amnesia (Race, Keane, & Verfaellie, 2011,
2013, 2015; Zeman, Beschin, Dewar, & Della Sala, 2013) and lifespan development (Abram,
Picard, Navarro, & Piolino, 2014), among others, has begun to incorporate this approach.

Distinguishing episodic from non-episodic processes involved in memory and
imagination is important for both theoretical and functional reasons. Theoretically, understanding
better the component processes involved in remembering and imagining can shed light on the
nature of episodic memory and what it is for. The constructive nature of memory (Bartlett, 1932;
Schacter, 2012; Schacter et al., 1998) suggests that the boundary conditions of the construct may
lie beyond the strict remembering of past events. Functionally, cognitive tasks like remembering
the past and imagining the future are common experiences in everyday life, and several
populations noted earlier exhibit deficits on these tasks. Isolating contributions of episodic
processes to memory and imagination could inform trainings that are used to boost episodic
detail in populations characterized by episodic memory deficits.

Given this outstanding issue, one motivation for the dissertation broadly is to isolate
episodic contributions to memory and imagination via an experimental manipulation that targets
episodic processes. Once the efficacy of the manipulation is established, a significant feature of
the tool is that it can be used to probe episodic memory’s involvement in cognitive tasks beyond
memory and imagination where little empirical attention has been given but where kernels of
evidence suggest that episodic memory may play a role in task performance. While much
research time has been devoted to examining the links between memory and imagination, less
time has been devoted to examining the links between memory and related tasks (e.g., planning, delay discounting) that may also nominally require episodic processes for completion (see Schacter, 2012). Theoretically, the lack of attention to links between memory and related tasks beyond imagination is another outstanding issue in the field; knowing more about the boundary conditions of episodic memory could shed light on the nature of the phenomenon and what it is for, and functionally could have implications for individuals characterized by overgeneralized memory on the completion of other tasks that may involve episodic processes. The first two papers of the dissertation are motivated by this point, where an experimental manipulation is used to probe episodic memory’s involvement in tasks beyond memory and imagination that may recruit episodic processes for completion. Paper 1 (Madore & Schacter, 2014) of the dissertation applies the manipulation to a means-end problem solving task where individuals are given a beginning problem and ending solution and generate steps to solve the problem and reach the solution state. Paper 2 (Madore, Addis, & Schacter, 2015) of the dissertation applies the manipulation to a divergent creative thinking task where individuals are given an everyday object cue and generate unusual and creative uses for it.

Before delving further into the motivation for each paper of the dissertation, background on the experimental manipulation developed to achieve this goal will be presented. Then, the neural literature and related outstanding issues most pertinent to the dissertation will be presented, from which the rationale for Paper 3 (Madore, Szpunar, Addis, & Schacter, 2016) emerges.

**Episodic Specificity Induction: Logic and Procedure**

To probe episodic memory’s involvement in particular cognitive tasks, we have developed and used what we call an *episodic specificity induction* – brief training in recollecting
the details of a past experience. The episodic specificity induction is based on the probes and
guidelines of the Cognitive Interview (CI), a well-established forensic protocol that has been
used with individuals across the lifespan to boost the number of accurate details generated about
eyewitness events (Fisher & Geiselman, 1992; Memon, Meissner, & Fraser, 2010). The
techniques of the protocol improve eyewitness recall by helping the individual to recreate the
experienced event in as detailed a manner as possible, and maximize the mental match between
the initial event and later recall (Tulving & Thomson, 1973). Mental imagery and ‘close your
eyes’ prompts are used to help the individual focus in on the setting, people, and actions of the
experienced event; temporal order probing (i.e., reporting about the event in either a forward or
reverse order) is also meant to help the individual adopt a more specific mindset than they
otherwise would. In a related vein, minimizing interruptions, asking mainly open-ended
questions, and telling the individual that they are the chief expert about the event helps to
transfer control to the interviewee and lower perceived expectations that the interview is a test
where determining right from wrong answers is important (Fisher, Milne, & Bull, 2011).

Most studies have found that the CI increases the number of accurate details contained in
event narratives of both young and older adults (e.g., Dornburg & McDaniel, 2006; Holliday et
al., 2012; Prescott, Milne, & Clark, 2011; Wright & Holliday, 2007; for alternative evidence, see
McMahon, 2000). For example, Holliday et al. (2012) found that young and older adults who
were interviewed with a CI after watching a video of a crime remembered more correct details
compared with those interviewed with a standard protocol lacking the probes and techniques of
the CI. Detail increases mainly stemmed from person and action categories. Another series of
studies by Wright and Holliday (2007) found similar results in young and older adults, with
increases for remembered details about an event following the CI compared with a control
protocol across person, action, setting, and object categories. The quality of the details elicited with the CI was also high; police officers rated the details for these features and found them to be similar across the CI and control protocol. More globally, a recent meta-analysis (Memon et al., 2010) indicates that the CI significantly increased correct details remembered about an event in all but one of 59 studies reviewed compared with various control protocols. This pattern of results suggests that the CI is an effective and reliable tool for increasing episodic detail content associated with a remembered event.

Because the CI and by extension the specificity induction tap into episodic memory processes, we hypothesize that the induction technique should selectively boost performance on subsequent tasks that index episodic detail – in this case internal details or a similar measure. Retrieving and reconstructing a remembered event in a very specific and detailed way focused on different event categories like people, actions, and settings should prime participants to complete subsequent tasks requiring these processes in a similar manner. This sort of transfer effect from one task that involves the retrieval and reconstruction of episodic details to another that involves these processes should also be selective. Only those cognitive tasks that nominally recruit episodic processes should show a benefit from the specificity induction. Non-episodic processes, such as semantic memory, should not be influenced by the induction and follow-up tasks that measure non-episodic processes in the form of external details or a similar measure should not see increases with the induction.

Given this logic, the general design for implementing the episodic specificity induction is as follows. Individuals come to the lab and watch a short video, and then after a short delay are asked questions about the video with the episodic specificity induction or one of two control inductions not focused on episodic retrieval. One of the control inductions requires participants
to retrieve information and talk about the video but not in an episodically specific way – what we have referred to as the *impressions control induction* – and the other requires participants to simply complete addition and subtraction math problems – what we have referred to as the *math control induction*. After receiving either a specificity or control induction, individuals complete subsequent tasks that invoke episodic memory processes (e.g., memory and imagination) and those that don’t (e.g., picture description). In the within-subjects format we have used, participants then receive whichever induction they did not receive the first time (i.e., either specificity-control or control-specificity) and complete the subsequent tasks again with new cues. The induction order is always counterbalanced to minimize carryover effects of the manipulation; sometimes the delay between inductions is at least a week, and sometimes it is after a short (i.e., 5 minute) span. Following both sessions, individuals’ narratives from the main tasks are transcribed and scored with the guidelines of the AI in terms of internal and external details (or other generative output measures), and patterns of performance are examined to see whether the specificity induction boosts performance on tasks that are thought to invoke episodic memory processes compared with baseline performance (i.e., performance after receiving the control induction).

It should be noted that a few previous studies have examined the impact of episodic specificity inductions similar to the one we have developed, and observed improvement in episodic detail on subsequent tasks that tap either remembering (Maestas & Rude, 2012; Moradi et al., 2014; Neshat-Doost et al., 2013; Rudoy, Weintraub, & Paller, 2009) or imagining (Williams et al., 1996) but none have examined memory and imagination together, and none have included tasks that measure non-episodic processes such as description. Including both episodic and non-episodic tasks is an important feature of the design we have built because
previous work suggests that non-episodic processes do indeed contribute to observed similarities in remembering and imagining (e.g., Gaesser et al., 2011), and an experimental tool for isolating episodic contributions to memory and imagination should be able to dissociate episodic from non-episodic processes.

In our first study on this topic (Madore, Gaesser, & Schacter, 2014), we tested the hypothesis that the specificity induction could be used to isolate episodic processes involved in memory and imagination as measured via 1) an increase in internal details on an AI for memory and imagination following the specificity induction compared with a control induction and 2) no difference in details generated on a picture description task following the specificity induction compared with a control induction. In Experiment 1, 48 young and older adults followed the procedure outlined above, where they came to the lab and received either the specificity induction or the impressions control induction before verbally generating responses on the AI for 4 personal past memories, 4 personal future imaginations, and 4 picture descriptions for 3 minutes each. After a delay of at least a week, each participant returned to the lab and received whichever induction they did not receive in the first session, and then generated responses on the AI with new cues for personal past memories, personal future imaginations, and picture descriptions. Narratives were transcribed and scored for internal and external details. Replicating previous work (e.g., Gaesser et al., 2011) older adults produced fewer internal details and more external details than young adults on memory, imagination, and description across the two sessions (irrespective of induction). Critically, both older and young adults benefited on memory and imagination selectively when they received the specificity induction compared with the control as indexed via increased internal/episodic details on these tasks alone. There were no differences in external/semantic details generated on memory or imagination as a function of
induction, and there were no differences in internal or external details generated on picture
description as a function of induction. Moreover, a multi-level regression model showed that the
predictors of induction, picture description internal details, and age all contributed significantly
and independently to memory and imagination internal details. The results suggest that episodic
processes involved in memory and imagination can be dissociated from non-episodic processes
involved in description, and that the specificity induction can be used as a tool to isolate episodic
contributions to cognitive tasks thought to draw on episodic memory.

In Experiment 2 of the study, we ran 12 young adults using the same procedure but with
the math control induction to ensure that differences on main task performance were due to an
increase from the specificity induction and not a decrease from gist-based processing that may
have been invoked with the impressions control (which asks individuals to focus on more global
thoughts and opinions; for related evidence, see Koutstaal & Cavendish, 2006; Rudoy et al.,
2009). With the more neutral baseline of the math control, we replicated and extended the pattern
of results found in Experiment 1: young adults generated more internal details on memory and
imagination alone after receiving the specificity induction compared with the control, with no
differences in external details and no differences in any details produced on the picture
description task. The multi-level model also showed the same pattern.

Theoretically, the results from the two experiments have implications for the constructive
episodic simulation hypothesis because they support the notion that episodic contributions to
memory and imagination can be isolated via experimental means. This point is critical because
one outstanding issue from prior work is whether parallels observed for memory and imagination
are due to episodic or non-episodic influences. The experimental induction tool indicates that
observed similarities in remembering the past and imagining the future are not solely due to non-
episodic influences. Functionally, these results are also important because they suggest that specificity trainings can boost performance on cognitive tasks that individuals use in everyday life and that may be related to measures of psychological well-being (for a recent meta-analysis of clinical work on this topic, see Hitchcock, Werner-Seidler, Blackwell, & Dalgleish, 2016). For example, Neshat-Doost et al. (2013) found that a memory training similar to the one we have developed boosted memory specificity in a group of depressed adolescents and was linked to a reduction in depressive symptoms compared with a control training. A similar finding was observed by Moradi et al. (2014) in a group of war veterans with posttraumatic stress disorder: those who received a memory specificity training exhibited greater memory specificity and a reduction in posttraumatic symptoms compared with those assigned to a control training. This approach has been extended recently to imagining the future in healthy young adults (Jing, Madore, & Schacter, 2016), where our own specificity training led to increases in internal details for simulating about personally worrisome future events in positive ways and reductions in anxiety and negative affect ratings compared with control inductions (for an additional review of future thinking, well-being, and memory, see MacLeod, 2016).

Given the results, it is important to ask which episodic processes are tapped via the specificity induction. Because the induction has a similar effect on both memory and imagination performance in young and older adults, it may affect an episodic process recruited for both remembering and imagining. One process common to both tasks is episodic retrieval orientation: a goal-directed strategy for retrieving an event when presented with a cue (Morcom & Rugg, 2012). Biasing individuals to adopt a more specific retrieval orientation would potentially assist them on later tasks that invoke an episodic retrieval orientation such as memory and imagination, without affecting them on a task that would not invoke an episodic retrieval orientation such as
picture description. Asking individuals to focus on recreating a detailed mental event with imagery during the induction, and filling in specific details related to settings, people, and actions of the event, may lead them to adopt a specific retrieval orientation that is drawn on for later tasks that also require building and filling in an event with specific episodic details (for further theoretical elaboration, see Schacter & Madore, 2016).

In a follow-up study (Madore & Schacter, 2016), we aimed to assess the generalizability of the basic specificity induction effect and build on the idea that the induction affects retrieval orientation. Our first study (Madore et al., 2014) used picture cues and a non-episodic task that required individuals to describe pictures that were directly in front of them. This task differs from memory and imagination in the degree to which individuals must engage in controlled, generative mental search and retrieval processes (e.g., Addis, Knapp, Roberts, & Schacter, 2012; Conway & Pleydell-Pearce, 2000). Responses for picture description are constrained by the properties of the picture cues themselves, and this sort of setup provides more environmental support (Craik, Routh, & Broadbent, 1983; Lindenberger & Mayr, 2014) than do the memory and imagination tasks. Environmental support involves providing external information or an external stimulus that limits the necessity for participants to engage in mental operations like generative search and retrieval while performing a given task. Thus, selective induction-related differences in our initial study for memory and imagination could potentially have stemmed from differences in the degree to which the memory, imagination, and description tasks involved environmental support and generative search and retrieval. Perhaps the induction impacts any task requiring generative search and retrieval irrespective of whether the task draws on episodic memory; the description condition in our initial study (which was not evenly matched in
environmental support with memory and imagination) does not allow us to make strong claims about which processes the induction targets.

To address the issue, we created a non-episodic task that minimizes environmental support and requires generative search and retrieval like the memory and imagination tasks but does not require drawing on episodic information. We call this task object comparison (based on similar tasks used by Addis, Pan, Vu, Laiser, & Schacter, 2009; Addis, Wong, & Schacter, 2007; Hach, Tippett, & Addis, 2014), and in the task individuals are presented with a word cue and are asked to come up with a size sentence involving the cue and two other words (e.g., if the cue were Apple, an appropriate size sentence would be “Tree is larger than Pie is larger than Apple”). After coming up with the size sentence, individuals are asked to provide a definition for each word in the size sentence. This task more closely matches the generative search and retrieval processes required in the memory and imagination tasks where individuals also build on, integrate, and generate details that are related to a respective cue (see Addis, Pan et al., 2009; Addis et al., 2007).

In the study itself, 32 young adults came to the lab and switched between the specificity induction and a control induction (either impressions or math) in one session. Because the study also served as a cognitive pilot for a functional magnetic resonance imaging (fMRI) experiment that is one of the papers of the dissertation, we adopted what is known as the construction-elaboration paradigm, a method that is often used in fMRI studies on memory and imagination (see Addis, Cheng, Roberts, & Schacter, 2011; Addis, Pan et al., 2009; Addis et al., 2007). Participants responded to 48 word cues (from Addis et al., 2011; for further information, see Clark & Paivio, 2004) in each pass of the study after receiving each induction (i.e., 18 memory trials, 18 imagination trials, and 12 word comparison trials per pass after each induction). In our
adapted version of the construction-elaboration paradigm, participants were presented with a cue and had 26 seconds to silently perform the task at hand. For memory and imagination, participants pressed the space bar once they had initially constructed an event specific in time and place either in the past or future, and then elaborated on the details of the event until the trial was over; for word comparison, participants pressed the space bar once they had initially constructed their size sentence, and then elaborated on the details of the definitions of each word in the size sentence until the trial was over. To ensure that the tasks were completed correctly and to have a measure of generative output to score, participants verbally stated out-loud what they had thought about after each trial in a self-paced manner.

Participants’ responses were later transcribed and scored with the internal and external detail criteria of the AI. Internal details for word comparison were bits of information contained in word definitions, and external details for word comparison were bits of information that were off-topic or repetitive. Because internal and external details for the three tasks are not necessarily equated (e.g., factual details for memory and imagination are external whereas for word comparison would be internal), we computed a total detail count and used this as our main dependent variable of interest. We hypothesized that the specificity induction would increase total details on the memory and imagination tasks selectively compared with the control inductions, and that this increase would be driven by an increase in internal details but not external details.

In line with hypotheses and replicating and extending our previous work (Madore et al., 2014), we found that after receiving the specificity induction participants provided more total details on the memory and imagination tasks than after receiving either control induction. Total details generated on the word comparison task did not differ as a function of induction. When we
examined total details split into internal and external details, we found that the specificity induction selectively boosted internal details on memory and imagination alone, without affecting external details generated on these tasks, and without affecting any sort of detail generated on word comparison. In light of these results, we re-examined picture description total details from Madore et al. (2014) and observed the same pattern of findings. Collectively, the results are important because they strengthen the idea that the specificity induction can be used as a tool to isolate contributions of episodic memory to particular cognitive tasks thought to draw on episodic processes. The results also suggest that even when a non-episodic task requires generative search and retrieval, the specificity induction can dissociate episodic processes from non-episodic ones, adding weight to the idea that episodic retrieval orientation in particular is a key process targeted by the induction.

Having established the cognitive signature and efficacy of the specificity induction for memory and imagination with a selectivity for episodic processes, two papers of the dissertation address the outstanding issue of links between episodic memory and other cognitive tasks beyond imagination that may nominally require such processes for completion: means-end problem solving (Paper 1: Madore & Schacter, 2014) and divergent creative thinking (Paper 2: Madore et al., 2015). The next section of the dissertation will focus on neural evidence and related outstanding issues from which Paper 3 emerges (Madore, Szpunar et al., 2016), followed by a more specific motivation for each paper.

**Neural Evidence for Memory and Imagination Overlap**

The studies previously outlined establish the logic and initial cognitive results from the episodic specificity induction, providing support for the idea that episodic contributions to memory and imagination are similar and can be measured empirically. A growing body of work
from neuroimaging also supports the idea that much of the overlap in memory and imagination is due to episodic processes. For example, in an event-related fMRI study, Addis et al. (2007) measured neural activity with the construction-elaboration paradigm as young adults remembered past episodes, imagined novel future episodes, and completed semantic control tasks in response to word cues during scanning. Addis et al. (2007) found a large degree of overlap in neural activity when participants remembered past events and imagined future events compared with the control tasks. During the construction phase, regions with increased activity for memory and imagination compared with the control tasks included the hippocampus, inferior parietal lobule, and occipital cortex. During the elaboration phase, regions with increased activity during memory and imagination compared with the control tasks included the hippocampus, inferior parietal lobule, medial prefrontal cortex, anterior cingulate cortex, posterior cingulate cortex (including retrosplenial cortex, precuneus, and parahippocampal cortex), and lateral temporal cortex. Buckner and Carroll (2007) and Schacter et al. (2007) have referred to this network of regions as the core network. It is thought that neural overlap in the core network during memory and imagination is due to the cognitive overlap in the recruitment of episodic processes during memory and imagination; these cognitive processes include the retrieval of bits of information from one or more memories specific in time and place, and the reconstruction of these bits of information into coherent events (Schacter et al., 2012). This idea is supported by the fact that many of the regions implicated in the core network are also part of the autobiographical memory retrieval network as outlined by Maguire (2001). Episodic retrieval orientation may thus be a key feature of observed overlap in these networks and processes.

The critical role of episodic retrieval orientation for memory and imagination is supported by various neuroimaging studies. For example, Addis et al. (2011) had young adult
participants generate remembered past events and imagined future events in the scanner in response to cues in either very specific detail or with gist-like, routine information. It was found that hippocampal activity was significantly increased for memories and simulations with specific details compared with routine details; the greatest hippocampal activity was observed for specific future event generation. This finding supports the idea that a specific retrieval orientation plays a role in both past memory and future simulation. In an earlier study, Addis and Schacter (2008) also found that the strength of hippocampal activity tracked with participants’ detail ratings of both remembered past events and imagined future events, such that increased activity in the hippocampus positively correlated with the ratings of event detail. This finding again suggests that the specificity of retrieval orientation may at least in part underserve neural commonalities observed in remembering and imagining (see also D’Argembeau, Jeunehomme, Majerus, Bastin, & Salmon, 2015).

In a related line of evidence, researchers have shown that different core network regions including the hippocampus are recruited to complete memory and imagination tasks for different cognitive functions. Of most relevance, Andrews-Hanna, Reidler, Sepulcre, Poulin, and Buckner (2010) have suggested that core network regions (which overlap with those regions that comprise the default network; see Raichle, 2015; Raichle et al., 2001) can be fractionated into two subsets: those involved in detailed mental event or scene building and those involved in self-relevant, social, and affective information generation (further information on these subsystems is contained in Andrews-Hanna, Saxe, & Yarkoni, 2014; Andrews-Hanna, Smallwood, & Spreng, 2014). The mental event or scene subset of regions has been labeled the medial temporal lobe subsystem, and includes the hippocampus, parahippocampal cortex, retrosplenial cortex, inferior parietal lobule, and ventromedial prefrontal cortex. The self-relevant, social, and affective subset
of regions has been labeled the dorsal medial prefrontal cortex subsystem, and includes the temporoparietal junction, lateral temporal cortex, temporal pole, and dorsal medial prefrontal cortex. Episodic retrieval orientation may be associated with the medial temporal lobe subsystem in particular, in that a specific retrieval orientation is required to generate detailed mental scenes or events. Recent neuropsychological evidence also fits in this framework. One study found that patients with hippocampal damage exhibited reductions in episodic detail in memory and imagination narratives but not self-relevant information, whereas patients with medial prefrontal damage exhibited reductions in self-relevant information but not episodic detail (Kurczek et al., 2015; for alternative evidence, see Bertossi, Aleo, Braghittoni, & Ciaramelli, 2016; Bertossi, Tesini, Cappelli, & Ciaramelli, 2016).

Collectively, prior neural work indicates that episodic retrieval orientation is a cognitive process that may be subserved by activity in regions of the core network, particularly those of the medial temporal lobe subsystem. Nonetheless, an outstanding issue from such work is how an experimental tool that identifies and makes specific a retrieval orientation would affect activity in regions of the core network on tasks that may invoke this sort of orientation. Thus, another motivation of the dissertation is to establish for the first time the neural signature of a specificity induction and thereby better understand the role of episodic processes on tasks that draw on episodic memory for completion, such as imagination and related domains. Theoretically, this work should inform our understanding of boundary conditions of episodic memory and what the phenomenon is for, and functionally could have implications for individuals characterized by overgeneralized memory and related constructs like imagination, such as cognitive aging and depression.
Having identified specific cognitive and neural issues that arise from previous work, the next section of the dissertation will present the motivation for each paper. Following the motivation subsections, each paper will be presented in full.

**Motivation for Papers of the Dissertation**

The main goal of the papers presented in the dissertation is to use the specificity induction to identify the contributions of episodic memory to cognitive tasks that are not episodic memory tasks in the strict sense but that may draw on retrieval of episodic details for completion. Each of the three papers in the dissertation uses a cognitive or neural approach to isolate the contributions of episodic memory to related cognitive tasks. Theoretically, experiments designed to achieve this goal should inform our understanding of the nature and purpose of episodic memory, and functionally, such experiments should provide a stronger basis for designing specificity inductions that lead to improvements on tasks that individuals experience in everyday life. Because the induction affects performance on an imagination task that requires detailed episodic simulations, we hypothesize that it should affect performance on a range of cognitive tasks that also require retrieving and recombining episodic details. Recently, researchers have begun exploring and outlining the contributions of episodic memory to tasks beyond strict remembered past events and imagined future events from cognitive and neural perspectives (e.g., Moscovitch, Cabeza, Winocur, & Nadel, 2016; Rubin & Umanath, 2015; Rubin, Watson, Duff, & Cohen, 2014; Schacter, 2012; Sheldon & Levine, 2016; Szpunar et al., 2014). Paper 1 (Madore & Schacter, 2014) of the dissertation examines the cognitive impact of the episodic specificity induction on a means-end problem solving task (MEPS; Platt & Spivack, 1975) in young and older adults. Paper 2 (Madore et al., 2015) extends this cognitive approach to divergent creative thinking in young adults. Paper 3 builds on this cognitive work by
investigating the neural signature of the specificity induction for imagined future events in young adults (Madore, Szpunar et al., 2016).

**Motivation for Paper 1: Episodic Memory and Means-end Problem Solving**

Recent research has suggested that means-end problem solving (MEPS; Platt & Spivack, 1975) may be a domain that nominally involves episodic processes. For a typical MEPS task, individuals are given a set of fictional scenarios that each have a beginning problem and an ending solution, and are asked to fill in the steps to solve the problem and reach the identified solution state. Problems involve meeting new people, handling a situation at work, courting a potential partner, finding a lost watch, and so on. Solutions are scored for relevant steps (i.e., steps that lead toward the identified solution state) and other steps (i.e., steps that do not lead toward the identified solution state, or other sorts of off-topic information). It should be noted that performance on the MEPS has been linked to performance on everyday problem solving (e.g., Anderson, Goddard, & Powell, 2011; Marx, Williams & Claridge, 1992; Sheldon et al., 2015), which strengthens the ecological validity of the task.

Preliminary links have been made between episodic memory and means-end problem solving previously. For example, studies have found that the specificity of episodic memory is correlated with MEPS performance in individuals with certain psychopathological conditions like depression and anxiety (e.g., Goddard, Dritschel, & Burton, 1996; Maccallum & Bryant, 2010; Raes et al., 2005; Sidley, Whitaker, Calam, & Wells, 1997; Sutherland & Bryant, 2008; Williams et al., 2006), which provides tentative evidence that episodic processes are recruited for both tasks. Work from cognitive aging has also suggested that older adults generate fewer relevant steps on the MEPS compared with matched young adults, and that their solutions also contain fewer internal/episodic details compared with young adults (Sheldon, McAndrews, &
Moscovitch, 2011; Vandermorris, Sheldon, Winocur, & Moscovitch, 2013; for a lack of age differences, see Beaman, Pushkar, Etezadi, Bye, & Conway, 2007). In this work (e.g., Sheldon et al., 2011), correlations have likewise been found between the number of internal/episodic details contained in AI memory narratives and the number of relevant steps and internal/episodic details contained in MEPS solutions. A recent study of individuals with amnestic mild cognitive impairment showed similar effects (Sheldon et al., 2015). This sort of evidence from populations characterized by episodic memory deficits suggests a link between means-end problem solving and episodic memory. Neural studies of autobiographical planning with process simulations – steps that lead toward a solution – also suggest that core network regions are recruited for this sort of task (e.g., Gerlach, Spreng, Gilmore, & Schacter, 2011; Gerlach, Spreng, Madore, & Schacter, 2014; Spreng, Gerlach, Turner, & Schacter, 2015).

Based on this literature, we hypothesize that we could use an experimental tool to isolate contributions of episodic processes to means-end problem solving for the first time. We expect that the episodic specificity induction given prior to the MEPS task, along with AI memory and imagination tasks, will boost performance on task indexes that have been linked to episodic memory – relevant steps and internal details – compared with a control induction. We do not expect the induction to boost performance on non-episodic indexes of performance on the tasks – other steps and external details.

If the findings are as hypothesized, then they would indicate that means-end problem solving is a cognitive task that draws on episodic processes. Such findings would suggest that biasing a specific retrieval orientation with the induction primes participants to approach the means-end problem solving task by creating and filling in mental scenarios with details like those emphasized during the induction (for a further outline of this point, see Schacter &
Madore, 2016). Theoretically, such findings would also support the constructive episodic simulation hypothesis by showing that the flexible retrieval and recombination of episodic details is utilized during means-ends problem solving. Functionally, the specificity technique could be fruitful in populations characterized by episodic retrieval and problem-solving deficits such as those with depression (Raes, Williams, & Hermans, 2009) and amnestic mild cognitive impairment (Sheldon et al., 2015). If the findings are not as hypothesized, then this would suggest that episodic processes do not contribute meaningfully to means-end problem solving.

The results and publication resulting from the study are presented in Paper 1 (Madore & Schacter, 2014). In Paper 2 below, we extend the approach of using the specificity induction to isolate contributions of episodic retrieval processes in another domain with functional applications: divergent creative thinking.

**Motivation for Paper 2: Episodic Memory and Divergent Creative Thinking**

The motivation for this paper came from preliminary evidence that episodic memory may contribute to certain types of creative thinking. Divergent thinking, in particular, has been linked to episodic memory. This type of creative thinking was defined by Guilford (1967) as the ability to generate creative ideas by combining diverse pieces of information in novel ways (see also Torrance, 1962; Welch, 1946), which parallels key tenets of the constructive episodic simulation hypothesis. The notion that divergent thinking and episodic memory are linked also fits under an approach to studying this topic known as *creative cognition* (Finke, Ward, & Smith, 1992; Smith, 1995; Smith & Ward, 2012; for a related recent review, see Beaty, Benedek, Silvia, & Schacter, 2016), which stresses that common subcomponent processes can be identified in divergent thinking and other generative cognitive tasks such as memory.
One line of preliminary evidence that episodic memory processes may be recruited for divergent thinking tasks comes from cognitive work. Gilhooly, Fioratou, Anthony, and Wynn (2007) found that young adult participants referred to particular episodic memories 10% of the time when completing a divergent thinking task. Addis, Pan, Musicaro, and Schacter (2016) also found that in young and older adults the episodic detail content of imagined future events was positively correlated with performance on a divergent thinking task (for related results, see Ononye, Blinn-Pike, & Smith, 1993). These findings are promising but limited in the sense that in Gilhooly et al. (2007) 90% of divergent thinking responses were not related to particular episodic memories, and in Addis, Pan et al. (2016) the episodic detail content of remembered past events and imagined past events was not correlated with divergent thinking performance.

Brain-based work tentatively suggests a link between episodic memory and divergent thinking as well. Recent neuropsychological evidence indicates that individuals with hippocampal amnesia perform poorly on a battery of divergent thinking tests, the Torrance Tests of Creative Thinking, compared with matched controls (Duff, Kurczek, Rubin, Cohen, & Tranel, 2013). Neural studies have similarly found that core network regions are implicated in divergent thinking tasks (e.g., Beaty, Benedek, Kaufman, & Silvia, 2015; Beaty et al., 2014; Benedek et al., 2014; Ellamil, Dobson, Beeman, & Christoff, 2013; Fink et al., 2009, 2012; Liu et al., 2015; Roberts et al., 2017; Shah et al., 2013; for a review, see Beaty et al., 2016). Core network activation typically comes online when individuals are presented with a cue and are asked to remember a past event or imagine a future event related to the cue. Because core network regions, including the hippocampus, are implicated in divergent thinking tasks, it follows that certain processes recruited for divergent thinking may overlap with certain processes recruited for memory and imagination.
In the current set of experiments, we hypothesize that the specificity induction could be used to show for the first time via an experimental tool that episodic processes contribute to divergent creative thinking. To measure divergent thinking we used the Alternate Uses Task (AUT), a typical and standardized task in this domain in which individuals are presented with everyday common objects and are asked to generate unusual and creative uses for each one (Guilford, 1967; Guilford, Christensen, Merrifield, & Wilson, 1960). For example, for the object cue bucket, unusual and creative uses could include playing drums with the bucket or wearing the bucket as a hat. Most research groups (e.g., Abraham et al., 2012; Benedek et al., 2014; Gilhooly et al., 2007; Smith & Ward, 2012) have examined how semantic memory processes contribute to performance on the AUT, in terms of mental imagery about typical object characteristics and how they can be manipulated in new ways or in terms of semantic conceptual expansion. However, given previous literature on this topic and the range of generative cognitive tasks for which retrieving and recombining episodic details may be important (e.g., Madore & Schacter, 2014), we hypothesize that episodic memory processes may also contribute to divergent thinking. When completing the AUT, individuals could potentially be retrieving elements of episodic memories where common objects are used in novel ways (e.g., recalling a movie scene where someone uses a bucket to play drums) or recombining elements of distinct episodic memories to create imagined scenes in which common objects are used in novel ways (e.g., on Halloween at a friend’s house in the future using a bucket as a hat for a costume).

Along with the AUT, we included an AI-based imagination task to ensure that the specificity induction was operating as expected. We also included two creative thinking tasks not thought to tap episodic processes and divergent thinking. In Experiment 1, we implemented the Object Association Task (OAT), a non-episodic index in which participants view object cues like
in the AUT and generate responses but with a focus on typical associates of each cue (based on Abraham et al., 2012). The Object Association Task most likely measures semantic imagery, which involves mentally drawing on appropriate facts and concepts to complete a given task from semantic knowledge stores using generative search and retrieval (based on Abraham et al., 2012). Cognitive performance on a task resembling the OAT has been dissociated from that on the AUT in terms of the content and number of outputs participants provide; neural activity on a task resembling the OAT has also been found to recruit the medial prefrontal cortex, inferior parietal lobule, and inferior and middle frontal gyri to a lesser extent than the AUT (based on Abraham et al., 2012). This pattern of findings suggests cognitive and neural dissociations between a task resembling the OAT and the AUT.

In Experiment 2, we replaced the OAT with a standard measure of convergent creative thinking, the Remote Associates Test (RAT; Bowden & Jung-Beeman, 1998, 2003; Mednick, 1962), and used this as our non-episodic index. Convergent thinking is defined as the ability to come up with the one best solution for a specific problem, and is contrasted with divergent thinking’s more open-ended framework (Guilford, 1967). In the RAT, participants are presented with a triad of words (e.g., Eight / Skate / Stick) and must come up with the one word that forms a common compound word or phrase with each part of the triad (e.g., the correct answer for the given triad would be Figure). Prior research has suggested that the RAT relies on semantic imagery and knowledge for successful completion. Participants perform better on the RAT when they are primed with semantically relevant concepts versus not; successful solution generation on the RAT is also associated with greater neural activation in the right than left hemisphere, the right hemisphere being a hub for what researchers call coarse semantic coding that is utilized on the RAT (Bowden & Jung-Beeman, 1998, 2003; Mednick, 1962).
Because the specificity induction isolates episodic processes involved in cognitive tasks rather than semantic ones, we hypothesize that the manipulation will boost performance on the AUT but not the non-episodic OAT and RAT. If the findings are as hypothesized, then they would suggest that divergent creative thinking is a task that recruits episodic processes. Such findings would provide support for the constructive episodic simulation hypothesis, in that a range of cognitive tasks including imagination, means-end problem solving, and divergent thinking may draw on the flexible retrieval and recombination of episodic details for completion. Because the induction may bias a specific episodic retrieval orientation and help individuals to fill in a mental scenario with many specific details, it may also help on later cognitive tasks – like divergent thinking – that potentially involve building a mental scenario and filling in many specific details for completion (for further elaboration on this point, see Schacter & Madore, 2016). If the findings are not as expected, then they would suggest that divergent creative thinking does not involve episodic processes for completion.

The results and publication stemming from the experiments is presented as Paper 2 (Madore et al., 2015). We have recently replicated and extended the findings of Paper 2 in another publication with young and older adults using the AUT and OAT, and a second index of divergent thinking, the Consequences Task (Madore, Jing, & Schacter, 2016). In the Consequences Task, participants are presented with impossible scenarios (e.g., being able to talk with animals, being able to live without sleep, etc.) and are asked to generate the consequences of these scenarios (Guilford, 1967; Torrance, 1962). While Papers 1 and 2 address the outstanding issue of links between memory and cognitive tasks beyond imagination in cognitive work, Paper 3 below focuses on the neural signature of the specificity induction for imagined
future events. This study addresses the outstanding issue of how the specificity induction impacts neural activity in regions of the core network during a task that draws on episodic processes.

**Motivation for Paper 3: Episodic Specificity Induction and fMRI**

The motivation for this paper came from prior work suggesting core network involvement in memory and imagination, with an emphasis on how activity in the medial temporal lobe subsystem is related to mental event or scene building (e.g., Addis et al., 2011, 2007; Andrews-Hanna et al., 2010). To examine the neural effects of the specificity induction on imagined future events, we designed and ran an fMRI project with an event-related design with 32 young adults. Modeling our cognitive approach (Madore & Schacter, 2016), participants underwent a single fMRI scanning session in a within-subjects design where they received the specificity induction and one of two control inductions (the impressions control or math control) followed by main task runs in which they imagined future events and completed semantic object comparisons and definitions in response to word cues. We did not include remembered past events as a main task condition in the fMRI paradigm to maximize power to find induction-related effects (i.e., the number of possible trials for each main task would have been very low with a third main task included). The construction-elaboration paradigm was used for the main tasks (see Addis et al., 2007), such that participants pressed a button when they had initially constructed an imagined event or an object size sentence, and then elaborated on the details of the imagined event or provided definitions of the objects from the size sentence until the respective trial was completed. One resting-state scan was completed following the main tasks in each induction segment.

For the main tasks, we hypothesize that the specificity induction compared with the control inductions would primarily affect neural activity for future events compared with object
comparisons in core network regions implicated in the medial temporal lobe subsystem (e.g., Andrews-Hanna et al., 2010), including the hippocampus and inferior parietal lobule. These two regions in particular have been associated with detailed mental event or scene building (e.g., Addis et al., 2011; Addis & Schacter, 2008; Guerin, Robbins, Gilmore, & Schacter, 2012), and in cognitive studies we have observed that the induction affects details generated for event or scene narratives (e.g., Madore et al., 2014; Madore & Schacter, 2016). For the main tasks, we also hypothesize that the specificity induction compared with the control inductions would target primarily the construction phase of future event simulations compared with object comparisons, given that episodic retrieval orientation should have its greatest effects when events are initially constructed versus elaborated upon; we have previously suggested that this cognitive process is most likely a key one that the induction targets (for further elaboration, see Schacter & Madore, 2016). A post-scan interview was also included where participants were presented with each cue they viewed in the scanner and were asked to generate their previous thoughts for each one. We included the post-scan interview to ensure that the induction manipulation was operating as expected in the scanner for the future events task – and for internal details selectively on the task – but not the object comparison task. For the resting-state portion of the experiment, we also hypothesize that stronger core network coupling should be observed following the specificity induction compared with the control inductions.

If the findings are as hypothesized, then they would suggest that the specificity induction targets episodic processes linked to core network activity, including the hippocampus. Such findings would establish a neural signature of the specificity induction and suggest that retrieval orientation is a key process linked to the induction. This pattern of results would also add support to the constructive episodic simulation hypothesis by showing that an induction focused on
episodic memory can boost cognitive measures and neural activity during an imagination task. As the hypothesis stipulates, a key function of episodic memory is the flexible retrieval and recombination of bits of prior experiences for simulation building. Such results would fit in this framework. If the findings are not as observed, then this would suggest that the induction does not target episodic processes and an alternative account of the experimental tool would have to be examined, as well as alternative explanations for similarities exhibited between memory and imagination beyond the constructive episodic simulation hypothesis.

The results and publication stemming from the experiment are presented in Paper 3 (Madore, Szpunar et al., 2016). The three papers of the dissertation will be presented next, having established the motivation for each one. A concluding chapter follows that highlights how each paper addresses outstanding issues and identifies the implications of and next steps for the research program.
Paper 1:

Abstract

Episodic memory plays an important role not only in remembering past experiences, but also in constructing simulations of future experiences and solving means-end social problems. We recently found that an episodic specificity induction – brief training in recollecting details of past experiences – enhances performance of young and older adults on memory and imagination tasks. Here we tested the hypothesis that this specificity induction would also positively impact a means-end problem-solving task on which age-related changes have been linked to impaired episodic memory. Young and older adults received the specificity induction or a control induction before completing a means-end problem-solving task, as well as memory and imagination tasks. Consistent with previous findings, older adults provided fewer relevant steps on problem solving than did young adults, and their responses also contained fewer internal (i.e., episodic) details across the 3 tasks. There was no difference in the number of other (e.g., irrelevant) steps on problem solving or external (i.e., semantic) details generated on the 3 tasks as a function of age. Critically, the specificity induction increased the number of relevant steps and internal details (but not other steps or external details) that both young and older adults generated in problem solving compared with the control induction, as well as the number of internal details (but not external details) generated for memory and imagination. Our findings support the idea that episodic retrieval processes are involved in means-end problem solving, extend the range of tasks on which a specificity induction targets these processes, and show that the problem-solving performance of older adults can benefit from a specificity induction as much as that of young adults.

Keywords: episodic specificity induction, means-end problem solving, autobiographical memory, imagination, aging
An Episodic Specificity Induction Enhances Means-end Problem Solving in Young and Older Adults

A large number of recent studies have shown striking neural and cognitive similarities between remembering the past and imagining the future (for reviews, see Klein, 2013; Schacter et al., 2012; Szpunar, 2010). Some of those similarities have been documented in studies of cognitive aging, which have revealed that age-related changes in remembering past experiences are paralleled by comparable age-related changes in imagining future or hypothetical experiences (for review, see Schacter, Gaesser, & Addis, 2013). For example, in a study by Addis, Wong, and Schacter (2008), participants completed an adapted version of the Autobiographical Interview (AI; Levine, Svoboda, Hay, Wincour, & Moscovitch, 2002), which includes a scoring procedure that distinguishes between the “internal” and “external” details that comprise either remembered or imagined personal experiences. Internal details consist of specific information concerning who, what, where, and when features of the retrieved experience, and are thought to draw largely on episodic memory, whereas external details involve related facts, elaborations, or references to other events, and are thought to draw largely on semantic memory. Addis et al. (2008) found that older adults reported significantly fewer internal details and more external details about both remembered past experiences and imagined future experiences compared with young adults, a result that has been replicated and extended in more recent studies (Addis, Musicaro, Pan, & Schacter, 2010; Cole, Morrison, & Conway, 2013; Gaesser, Sacchetti, Addis, & Schacter, 2011; Madore, Gaesser, & Schacter, 2014; Rendell et al., 2012; Romero & Moscovitch, 2012).

Addis et al. (2010, 2008) interpreted these findings in the context of the constructive episodic simulation hypothesis (Schacter & Addis, 2007, 2009), which holds that remembering
past experiences and imagining future experiences recruit many of the same underlying processes, and that episodic memory supports the construction of imagined future events by allowing individuals to flexibly retrieve and recombine details of past experiences into a novel scenario or episodic simulation. From this perspective, impaired episodic memory mechanisms are the primary source of age-related changes in remembering the past and imagining the future. However, the results of a study by Gaesser et al. (2011) suggest an alternative interpretation.

Gaesser et al. (2011) showed that older adults reported fewer internal and more external details not only when remembering the past and imagining the future, but also when describing a picture of an everyday scene—a task that should draw minimally if at all on episodic memory. These findings thus suggest a role for nonepisodic mechanisms in driving age differences on memory and imagination tasks using the AI or similar procedures, such as changes in communicative goals, narrative style, or inhibitory control (cf. Adams, Smith, Nyquist, & Perlmutter, 1997; Arbuckle & Gold, 1993; Labouvie-Vief & Blanchard-Fields, 1982; Trunk & Abrams, 2009; Zacks & Hasher, 1994; for further discussion, see Gaesser et al., 2011; Schacter et al., 2013).

In a more recent study, we (Madore et al., 2014) were able to distinguish between episodic and nonepisodic mechanisms involved in memory, imagination, and picture description tasks by using an episodic specificity induction: brief training in recollecting the details of a recent experience. Our induction is based on the Cognitive Interview (CI; Fisher & Geiselman, 1992), which has proven useful for increasing detailed episodic recall in eyewitnesses in written or verbal form (e.g., Gawrylowicz, Memon, Scoboria, Hope, & Gabbert, 2014; for review, see Memon, Meissner, & Fraser, 2010). As described in Madore et al. (2014), participants first viewed a video of an everyday scene (people interacting in a kitchen) and were then guided to recall the video in specific episodic detail with procedures adapted from the CI, such as
generating a mental picture and reporting everything they remembered about the scene in as much detail as possible, including what people looked like and did, how objects were arranged, and so forth (see Method for more details). Following the induction, participants were given separate tasks in which they were asked to remember past experiences, imagine future experiences, or describe a picture, using the same materials, instructions, and AI procedure as in Gaesser et al. (2011). We compared the effects of the episodic specificity induction on these three tasks with the effects of a control induction in which the same participants watched a video similar to the one shown during the specificity induction and then provided general impressions of the video without recalling specific details. Compared with this control induction, the episodic specificity induction produced an increase in the number of episodic (internal) – but not semantic (external) – details that young and older adults provided on the memory and imagination tasks. In sharp contrast, however, the specificity induction had no effect on picture description performance in either age group. We obtained similar findings in a follow-up experiment in which the control induction involved completing math problems after viewing the video. Based on the overall pattern of results, we argued that the specificity induction selectively targets and enhances episodic retrieval, dissociating it from both semantic retrieval and narrative description.

A potentially important implication of these results for cognitive aging is that an episodic specificity induction may enhance the performance of older adults on other tasks that rely on episodic memory in addition to the remembering and imagining tasks used by Madore et al. (2014), and where differences between young and older adults’ performance reflect, at least in part, age-related impairments in episodic retrieval. Given the variety of cognitive tasks on which episodic retrieval plays some role (e.g., Schacter, 2012; Sheldon & Moscovitch, 2012), the use of an episodic specificity induction could have wide ranging beneficial consequences for older
adults. One such cognitive task is Means-End Problem Solving (MEPS; Platt & Spivack, 1975). On this task, participants are presented with a series of hypothetical social problems encountered by fictional individuals, such as meeting new people or handling a situation at work, along with solutions to those problems, and are asked to generate steps or means that lead to the problem solutions (e.g., “J is having trouble getting along with the boss on his job. J is very unhappy about this. The story ends with J’s boss liking him. You begin the story where J isn’t getting along with his boss”). Standardized scoring procedures (Platt & Spivack, 1975) provide methods for characterizing participants’ responses as relevant means (i.e., steps or events that move the protagonist toward reaching an identified solution), irrelevant means (i.e., steps or events that move the protagonist toward reaching a different solution), or no means (i.e., off-topic information, commentary, or repetitive information; see Method for further details). Some investigators have also attempted to rate the effectiveness of solutions provided on the MEPS (e.g., Anderson, Goddard, & Powell, 2011; Brown, Dorfman, Marmar, & Bryant, 2012). Several studies have demonstrated that performance on the MEPS is positively correlated with the specificity of episodic or autobiographical memory retrieval in depressed and anxious individuals (Goddard, Dritschel, & Burton, 1996; Maccallum & Bryant, 2010; Raes et al., 2005; Sidley, Whitaker, Calam, & Wells, 1997; Sutherland & Bryant, 2008; Williams et al., 2006), and with measures of everyday problem solving in such individuals (Anderson et al., 2011; Marx, Williams, & Claridge, 1992). Most important for the present study, Sheldon, McAndrews, and Moscovitch (2011) recently extended the link between episodic memory and MEPS performance to cognitive aging: they reported that older adults generated fewer relevant means (i.e., steps that led to solving the problem) on the MEPS task than did young adults, but generated similar numbers of irrelevant means. Moreover, they also found that the solutions generated by older
adults contained fewer episodic (internal) details than those of young participants, along with no differences in semantic (external) details, and that the number of internal (but not external) details in the autobiographical memories of older adults was positively correlated with the number of relevant means produced on the MEPS task (but see Beaman, Pushkar, Etezadi, Bye, & Conway, 2007, for a lack of age differences on the MEPS task). Vandermorris, Sheldon, Winocur, and Moscovitch (2013) replicated these results and also showed that the positive correlation between relevant steps on the MEPS task and internal details on the memory task was exhibited in young adults (along with older adults) even after executive processes were controlled for.

Overall, then, these data strongly support the idea that episodic retrieval contributes importantly to performance on the MEPS task and that impairments in episodic retrieval contribute to age deficits documented on the MEPS task. While there are situations in which the everyday problem-solving performance of older adults can exceed that of young adults (e.g., Blanchard-Fields, Mienaltowski, & Seay, 2007; see Discussion), the observations of Sheldon et al. (2011) and Vandermorris et al. (2013) are consistent with results from previous cognitive studies indicating that older adults retrieve fewer episodic details than do young adults when they remember past experiences and imagine future experiences (Addis et al., 2010, 2008; Cole et al., 2013; Gaesser et al., 2011; Madore et al., 2014; Rendell et al., 2012; Romero & Moscovitch, 2012), and also with neuroimaging evidence indicating that older adults, compared with young adults, exhibit reduced activity in brain regions linked with retrieval of episodic detail, including medial temporal lobes and precuneus, when they remember the past and imagine the future (Addis, Roberts, & Schacter, 2011). More broadly, these findings also fit with views of cognitive aging that hold that a key source of age-related memory deficits stems from difficulties with self-
initiated or reconstructive retrieval (e.g., Craik, Routh, & Broadbent, 1983; Jacoby & Rhodes, 2006; Lindenberger & Mayr, 2014). The evidence of aging effects on MEPS and future imagining tasks indicates that these retrieval problems are not confined to episodic memory tasks, but also include a variety of cognitive tasks that draw on reconstructive episodic retrieval abilities.

**The Present Study: Overview and Predictions**

Given the role of episodic processes on a range of cognitive tasks, in the current study older and young adult participants completed a MEPS problem-solving task and AI-based memory and imagination tasks after receiving an episodic specificity induction that targeted these processes or a control induction. As done previously (e.g., Addis et al., 2008; Sheldon et al., 2011), performance on the MEPS task was measured via standardized step scoring (i.e., relevant, irrelevant, and no step) and detail scoring (i.e., internal and external), and performance on the AI-based memory and imagination tasks was measured via detail scoring (i.e., internal and external). Our initial predictions are age-related. We hypothesized that older adults would provide fewer relevant steps than young adults on the MEPS task – with no difference in other types of steps – and that their solutions would also contain fewer internal details – with no difference in external details. These hypotheses were driven by the findings of Sheldon et al. (2011) and Vandermorris et al. (2013). We also expected to replicate typical age-related differences on the memory and imagination tasks, with fewer internal details and more external details generated by older adults compared with young adults (e.g., Addis et al., 2008).

Our main predictions are induction-related. Critically, we expected that older and young adults would generate more relevant steps and internal details on the MEPS task when they received the specificity induction compared with the control induction. If the specificity
induction targets episodic processes (Madore et al., 2014) and these processes are recruited when participants complete a MEPS task (e.g., Sheldon et al., 2011), then participants should see a boost in performance on the MEPS task after the specificity induction compared with a control induction. In light of our previous findings that the episodic specificity induction produced similar performance increases in young and older adults on memory and imagination tasks, we also predicted that MEPS performance in young and older adults would benefit similarly from the specificity induction. Likewise, we expected to replicate our basic specificity induction effect for memory and imagination in both age groups (in particular, an increase in internal details following the specificity induction compared with the control induction).

The primary reason for including the memory and imagination tasks in the current study was to allow direct comparison of older and young adults’ performance on these tasks with their performance on the MEPS task. In this vein, we expected to replicate findings (e.g., Sheldon et al., 2011) pointing to positive correlations between episodic indices of problem solving and memory (e.g., relevant steps with internal details for memory, and internal details for problem solving with internal details for memory), and extend these findings to episodic indices of problem solving and imagination (e.g., relevant steps with internal details for imagination). We did not expect relevant steps in problem solving or internal details on the three tasks to positively correlate with the other step or external detail measures. We also did not expect to find age-related differences in the correlational analyses because all three tasks should recruit episodic processes in both age groups.

Moreover, because the scenarios on the MEPS involve fictional individuals, they may or may not have been relevant to the concerns of study participants. Previous evidence indicates that the relevance of problems to older adults’ goals and concerns can influence problem-solving
performance (e.g., Artistico, Cervone, & Pezzuti, 2003; Artistico, Orom, Cervone, Krauss, & Houston, 2010; Hoppmann, Coats, & Blanchard-Fields, 2008; Thornton, Paterson, & Yeung, 2013). In light of this research, it was important to assess whether age-related impairments on the MEPS were reduced or eliminated with relevant problems, and also to determine whether any effects of the episodic specificity induction differed for self-relevant problems versus the standard MEPS problems. Accordingly, we included a condition using means-end social problems involving goals and steps that were deemed relevant to both young and older adults in an independent sample.

Method

Participants

Forty-eight young adults (age = 18-24 years, $M = 20.10, SD = 1.56, 34$ women) and 48 older adults (age = 65-83 years, $M = 72.23, SD = 5.62, 34$ women) participated in the study. Young adults were recruited via postings at Harvard University and Boston University, and older adults were recruited via postings around the Greater Boston area. Participants were paid or received course credit for their participation. All participants had normal or corrected-to-normal vision and no history of neurological impairment. Older adults were screened with an extensive neuropsychological battery and were considered cognitively healthy: they had a mean Mini-Mental Status Examination (Folstein, Folstein, & McHugh, 1975) score of $28.63 (SD = 1.27, range = 26-30)$. Older adults had completed significantly more years of education ($M = 15.67, SD = 2.37$) than young adults ($M = 14.77, SD = 1.29$) and had a mean verbal fluency (i.e., phonemic FAS test; Lezak, 1995) score of $41.69 (SD = 15.37, range of 8-86)$. Educational level and verbal fluency did not predict performance on any of our main tasks, and neither factor correlated significantly with any of our dependent variables of interest. All participants provided
written consent before completing the study and were treated in accordance with guidelines established by the Committee on the Use of Human Subjects in Research at Harvard University.

**Experimental Design**

Participants completed the study in two sessions, with session two occurring approximately a week after session one ($M = 7.80$ days, $SD = 2.20$, median and mode $= 7.00$). In each session, participants (a) watched a video of two adults performing routine activities in a kitchen, (b) received questions about the video’s contents in the form of the episodic specificity induction or the control induction, and (c) completed the MEPS problem-solving task and the AI-based memory and imagination tasks. Participants viewed different stimuli in each session in terms of the video, induction, and task cues. The video-induction sequence used in each session was counterbalanced across participants. Participants generally took 1.5 to 2 hr to complete each session. Figure 1.1 illustrates the experimental design and how the main variables were measured.

**Figure 1.1.** Schema of experimental design.

**Materials and Procedure**
Inductions

As in our previous study (Madore et al., 2014), the episodic specificity induction was a modified version of the CI (Fisher & Geiselman, 1992). At the start of the induction, participants were told that they were the chief expert about the video, and they were asked to recall details about the setting, people, and actions in the video they had seen using mental imagery probing; they were also asked to report everything they could remember and to be as detailed as possible (e.g., “Please close your eyes and get a picture in your mind about the setting of the video you saw… After you have a really good picture I want you to tell me everything you remember about the setting. Try to be as specific and detailed as you can”). For the setting probe, participants were asked to report about the environment, the objects in it, and how they were arranged; for the people probe, participants were asked to report about what the people looked like and what they were wearing; and for the actions probe, participants were asked to report about what the people had done in the video and how they did these things, starting with the first action and ending with the last action. Follow-up probes asked participants to elaborate on details they had mentioned and were framed in as open-ended a manner as possible (e.g., “You said the man had on a shirt with pants. Tell me more what his shirt and pants looked like”). One follow-up probe was generally asked for each category.

The control induction consisted of an impressions interview (as in Madore et al., 2014). This induction focused on participants’ opinions, impressions, and thoughts about the video. Participants were first asked to express their opinions of the video as a whole and were then asked to respond to several different questions from a question bank. These included questions about participants’ impressions of the environment, people, and actions, along with adjectives they would use to describe each. Participants were also asked questions such as when they
thought the video was made, if they liked the video, and if it reminded them of anything from their own lives. After answering these questions, participants were asked if they had any other opinions or thoughts about the video and if there was anything else they wanted to say about it. Like the episodic specificity induction, the control induction required participants to think and speak about the video in both sessions. The main difference was that the specificity induction instructed participants to discuss episodic details about the video whereas the control induction instructed participants to discuss their general impressions of the video.

Problem-Solving Task

After working through the induction phase, participants completed the problem-solving task. They viewed 5 different problem stories in each session, each of which contained a beginning problem and an ending solution. Participants were asked to write down on lined paper the steps they would take to reach the solution in each story. They were instructed to write down as many steps as they could in as much detail as they could, without reference to omitting off-topic steps or details. Participants had 5 min to generate solution steps for each story, and they completed this task without any input or probing from the experimenter to minimize environmental support (as done in Sheldon et al., 2011). The order of stories was randomized across participants.

Half of the young adults and half of the older adults viewed standard MEPS stories (Platt & Spivack, 1975). Each of the stories introduced a different third-person, fictional character and identified a problem they had at the beginning of the story and a successful solution they came to at the end of the story. The stories contained problems such as making new friends, finding a watch, and becoming a leader in a community organization. Each story contained either a male
or female character, and participants viewed stories containing characters of each gender. See Appendix for the MEPS task instructions and story stimuli.

The other half of young and older adults viewed self-relevant MEPS stories we created drawing on data collected from an independent sample (Spreng & Schacter, 2012), where young and older adults had identified goals they found personally relevant in their own lives and could generate solution steps to solve. For the current study, we chose a subset of these goals that members from both age groups deemed personally relevant and could supply solution steps to solve. We matched the personal goals in story form to the standard MEPS format with a beginning problem and an ending solution. The stories contained self-relevant problems such as exercising more, making more time for family, and managing personal finances better. The stories introduced the problems in first-person form rather than third-person, fictional form (e.g., “You would like to exercise more” as opposed to “J would like to exercise more”). See Appendix for the self-relevant task instructions and story stimuli.

Participants were randomly assigned to one of the two problem sets and there were no significant differences at the $p < .05$ level in terms of age, educational level, Mini-Mental Status Examination score, verbal fluency, or gender between the two groups. The standard prompts had slightly more details attached to them compared with the self-relevant prompts, which could have assisted participants in the former group by providing more environmental support (Lindenberger & Mayr, 2014). Nonetheless, participants who completed the self-relevant problems rated them as significantly less difficult ($M = 2.00, SD = 0.74$, on a 5-point Likert scale where 1 = least difficult and 5 = most difficult) than those participants who completed the standard problems ($M = 2.54, SD = 0.80$), $t(94) = 3.40, p = .001, d = 0.70$. This pattern of significance held in both young and older adults. This finding was not surprising, because the
self-relevant problems were created so that participants would have an easier time identifying with them compared with the standard MEPS problems. Young and older adults also did not differ significantly in how difficult they perceived the problems to be overall.

**Adapted AI**

After finishing the problem-solving task, participants moved to the adapted AI task, where they viewed 8 different pictures and were asked to write down a personal memory or imagined future experience that was related to some aspect of the picture. Each remembered experience had to have occurred within the past few years and each imagined experience had to occur within the next few years. Participants were asked to focus on a single event on a single day that lasted a few minutes to a few hours, and to think about the event from their own perspective. They were instructed to write down everything they could remember or imagine about the event in as much detail as they could, including actions, people, and feelings, without reference to omitting off-topic details. Participants had 3 min to generate a response for each picture. The picture stimuli showed scenes common to both young and older adults, such as an airport, a museum, and a park. Pictures were blocked by task, and the order of the two tasks was counterbalanced across participants (i.e., sometimes memory preceded imagination and sometimes memory followed imagination). Pictures were randomized across tasks and participants. As in the problem-solving task, there was no experimenter input or probing here to minimize the effects of environmental support on performance (as done in Sheldon et al., 2011).

**Coding**

Participants’ responses for the problem-solving and AI tasks were transcribed and scored. Responses for both the standard and self-relevant problem-solving tasks were scored according to the step categories set forth by Platt and Spivack (1975) and used by other research teams.
(e.g., Sheldon et al., 2011). A response containing a step or event that moved the protagonist toward reaching the identified solution state was coded as a relevant step. A response containing a step or event that moved the protagonist toward a different solution state was coded as an irrelevant step. A response containing other types of off-topic information, commentary, or repetitive information from the story prompt was coded as a no step. For example, in the standard MEPS story asking participants to generate solution steps for resolving J’s conflict with their boss, a relevant step could be J scheduling a meeting with their boss, an irrelevant step could be J quitting their job, and a no step could be a participant’s commentary on J (such as “I feel bad for J”). Irrelevant steps and no steps were collapsed into a single other steps category. Responses for the standard and self-relevant problem-solving tasks were also scored with the internal and external categories typically used in AI tasks. Internal details were any bits of episodic information that corresponded to a relevant step and external details were any bits of semantic, off-topic, or repetitive information that corresponded to an other step. As in our previous study (Madore et al., 2014), responses for the memory and imagination tasks were also scored for internal and external details (see Levine et al., 2002). Internal details were any bits of episodic information about the central memory or imagination (e.g., actions, people, thoughts, feelings, setting, time, objects, etc.) and external details were any bits of semantic, off-topic, or repetitive information. Hypothetically, external details could also include episodic information that was off-topic in nature on each task (e.g., episodic details about an event other than the central event for a memory or imagination trial, or episodic details contained in an irrelevant step toward a different solution state for a problem-solving trial) though this happened very infrequently.
One of five raters scored the responses of each participant. Before coding for the experiment commenced, raters independently completed training and attained high interrater reliability on a practice set of 20 responses from young and older adults (standardized Cronbach’s alpha = .92 for steps, .95 for internal details, and .94 for external details). All raters were blind to all experimental hypotheses and to which induction had been received. Table 1.1 contains excerpts that both young and older participants gave in response to the same cues for the problem solving, memory, and imagination tasks, and illustrates how the raters categorized these excerpts in terms of steps and details. We also conducted additional analyses based on procedures that have been developed in the event segmentation literature (e.g., Kurby & Zacks, 2011; Zacks, Tversky, & Iyer, 2001). Although these analyses did not change any of our main conclusions, the interested reader is referred to Appendix.

Table 1.1

<table>
<thead>
<tr>
<th>Task / Cue</th>
<th>Age</th>
<th>Relevant steps / Internal details</th>
<th>Other steps / External details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem solving /</td>
<td>Young</td>
<td>“I first gauge everyone’s interest in the trip… and decide on a day that fits in everyone’s schedule. Then I research the hiking trail we want to take… I go to the grocery store and buy snacks to take on the hike, such as granola, bananas, dried fruit, and energy drinks… I pack everything into the car…”</td>
<td>“Trip is planned…”</td>
</tr>
<tr>
<td>Plan a day trip</td>
<td>Older</td>
<td>“Look into the train schedule having decided to go to Portsmouth… I get us some lunch food… inquire about a city bus tour…”</td>
<td>“The train ride is always pleasant…”</td>
</tr>
<tr>
<td>(story cue)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Problem solving /</td>
<td>Young</td>
<td>“I had a [sorority] formal in November. I wore a beige/pale pink dress with a strapless sweetheart neckline and had rhinestones at the top. I had a date… who wore a dark gray suit with a plaid black and gray and white tie…”</td>
<td>“I joined… for one year and then quit…”</td>
</tr>
<tr>
<td>Plan a day trip</td>
<td>Older</td>
<td>“A wedding I attended last January. People were dressed lovely, the music was great, and I danced the night away…”</td>
<td>“Kind of wish we could do this more often…”</td>
</tr>
<tr>
<td>(story cue)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Problem solving /</td>
<td>Young</td>
<td>“I am at the MET museum. After I have exited the classics exhibition and enjoyed all the statues… I would find myself sitting down… to check out Impressionist paintings. I would note the colors of the shadows… there would be guards looking for cameras…”</td>
<td>“When I was in high school I loved art, especially sculptures…”</td>
</tr>
<tr>
<td>Plan a day trip</td>
<td>Older</td>
<td>“I got to the new exhibit at the MFA. I got there at 10:30am… off to the cafeteria for lunch… busy…”</td>
<td>“I like to go frequently… because too long there does not seem to suit me…”</td>
</tr>
<tr>
<td>(story cue)</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Excerpts From Different Young and Older Adults Categorized by Step and Detail Type
Results

To address our hypotheses, we conducted a series of mixed-factorial analyses of variance (ANOVAs), which involved the between-subjects factors of age (young vs. older) and problem set (standard vs. self-relevant MEPS) and the within-subjects factors of induction (control vs. specificity), task (problem solving vs. memory vs. imagination), step type (relevant vs. other), and detail type (internal vs. external detail). For each analysis, we tested for main effects and interactions. Results reported here focus on the interactions found because they most directly addressed our hypotheses and trumped the main effects. Post hoc tests conducted were two-tailed and Bonferroni corrected at the $p < .05$ level. We first present the age-related findings, followed by the induction effects and correlational evidence.

Age-Related Differences

Steps

We first examined whether young and older adults differed in the number of relevant steps and other steps generated on the problem-solving task as a function of age and problem set, irrespective of which induction they initially received. We found that the Age x Step Type interaction was significant, $F(1, 92) = 25.52, p < .001, \eta_p^2 = .22$, but the Age x Problem Set x Step Type interaction was not, $F(1, 92) = 0.83, p = .37, \eta_p^2 = .01$. For the Age x Step Type interaction (see Figure 1.2), post hoc tests indicated that older adults generated significantly fewer relevant steps than young adults when responding to the problems, whether they were standard MEPS or self-relevant ones, $t(94) = 5.16, p < .01, d = 1.05$; older adults and young adults did not significantly differ in the number of other steps generated across problem set, $t(94) = 0.16, p = .87, d = 0.03$. This pattern of results indicates that there are age-related differences in generating relevant steps on means-end problem solving that are of similar magnitude regardless
of whether the problem set is comprised of standard or self-relevant MEPS problems, thereby replicating and extending the results of Sheldon et al. (2011) and Vandermorris et al. (2013).

Figure 1.2. Mean relevant steps (A) and internal details (B) reported by young and older adults in problem solving across inductions as a function of problem set. Error bars represent 1 SE.

Internal and External Details for Steps

We next examined whether young and older adults differed in the number of internal and external details provided on the problem-solving task as a function of age and problem set, irrespective of which induction they initially received. We found that the Age x Detail Type interaction was significant, $F(1, 92) = 19.21, p < .001, \eta_p^2 = .17$, whereas the Age x Problem Set x Detail Type interaction approached but did not attain significance, $F(1, 92) = 3.72, p = .057, \eta_p^2 = .04$. For the Age x Detail Type interaction (see Figure 1.2), post hoc tests indicated that older adults’ solutions to the MEPS problems contained significantly fewer internal details than young adults’, whether they were generated in response to the standard or self-relevant MEPS, $t(94) = 3.95, p < .01, d = 0.81$ (though there was a non-significant trend for a greater age difference with the standard than self-relevant problems). Older and young adults’ solutions did not differ in the number of external details they contained across problem set, $t(94) = 0.25, p = .81, d = 0.05$. This pattern suggests that there are age-related differences in the number of
internal details contained in means-end problem-solving solutions irrespective of whether the MEPS problems are standard or self-relevant, again replicating and extending previous results from Sheldon et al. (2011) and Vandermorris et al. (2013).

**Internal and External Details for Memory and Imagination**

We next examined whether young and older adults differed in the number of internal and external details provided on the memory and imagination tasks as a function of age and problem set, irrespective of which induction they initially received. Consistent with previous findings (e.g., Addis et al., 2010, 2008; Gaesser et al., 2011; Madore et al., 2014), we found a significant interaction of Age x Detail Type, $F(1, 92) = 37.01, p < .001, \eta_p^2 = .29$, which did not interact with the Task and/or Problem Set variables ($F$s < 2.08, $p$s > .15). For the Age x Detail Type interaction (see Table 1.2), post hoc tests indicated that older adults provided significantly fewer internal details for memory and imagination tasks than young adults irrespective of whether participants first generated solutions to standard or self-relevant MEPS, $t(94) = 5.98, p < .01, d = 1.22$; older and young adults did not significantly differ in the number of external details provided for memory and imagination, $t(94) = 1.96, p = .106, d = 0.40$. This pattern indicates that there are age-related differences in the number of internal details provided for memory and imagination after completing a MEPS task with either standard or self-relevant problems.

**Table 1.2**

*Mean Details Generated by Young and Older Adults in Memory and Imagination*

<table>
<thead>
<tr>
<th></th>
<th>Young</th>
<th></th>
<th></th>
<th>Older</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>Specificity</td>
<td>Collapsed</td>
<td>Control</td>
<td>Specificity</td>
<td>Collapsed</td>
</tr>
<tr>
<td>Memory internal details</td>
<td>26.70 (1.64)</td>
<td>31.44 (1.49)</td>
<td>29.97 (1.45)</td>
<td>15.93 (1.47)</td>
<td>21.41 (1.46)</td>
<td>18.67 (1.34)</td>
</tr>
<tr>
<td>Imagination internal details</td>
<td>25.20 (1.41)</td>
<td>30.22 (1.13)</td>
<td>27.71 (1.06)</td>
<td>15.17 (1.39)</td>
<td>20.41 (1.43)</td>
<td>17.79 (1.31)</td>
</tr>
<tr>
<td>Memory external details</td>
<td>1.37 (0.21)</td>
<td>0.77 (0.15)</td>
<td>1.07 (0.15)</td>
<td>1.59 (0.20)</td>
<td>0.98 (0.18)</td>
<td>1.29 (0.16)</td>
</tr>
<tr>
<td>Imagination external details</td>
<td>1.05 (0.17)</td>
<td>0.52 (0.11)</td>
<td>0.79 (0.12)</td>
<td>1.63 (0.24)</td>
<td>1.15 (0.25)</td>
<td>1.39 (0.22)</td>
</tr>
</tbody>
</table>
Table 1.2 (Continued)

*Note. SE in parentheses.*

**Induction Effects**

**Steps**

Given that we found the expected age-related differences for relevant steps and internal details on the problem-solving task, and internal details on the memory and imagination tasks, we next examined the critical issue of how the episodic specificity induction impacted steps generated on the problem-solving task as a function of age, problem set, and step type. Participants spent slightly longer discussing the contents of the video under the specificity induction ($M = 3$ min, $56$ s, $SD = 1$ min, $26$ s) compared with the control induction ($M = 3$ min, $8$ s, $SD = 1$ min, $19$ s), $t(95) = 5.70, p < .001, d = 0.58$. When the difference score in time between inductions was added as a covariate for the analyses below involving the induction variable, it did not significantly affect any results.

We found a significant interaction of Induction x Step Type, $F(1, 92) = 29.61, p < .001, \eta^2_p = .24$, but this was qualified by a significant interaction of Induction x Age x Step Type, $F(1, 92) = 5.77, p < .05, \eta^2_p = .06$. These combinations of variables did not interact with Problem Set ($F$s $< 0.19, ps > .67). Irrespective of problem set, post hoc tests indicated that young adults generated significantly more relevant steps after receiving the specificity induction compared with the control induction, $t(47) = 4.54, p < .01, d = 0.66$, and significantly fewer other steps after receiving the specificity induction compared with the control induction, $t(47) = 3.20, p < .01, d = 0.46$. Critically, older adults also generated significantly more relevant steps after receiving the specificity induction compared with the control induction, $t(47) = 3.25, p < .01, d = 0.47$. However, they did not differ in the number of other steps generated after receiving the
specificity or the control induction, \( t(47) = 0.37, p = .71, d = 0.05 \). As seen in Figure 1.3, this pattern of results points to the efficacy of the specificity induction in boosting the production of relevant steps during means-end problem solving in both young and older adults irrespective of whether the problems are standard or self-relevant MEPS.

![Figure 1.3](image)

**Figure 1.3.** Mean steps reported by young (A) and older adults (B) in problem solving as a function of induction and step type, and mean details corresponding to steps reported by young (C) and older adults (D) in problem solving as a function of induction and detail type. Error bars represent 1 SE.

### Internal and External Details for Steps

We also examined how the episodic specificity induction affected the number of internal and external details provided as part of solutions to the problem-solving task in young and older

52
adults as a function of age, problem set, and detail type. Like our previous analysis with steps, we found a significant interaction of Induction x Detail Type, $F(1, 92) = 41.36, p < .001, \eta_p^2 = .31$, but this was qualified by a significant interaction of Induction x Age x Detail Type, $F(1, 92) = 4.18, p < .05, \eta_p^2 = .04$. There were no further interactions with Problem Set ($F$s < 0.38, $p$s > .54). Irrespective of problem set, post hoc tests indicated that young adults’ solutions contained significantly more internal details after receiving the specificity induction compared with the control induction, $t(47) = 5.28, p < .01, d = 0.76$, and significantly fewer external details after receiving the specificity induction compared with the control induction, $t(47) = 3.22, p < .01, d = 0.47$. Critically, older adults’ solutions also contained significantly more internal details after receiving the specificity induction compared with the control induction, $t(47) = 3.91, p < .01, d = 0.56$. However, their solutions did not differ in the number of external details as a function of induction, $t(47) = 0.68, p = .50, d = 0.10$. As seen in Figure 1.3, this pattern of findings highlights the efficacy of the specificity induction in boosting the number of internal details contained in the problem-solving solutions of young and older adults.

**Internal and External Details for Memory and Imagination**

We also examined how the episodic specificity induction affected internal and external details provided for memory and imagination as a function of age, problem set, task, and detail type. We found a significant interaction of Induction x Detail Type, $F(1, 92) = 58.39, p < .001, \eta_p^2 = .39$. The Induction x Detail Type interaction was nonsignificant with any combination of the Age, Problem Set, and Task variables ($F$s < 0.49, $p$s > .48). Post hoc tests indicated that young and older adults provided significantly more internal details on the memory and imagination tasks after receiving the specificity induction compared with the control induction, $t(95) = 7.47, p < .01, d = 0.76$, and significantly fewer external details for memory and
imagination after receiving the specificity induction compared with the control induction, \( t(95) = 5.52, p < .01, d = 0.56 \). This pattern of findings (see Table 1.2) replicates and extends the findings of our previous study concerning the effects of the specificity induction on memory and imagination tasks (Madore et al., 2014).

**Correlations between Problem Solving and Memory/Imagination Performance**

We also ran a series of bivariate correlational analyses to investigate further the degree to which episodic processes are involved in the problem solving, memory, and imagination tasks. We computed averages of the different step measures and detail measures for each participant collapsed across induction and problem set. In the analyses we also collapsed across age (i.e., all 96 participants were included; the same general patterns were found when we performed these analyses separately for the two induction types, age groups, and problem sets, with some minor variations that do not affect our main conclusions). The correlations were tested at a two-sided significance level of \( p < .05 \). As Table 1.3 displays, the contrasting patterns for significant positive correlations between internal details and relevant steps on the one hand versus significant positive correlations between external details and other steps on the other provide additional evidence that coming up with task-relevant solution steps on the problem-solving task tapped into episodic processes that are also involved in memory and imagination. The correlations between age itself and the different step and detail measures are included in Table 1.3 for the interested reader.
Table 1.3

*Correlations Between Step Measures, Detail Measures, and Age*

<table>
<thead>
<tr>
<th>Variable</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Relevant steps</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Step internal details</td>
<td>.80 ***</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Memory internal details</td>
<td>.49 ***</td>
<td>.66 ***</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 Imagination internal details</td>
<td>.46 ***</td>
<td>.57 ***</td>
<td>.79 ***</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>5 Other steps</td>
<td>-.25 *</td>
<td>-.16</td>
<td>.08</td>
<td>.02</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 Step external details</td>
<td>-.18</td>
<td>-.16</td>
<td>.09</td>
<td>.03</td>
<td>.96 ***</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 Memory external details</td>
<td>.14</td>
<td>.09</td>
<td>-.28 **</td>
<td>-.18</td>
<td>.27 **</td>
<td>.29 **</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 Imagination external details</td>
<td>.13</td>
<td>.19</td>
<td>-.07</td>
<td>-.40 ***</td>
<td>.35 **</td>
<td>.35 **</td>
<td>.57 ***</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>9 Age</td>
<td>-.47 ***</td>
<td>-.39 ***</td>
<td>-.51 ***</td>
<td>-.54 ***</td>
<td>.03</td>
<td>-.01</td>
<td>.13</td>
<td>.24 *</td>
<td>-</td>
</tr>
</tbody>
</table>

*Note. *p < .05. **p < .01. ***p < .001.*

**Discussion**

The results of the present experiment both extend the range of tasks on which our CI-based episodic specificity induction enhances performance in both young and older adults, and also adds to our knowledge of the contribution of episodic retrieval processes to means-end problem solving. Consistent with our predictions, the specificity induction selectively increased the number of relevant steps produced by young and older adults on means-end problem solving with both standard and self-relevant problems, and increased the number of internal details contained in those solution steps. This pattern of findings is consistent with the constructive episodic simulation hypothesis (Schacter & Addis, 2007), in that it shows that an induction that targets episodic processes can impact performance on a cognitive task, means-end problem solving, that does not nominally require episodic retrieval, but where previous evidence (e.g., Sheldon et al., 2011) suggests an important role for retrieving and recombining episodic details. Correlational analyses confirmed that means-end problem solving draws on episodic mechanisms: relevant steps and internal details, which were both significantly increased by the
specificity induction, were positively associated with one another; by contrast, other steps and external details, which were not increased by the induction, were positively associated with each other but not with relevant steps or internal details. Overall, the pattern of results observed here is consistent with, and provides a basis for expanding on, the results and theoretical account offered by Sheldon et al. (2011) and Vandermorris et al. (2013), who also emphasized the contribution of episodic memory and simulation processes to means-end problem solving in both young and older adults.

It should be noted that several previous studies of means-end problem solving have failed to find benefits of manipulations that in some respects resemble the specificity induction used in the present study (e.g., Beaman et al., 2007; Dennis, Astell, & Dritschel, 2012; Goddard, Dritschel, & Burton, 2001). While these studies suggest that a specificity induction may not always be useful for improving means-end problem solving, they differ from the current study in at least two important respects. First, they all used a between-subjects design for the specificity manipulation, where participants were assigned to either a control or a specificity condition. By contrast, we used a within-subjects design, where participants received the control induction and the specificity induction in separate sessions (the order of which was counterbalanced across participants; there was no effect of induction order on the main results). This design feature allowed us to test for change in performance as a function of the induction at both the participant and group level, and reduced variability unrelated to the experimental manipulation. When we examined induction effects between-subjects (e.g., participants who had the specificity induction first versus control induction first), we found that the specificity induction significantly boosted relevant steps in young adults but showed only a trend for such an effect in older adults. Thus, within- vs. between-subjects designs may play some role in differences across studies. Second,
not all specificity manipulations incorporate the same techniques for targeting episodic processes. The specificity induction used here, based on the principles of the CI, provides participants with online feedback, multiple prompts for mental imagery, and a report everything instruction that encourages participants to recall all aspects of the experienced event in as open-ended a framework as possible (Memon et al., 2010). These features of the induction are different from those used in other studies where participants are asked to retrieve specific memories without much further instruction or with more rigid demands about when and how they should do so.

While the specificity induction used here did enhance performance for problem solving, memory, and imagination, it should be noted that, consistent with predictions, the induction did not reduce or eliminate age-related differences on these tasks. Older adults provided fewer relevant steps and fewer internal details on the three tasks compared with young adults, whether they received the specificity induction or not. This finding replicates and extends our previous work with memory and imagination tasks (Madore et al., 2014), and leaves open the question of what sort of training conditions could boost older adult performance to young adult levels— if such conditions exist at all. Based on previous studies cited earlier indicating that personal relevance can affect problem-solving performance in older adults (Artistico et al., 2003, 2010; Hoppmann et al., 2008; Thornton et al., 2013), we had suspected that making the means-end problems self-relevant might differentially improve the performance of older adults. However, we found that making MEPS problems more self-relevant had little effect overall and did not differentially impact performance across age groups. While there may be age-related differences on episodic tasks that cannot be reduced by a specificity induction, future work should continue to test ways of doing so.
It should also be noted that irrespective of induction, young and older adults did not differ in the number of other steps or external details that they generated in problem solving, memory, and imagination. Sheldon et al. (2011) also found that age had no effect on the number of other steps and external details that participants generated in problem solving. Nonetheless, previous research has also found that when older adults provide fewer internal details on memory and imagination tasks, they typically provide a greater number of external details on these tasks compared with young adults (Addis et al., 2010, 2008; Cole et al., 2013; Gaesser et al., 2011, Madore et al., 2014). The pattern of findings we obtained with external details for memory and imagination is important, because it suggests that an age-related decrease in internal details on these tasks is not necessarily a secondary by-product of increased external details. One difference between the current study and others involving memory and imagination is that we required participants to write out their answers rather than verbalizing them aloud (as had Sheldon et al., 2011). Participants also worked on the tasks without any input or probing from the experimenter. The act of writing and generating answers to oneself may have triggered self-regulatory processes that helped participants stay on topic and on task, thereby reducing the number of external details that older adults in particular might have otherwise produced.

It is worth noting that our specificity induction effects were obtained in comparison with a control induction that required participants to provide general impressions of the video they watched prior to the induction. We think that this is an appropriate control for the specificity induction because it requires participants to think and speak about the video, just like the specificity induction, but does not require retrieval of episodic details. It is possible, however, that the impressions control induction results in a suppression of internal details on subsequent tasks relative to a neutral baseline, rather than the specificity induction producing an increase. To
address this possibility, in our previous study (Madore et al., 2014) we compared the specificity induction to a neutral baseline in which young adult participants completed math problems prior to completing memory and imagination tasks. We found a nearly identical pattern of results as with the impressions control: there was a significant increase in internal details on memory and imagination tasks following the specificity induction compared with the math problems control, indicating that our effects reflect an increase above baseline from the specificity induction rather than a suppression below baseline produced by the impressions control. However, because we ran the math problems control only with young adults, it is conceivable that the effects with older adults are attributable to suppression below baseline from the impressions control rather than an increase from the specificity induction. We think that this possibility is highly unlikely because in the present study and in our previous experiment (Madore et al., 2014), the specificity induction has had parallel effects on the performance of young and older adults: nothing in the pattern of data obtained so far would indicate that there is a fundamentally different basis for the effects obtained in the two groups. Moreover, we are not aware of any plausible theoretical rationale for why the basis of the effects should differ fundamentally in young and old. Nonetheless, it would be useful for a future study to examine the effects obtained here using a control condition such as the math problems control we used previously instead of the impressions control.

Taken together, our finding here and in our previous study (Madore et al., 2014) that the specificity induction boosts memory, imagination, and problem-solving internal details in both age groups offers evidence that the specificity induction could be targeting a process that is involved in all three tasks. The constructive episodic simulation hypothesis (Schacter & Addis, 2007) indicates that both remembering and imagining require retrieving episodic details from the
past, though imagining also requires recombining elements of past experiences into novel scenarios (see Schacter et al., 2012, for review). The process of retrieving episodic details appears to be common to memory, imagination, and problem solving, and thus may be the mechanism that is affected by the specificity induction.

This point may also be relevant to studies conducted by Blanchard-Fields and colleagues noted earlier (e.g., Blanchard-Fields et al., 2007) showing that older adults can sometimes exhibit more effective everyday problem solving than young adults. These studies have two major methodological differences from the current one. The first involves a procedure that is frequently used to measure everyday problem solving. For example, in the study by Blanchard-Fields et al. (2007), older and young adults endorsed particular strategies for dealing with various everyday situations among various strategic options that were presented to them, and their responses were correlated with effectiveness ratings of judges for the selected strategies; more effective problem solving was inferred from stronger correlations between the responses of older adults and judges than young adults and judges (for related studies, see Blanchard-Fields, Chen, & Norris, 1997; Cornelius & Caspi, 1987; Hoppmann & Blanchard-Fields, 2010). Such tasks likely place much less demand on episodic retrieval processes than does a generative task such as the MEPS or other problem-solving tasks that require a combination of selection and generation (e.g., Lyons, Henry, Rendell, Corballis, & Suddendorf, 2014), perhaps accounting for the differing patterns of results.

The second difference concerns the scoring criteria for what makes an effective problem solver. Some studies have characterized older adults as more effective problem solvers than young adults even when step generation is examined rather than step endorsement. However, these studies have typically used different coding schemes than the one we used (e.g., Blanchard-
Fields, Jahnke, & Camp, 1995; Blanchard-Fields, Stein, & Watson, 2004; Hoppmann et al., 2008). In these studies, raters scored how well participants’ generated responses fit under different predetermined and qualitative strategic styles (e.g., “problem focused action” or “avoidant thinking and denial”) rather than tabulating quantitative fluency or detail. Here, emphasis is often placed on solution diversity for different types of problems as measured by these strategic styles (see Blanchard-Fields, 2007, and Mienaltowski, 2011, for relevant reviews). Future work should continue to examine what facets of problem-solving scoring are the most useful for measuring effectiveness in young and older adults, and whether different patterns of age-related findings can be explained by which cognitive processes are being targeted and measured via the paradigm, stimuli, and scoring criteria used.

Future work should also examine whether our episodic specificity induction can influence problem-solving performance in everyday life. The effects from our induction appear to be short-lived (i.e., specificity vs. control induction effects were observed on a within-participants basis, and order of induction had no effect on performance), so an important task will be to determine how the induction effect can be strengthened, perhaps through additional booster sessions.

In summary, the current research highlights how episodic specificity can positively impact performance on cognitive tasks ranging from means-end problem solving to memory and imagination in both young and older adults. The efficacy of the specificity induction observed here, together with our previous evidence that the induction can dissociate episodic retrieval from nonepisodic processes (Madore et al., 2014), calls for further use of the specificity induction as a tool to isolate contributions of episodic retrieval processes across a range of
cognitive domains, and also to examine the ways in which malleable episodic processes in young and older adults can enhance functioning on tasks that are important in everyday life.
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**Paper 2:**

Abstract

People produce more episodic details when imagining future events and solving means-end problems after receiving an episodic-specificity induction – brief training in recollecting details of a recent event – than after receiving a control induction not focused on episodic retrieval. Here we show for the first time that an episodic-specificity induction also enhances divergent creative thinking. In Experiment 1, participants exhibited a selective boost on a divergent-thinking task (generating unusual uses of common objects) after a specificity induction compared with a control induction; by contrast, performance following the two inductions was similar on an object association task thought to involve little divergent thinking. In Experiment 2, we replicated the specificity-induction effect on divergent thinking using a different control induction, and also found that participants performed similarly on a convergent-thinking task following the two inductions. These experiments provide novel evidence that episodic memory is involved in divergent creative thinking.

*Keywords*: episodic-specificity induction, episodic memory, creativity, divergent thinking, convergent thinking, imagination
Creativity and Memory: Effects of an Episodic-specificity Induction on Divergent Thinking

Episodic memory is typically thought of as a neurocognitive system that supports the ability to recollect specific personal experiences that happened in a particular time and place (Tulving, 1983, 2002). However, it has become clear that episodic memory also plays an important role in a variety of tasks and functions that do not require recollection of specific past personal experiences. For example, Tulving (2002) argued that episodic memory supports “mental time travel” into the future as well as the past, and indeed, numerous recent studies have provided evidence that episodic memory contributes importantly to imagining or simulating possible future experiences (for recent reviews, see Schacter et al., 2012; Szpunar, 2010). In a related vein, recent studies indicate that episodic memory contributes to solving open-ended or means-end problems that involve hypothetical social situations: More effective solutions to means-end problems are characterized by more episodic detail (Madore & Schacter, 2014; Sheldon, McAndrews, & Moscovitch, 2011).

The starting point for the present investigation comes from evidence suggesting that episodic memory may also contribute to aspects of creative thinking. For example, Duff, Kurczek, Rubin, Cohen, and Tranel (2013) reported that amnesic patients with bilateral hippocampal damage, who exhibit severe impairments of episodic memory, also exhibit impairments on a widely used battery of creativity tasks, the Torrance Tests of Creative Thinking. Consistent with these findings, a recent functional MRI study (Ellamil, Dobson, Beeman, & Christoff, 2012) revealed that brain regions typically associated with episodic memory, including the hippocampus, show increased activity when participants generate creative ideas while designing book cover illustrations. Benedek et al. (2014) obtained similar results when participants performed a task that requires generating alternative uses for common objects.
(the Alternate Uses Task, or AUT; Guilford, 1967), which is thought to tap a key component of creativity known as *divergent thinking* – the capacity to generate creative ideas by combining diverse types of information in novel ways. In related work, Gilhooly, Fioratou, Anthony, and Wynn (2007) found that participants sometimes draw on specific past experiences when performing the AUT, and Addis, Pan, Musicaro, and Schacter (2016) found that performance on the AUT is positively correlated with the amount of episodic detail that young and older adults generate when they imagine scenarios that might occur in their personal futures.

Although the foregoing studies all suggest a link between episodic memory and creativity, the evidence is subject to various caveats and qualifications. Amnesic patients with hippocampal damage typically exhibit deficits in forming both new episodic and new semantic memories (i.e., their declarative memory is impaired; Eichenbaum & Cohen, 2001; Squire, Stark, & Clark, 2004), so it is unclear whether creativity deficits in such patients specifically implicate episodic memory. Evidence for activation in the hippocampus and related structures during generation of creative ideas and divergent thinking (Benedek et al., 2014; Ellamil et al., 2012) is consistent with a role for episodic memory, but does not provide conclusive evidence for it. In the study by Gilhooly et al. (2007), retrieval of particular episodic memories occurred infrequently during the AUT (i.e., less than 10% of the time). And although Addis et al. (2016) observed a link between divergent thinking and the amount of episodic detail in imagined future scenarios, no such link was observed between divergent thinking and the amount of episodic detail in imagined or recalled past events.

To assess more directly the possible contribution of episodic memory to specific forms of creativity, in the present experiments we took a novel approach involving the use of what we have called an *episodic-specificity induction*: brief training in recollecting details of recent
experiences (Madore, Gaesser, & Schacter, 2014; Madore & Schacter, 2014, 2016). The logic of our approach is straightforward: If a cognitive task relies on episodic memory, then performance on that task should be affected by an episodic-specificity induction given prior to the task. By contrast, if performance on a cognitive task does not rely on episodic memory, then task performance should not be influenced by an episodic-specificity induction given prior to the task.

Adopting this logic, we have previously shown that compared with control inductions, an episodic-specificity induction given prior to separate tasks that require remembering past experiences, imagining future experiences, and describing a pictorial scene selectively boosts the number of episodic details that participants generate when they remember the past and imagine the future, but has no effect on the number of semantic details they generate when remembering and imagining, and no effect on the number of details they generate when describing a picture (Madore et al., 2014). An additional study demonstrated that an episodic-specificity induction has no effect on the number of details participants provide when defining and comparing words (Madore & Schacter, 2016). We have also shown that an episodic-specificity induction has beneficial effects on performance on a means-end social problem-solving task (Platt & Spivack, 1975): Participants generated more relevant solution steps after receiving the specificity induction than they did following a control induction (Madore & Schacter, 2014). On the basis of this evidence, we have suggested that the induction could influence episodic-retrieval orientation: a flexible, goal-directed strategy for retrieving an episode in a more or less specific way when presented with a cue (Morcom & Rugg, 2012). In the experiments reported here, we tested whether inducing a bias toward specificity in episodic retrieval affects divergent thinking.

In Experiment 1, we tested and obtained evidence for the hypothesis that performance on the AUT, which is widely used to test divergent thinking, will be enhanced after an episodic-
specificity induction compared with a control induction. We dissociated this effect from performance on a semantic object association task (OAT) that also required generative responses but placed less demand on divergent thinking than does the AUT (Abraham et al., 2012). In Experiment 2, we attempted to replicate this effect and examined whether the beneficial effects of the specificity induction extend to a task that taps a form of creativity known as convergent thinking – the ability to generate the best single solution to a specific problem (Guilford, 1967). In both experiments we also included an imagination task that we have previously shown to be affected by the specificity induction (Madore et al., 2014; Madore & Schacter, 2014, 2016) as a manipulation check to ensure that the specificity induction was operating as expected in the present study.

**Experiment 1 Method**

**Participants**

Twenty-four young adults ($M_{age} = 22.50$ years, $SD_{age} = 3.72$ years; 15 female) were recruited via advertisements at Boston University and Harvard University. All had normal vision and no history of neurological impairment. They gave informed consent, were treated in accordance with guidelines approved by the ethics committee at Harvard University, and received pay for completing the study. Prior to the experiment, we decided on a sample size of 24 because in our previous studies with the induction paradigm (e.g., Madore et al., 2014), this sample size has been adequate for detecting at least a medium-sized effect (i.e., $d = 0.60$) if it exists (power > .80, two-tailed, for a within-subjects design). We stopped data collection after reaching the target of 24 participants. One participant was excluded because of a technical error; thus, our final sample consisted of 23 participants.

**Overview of the Procedure**
Participants came to the lab for two sessions, at least a week apart ($M = 7.35$ days, $SD = 1.11$). In each session, participants (a) watched one of two versions of a short video of a man and woman performing various activities in a house, (b) completed a short filler task and then were questioned about the video according to the protocol of the episodic-specificity induction or control induction, and (c) completed the AUT, OAT, and imagination task. In the second session, participants watched the video they had not seen in the first session, received the induction they had not received in the first session, and performed the same three tasks but with new cues. The order of the inductions and video-induction pairing was counterbalanced across participants.

**Inductions**

Half of the participants were randomly assigned to receive the episodic-specificity induction in the first session (and the control induction in the second session). During this induction, participants were asked questions about the specific contents of the video they had seen; the probes used were based on the Cognitive Interview, a protocol that boosts the number of accurate details that eyewitnesses recall about an event (Fisher & Geiselman, 1992; Memon, Meissner, & Fraser, 2010). The goal of the specificity induction was to help participants recall an experienced event in an episodically specific way. Participants were first told that they were the expert about the video. They were then guided through three mental-imagery exercises, during which they were asked to close their eyes and generate a picture in their mind about the setting, people, and actions they had seen. They were asked to verbalize everything they remembered and to be as specific as possible, and were probed for more detail with open-ended questions about elements they had mentioned.

The other half of the participants were randomly assigned to receive a control induction in the first session (and the specificity induction in the second session). During the control
induction, participants were also asked questions about the contents of the video they had seen. They were first asked to describe their impressions and opinions of the video and were then asked general questions about it (e.g., what adjectives they would use to describe the setting, people, and actions; what equipment might have been used to make the video). There were no mental-imagery exercises in this induction, and participants were not asked to focus on or speak about specific details from the video. We used this as our control because we wanted participants in both inductions to reflect on and speak about the contents of the video they had seen so that an effect of the specificity induction could not be attributed to simply speaking about the video. The main difference between the inductions was the degree to which participants recalled information in an episodically specific way. The inductions were approximately 5 min long (see Appendix for full scripts).

**Main Tasks**

After completing the induction phase in each session, participants typed responses to the AUT, OAT, and imagination task on a computer screen. The three tasks were presented as separate blocks; the order of the object cues within each task and the order of the tasks was randomized across participants and inductions. Seventeen different object cues were presented in each session. The cues were everyday objects (e.g., newspaper, bedsheets, eyeglasses) used in the official test booklet for the AUT (Guilford, Christensen, Merrifield, & Wilson, 1960) and other studies on divergent thinking. Instructions for each task were presented on the screen before participants began the task. These instructions emphasized that participants should report everything in as much detail as possible, so that they would use comparable criteria for the three tasks when reporting the details that came to mind. Participants then responded to a practice cue to ensure that they understood the instructions and response interface. On each of the following
experimental trials, a new object cue appeared on the screen, and participants had 3 min to respond to it. The experimenter asked no questions and provided no inputs during these trials.

**AUT.** Participants listed as many unusual and creative uses as possible for each of five different object cues (plus one practice cue). They were told that although each object cue had a common use, they should generate as many other uses as they could in as much detail as they could (Guilford et al., 1960). The AUT is thought to tap divergent thinking in that participants are asked to flexibly recombine information in novel ways (Guilford, 1967).

**OAT.** Participants saw five different object cues (plus one practice cue) and listed other objects typically associated with each (Abraham et al., 2012). They were instructed to list as many objects as possible, in as much detail as they could. We consider this task a good complement to the AUT because participants generate information in response to object cues for the same amount of time in the two tasks. The main difference is that the OAT is thought to involve divergent thinking and episodic imagery to a lesser degree than the AUT; generating typical semantic associates does not require the same level of flexible thinking as does generating unusual and creative uses for objects, and behavioral and neural dissociations have previously been found between these two tasks (Abraham et al., 2012).

**Imagination Task.** Participants saw four different object cues (plus one practice cue) and generated an event (on one day in one place) that somehow incorporated each cue (Addis, Wong, & Schacter, 2008). Participants were told to generate novel events that could happen to them within the next few years and to imagine the events from a field perspective. They were asked to type everything they could imagine (e.g., people, actions) about each event in as much detail as possible. Given previous findings of a robust effect of the episodic-specificity induction on
performance on the imagination task (Madore et al., 2014; Madore & Schacter, 2014, 2016), we included this task to ensure that the specificity manipulation operated as expected.

**Scoring**

Participants’ responses were scored by one of two raters who were blind to which induction had been received and to all experimental hypotheses. For the AUT, we focused on the number of *categories of appropriate uses* (modification of the scoring system of Addis et al., 2016; Guilford, 1967; Guilford et al., 1960) because appropriateness is the most stringent criterion for a use. Appropriate, or feasible and possible, uses were clustered into distinct categories (e.g., using a safety pin for earrings and for a bracelet charm are appropriate uses that both fall under the category of jewelry; using a shoe to hold an adult and to hold a big-screen television are both inappropriate uses and would not contribute to the score); the number of categories of appropriate uses was summed across cues for each participant. To establish interrater reliability for categories of appropriate uses, we had the raters separately score 10 participants’ practice response (i.e., responses not from the experimental set); after high interrater reliability (Cronbach’s $\alpha = .92$) was established using this set, the raters separately scored the experimental responses.

For the OAT, raters identified responses referring to *objects* and excluded other words, to ensure consistency with previous work and task instructions (Abraham et al., 2012). For example, if the cue was a sock, “washing machine” would be counted as an associated object, and “dirty” would be excluded. The number of objects was summed across cues for each participant. The raters separately scored responses for the experimental trials after high interrater reliability (Cronbach’s $\alpha = .98$) was established using a set of 10 participants’ practice responses, which the raters also scored separately.
For the imagination task, we focused on internal and external details (Levine, Svoboda, Hay, Winocur, & Moscovitch, 2002). Internal details – or episodic details – are any bits of information that are tied to the central event (e.g., people, setting, actions, feelings, objects). External details – or primarily semantic details – are typically any bits of information that are nonepisodic (e.g., facts, commentary). The average number of internal details and the average number of external details were computed across events for each participant. The raters separately scored responses for the experimental trials after high interrater reliability (Cronbach’s α ≥ .92) was established using a set of 12 participants’ practice responses, which the raters also scored separately along these dimensions.

**Experiment 1 Results**

To assess whether the specificity induction had the same effects as in previous research, we examined performance on the imagination task with a 2 (induction: control vs. specificity) x 2 (detail type: internal vs. external) repeated measures analysis of variance (ANOVA). Five responses were excluded (2.71% of the total) for not referring to events falling in the next few years (results were the same when these trials were included). We found no main effect of induction, $F(1, 22) = 0.95, p > .250, \eta_p^2 = .04$; a main effect of detail type, $F(1, 22) = 53.46, p < .001, \eta_p^2 = .71$; and most critically, an interaction between induction and detail type, $F(1, 22) = 9.30, p = .006, \eta_p^2 = .30$. Participants generated more internal details after the specificity induction ($M = 30.30, SE = 2.79$) than after the control induction ($M = 26.12, SE = 2.87$), $t(22) = 2.46, p = .022$, mean difference = 4.18, 95% confidence interval (CI) = [0.66, 7.71], $d = 0.51$. They also generated fewer external details after the specificity induction ($M = 3.44, SE = 1.01$) than after the control induction ($M = 5.81, SE = 1.43$), $t(22) = -2.23, p = .036$, mean difference = -2.37, 95% confidence interval (CI) = [-4.58, -0.16], $d = 0.46$. These results closely replicate our
previous findings (e.g., Madore & Schacter, 2014) and thus indicate that the specificity induction operated as expected.

To address our main hypothesis – that the episodic-specificity induction would enhance performance to a greater extent on the AUT than on the OAT – we conducted another 2 (induction: control vs. specificity) x 2 (task: OAT vs. AUT) repeated measures ANOVA. There was no main effect of induction, $F(1, 22) = 0.51, p > .250, \eta_p^2 = .02$; a main effect of task, $F(1, 22) = 37.77, p < .001, \eta_p^2 = .63$; and, most critically, an interaction between induction and task, $F(1, 22) = 7.18, p = .014, \eta_p^2 = .25$. Participants generated more categories of appropriate uses when they received the specificity induction ($M = 34.48, SE = 3.55$) than when they received the control induction ($M = 28.57, SE = 2.72$), $t(22) = 2.49, p = .021$, mean difference = 5.91, 95% CI = [0.98, 10.85], $d = 0.52$. By contrast, participants generated similar numbers of objects following the two inductions (control: $M = 52.83, SE = 4.49$; specificity: $M = 49.83, SE = 5.19$), $t(22) = -1.05, p > .250$, mean difference = -3.00, 95% CI = [-8.93, 2.93], $d = 0.22$. Figure 2.1 depicts the mean difference score for each task. We found the same selective boost from the specificity induction when we examined other standard scoring dimensions for the AUT: total uses, appropriate uses, and categories of all uses (see Appendix, and Appendix Figure 2.1).
Figure 2.1. Mean difference scores for the Object Association Task (number of objects generated) and the Alternate Uses Task (number of categories of appropriate uses generated) in Experiment 1. Difference scores were calculated by subtracting performance following the control induction from performance following the specificity induction. Thus, a greater positive difference reflects a boost with the specificity induction. Error bars represent 95% confidence intervals.

Experiment 1 Discussion

The results of Experiment 1 show clearly that an episodic-specificity induction significantly boosted performance on a task that involves divergent thinking, the AUT, but had little effect on performance of a task that is thought to involve little divergent thinking, the OAT (Abraham et al., 2012). The specificity induction also produced effects very similar to those observed in our previous studies (Madore et al., 2014; Madore & Schacter, 2014, 2016) on performance of an imagination task, boosting the number of episodic but not semantic details that participants generated when they imagined possible future events. The parallel effects of the specificity induction on divergent thinking and imagination provide novel support for the idea that both draw importantly on episodic retrieval, which is consistent with previous findings and
ideas about creative cognition (Addis et al., 2016; Benedek et al., 2014; Ellamil et al., 2012; Finke, Ward, & Smith, 1992; Gilhooly et al., 2007; Smith, 1995; Smith & Ward, 2012). To our knowledge, this experiment provides the first evidence that an experimental manipulation that specifically increases episodic retrieval also increases a measure of creative thinking (for an example of related evidence, see Storm & Patel, 2014).

In Experiment 2, we addressed three issues raised by Experiment 1. First, we attempted to determine whether we could replicate the effects of the specificity induction on AUT performance. Second, we examined whether the differential effects of the specificity induction and the control induction on AUT performance reflects an increase relative to baseline produced by the specificity induction or a decrease relative to baseline produced by the control induction. The latter induction emphasizes general impressions and thoughts, which conceivably could suppress divergent thinking below the levels that would be attained following a more neutral baseline (see Koutstaal & Cavendish, 2006, and Rudoy, Weintraub, & Paller, 2009, for related evidence of retrieval-orientation manipulations). To address this issue, we replaced the impressions control induction with a task that involved completing math problems. We have previously found that the specificity induction has a similar effect on memory and imagination whether it is compared with the impressions control or the math-problems control (Madore et al., 2014; Madore & Schacter, 2016), and we expected to observe the same effect on the AUT. Third, we asked whether the effects of the specificity induction are limited to divergent thinking, or whether they also extend to the component of creativity known as convergent thinking (which, as we noted earlier, is the ability to generate the best single solution to a specific problem; Guilford, 1967). To address this issue, we used the Remote Associates Test (RAT; Bowden & Jung-Beeman, 1998; Mednick, 1962), a standard measure of convergent thinking.
Experiment 2 Method

Participants

Twenty-four young adults ($M_{age} = 20.75$ years, $SD_{age} = 2.69$ years; 14 female) participated in this study, which had the same recruitment and data collection parameters as Experiment 1. Participants received pay or course credit for the study. One participant was excluded for not following task instructions; thus, our final sample consisted of 23 participants.

Procedure

Participants again came to the lab for two sessions, at least a week apart ($M = 7.30$ days, $SD = 1.46$). The design parameters and stimuli were exactly the same in Experiment 2 as in Experiment 1 with two exceptions. First, the impressions control induction was replaced with a math-packet control induction (as in Madore et al., 2014; Madore & Schacter, 2016). In this condition, after watching the video and completing the filler task, participants worked on math problems. This control condition did not explicitly call for episodic retrieval of any kind and therefore was a more neutral baseline than the impressions control. As in Experiment 1, inductions were approximately 5 min long.

Second, the OAT was replaced with the RAT. Participants saw 30 triads (plus 1 practice triad), each consisting of three words, and were asked to generate a solution word that could be combined with each word in the triad to form a common compound word or phrase (e.g., for eight-skate-stick, the solution word would be figure). We allowed participants 30 s to generate the solution word for each triad, so that equal time would be spent completing the experimental trials for this task and the AUT. Participants viewed 30 different triads (plus 1 practice triad) in the second session. The triads presented were randomized across participants and inductions. We chose 62 triads from Bowden and Jung-Beeman’s (2003) normative list; to avoid floor and
ceiling effects, we limited our selection to triads that between 0% and 46% of individuals could solve in 30 s (average normative success percentages were approximately 27% for the triads in both inductions after randomization).

**Scoring**

Participants’ responses were again scored by one of two raters blind to induction and to all experimental hypotheses. For the AUT, we focused again on categories of appropriate uses (Cronbach’s α = .95) and for the imagination task, we looked at the numbers of internal and external details (Cronbach’s αs ≥ .92). Interrater reliability was not calculated for RAT solution words because we simply summed the number of correct responses across all trials for each participant. Results for other dimensions of AUT performance are presented in Appendix and Appendix Figure 2.2; for these dimensions, we replicated the induction effects found in Experiment 1.

**Experiment 2 Results**

As in Experiment 1, we confirmed that the manipulation had worked as intended by examining performance on the imagination task with a 2 (induction: control vs. specificity) x 2 (detail type: internal vs. external) repeated measures ANOVA. Two responses (1.09% of the total) were excluded for not referring to events falling in the next few years (results were the same when these trials were included). There was no main effect of induction, $F(1, 22) = 1.41, p = .247, \eta_p^2 = .06$; a main effect of detail type, $F(1, 22) = 75.24, p < .001, \eta_p^2 = .77$; and an interaction between induction and detail type, $F(1, 22) = 12.01, p = .002, \eta_p^2 = .35$. Participants generated more internal details after the specificity induction ($M = 32.86, SE = 3.04$) than after the control induction ($M = 26.84, SE = 2.55$), $t(22) = 2.95, p = .007$, mean difference = 6.02, 95% CI = [1.79, 10.25], $d = 0.62$, and they generated fewer external details after the specificity
induction ($M = 5.09, SE = 1.65$) than after the control induction ($M = 9.21, SE = 1.43$), $t(22) = -3.48, p = .002$, mean difference = -4.12, 95% CI = [-6.57, -1.67], $d = 0.73$.

For our main analysis, we conducted another 2 (induction: control vs. specificity) x 2 (task: RAT vs. AUT) repeated measures ANOVA to examine whether (a) the effect of the specificity induction on use generation from Experiment 1 was replicated and (b) whether this effect extended to the RAT. As in Experiment 1, we found a selective boost on AUT performance after participants received the specificity induction. There were main effects of induction, $F(1, 22) = 12.42, p = .002, \eta_p^2 = .36$, and task, $F(1, 22) = 80.54, p < .001, \eta_p^2 = .79$, and a marginal interaction between induction and task, $F(1, 22) = 4.26, p = .051, \eta_p^2 = .16$.

Participants generated more categories of appropriate uses when they received the specificity induction ($M = 26.57, SE = 1.96$) than when they received the control induction ($M = 23.09, SE = 2.05$), $t(22) = 3.67, p = .001$, mean difference = 3.48, 95% CI = [1.51, 5.45], $d = 0.77$.

Participants generated nonsignificantly more correct solution words on the RAT after the specificity induction ($M = 7.83, SE = 0.76$) than after the control induction ($M = 6.91, SE = 0.77$), $t(22) = 1.13, p > .250$, mean difference = 0.91, 95% CI = [-0.76, 2.58], $d = 0.24$. Figure 2.2 depicts the mean difference score for each task.
Figure 2.2. Mean difference scores for the Remote Associates Test (number of correct solution words) and the Alternate Uses Task (number of categories of appropriate uses generated) in Experiment 2. Difference scores were calculated by subtracting performance following the control induction from performance following the specificity induction. Thus, a greater positive difference reflects a boost with the specificity induction. Error bars represent 95% confidence intervals.

General Discussion

The two experiments reported here provide clear and consistent evidence that an episodic-specificity induction that increases the number of episodic details participants generate in imagining future events also boosts their performance on the AUT, a classic test of divergent thinking. In both experiments, the most stringent measure of performance on the divergent-thinking task – categories of appropriate uses – showed a significant increase following the specificity induction compared with the control induction. We observed similar effects of the specificity induction when we compared it with the impressions control induction in Experiment 1 and the math-problems control induction in Experiment 2; these results are consistent with the idea that our AUT findings reflect an increase above baseline produced by the specificity
induction, rather than a decrease produced by a focus on general impressions and thoughts in the impressions induction.

In Experiment 1, the effects of the specificity induction were limited to the divergent-thinking task; no comparable effects were observed on the OAT, which is thought to elicit little divergent thinking (Abraham et al., 2012). Experiment 2 suggests that the observed effects do not extend to convergent thinking: We failed to observe reliable effects of the specificity induction on RAT performance. However, some interpretive caution is required on this point, because the Induction x Task interaction was marginal.

Why does the episodic-specificity induction boost performance on the AUT? We have previously argued (e.g., Madore et al., 2014) that because the specificity induction increases episodic details reported on both memory and imagination tasks, it affects a process tapped by both remembering and imagining. As mentioned in the introduction, one process common to both is episodic-retrieval orientation, a flexible, goal-directed strategy invoked when one is presented with a retrieval cue (Morcom & Rugg, 2012). The episodic-specificity induction biases retrieval towards specificity – that is, toward a focus on episodic details related to places, people, or actions – and may affect performance on subsequent memory, imagination, and divergent-thinking tasks because they all involve creating mental scenarios that contain details like those emphasized during the induction (for additional theoretical elaboration, see Schacter & Madore, 2016). By contrast, the OAT and RAT focus more on generating semantic information, and hence performance on these tasks shows little effect of the specificity induction.

An interesting question concerns whether adopting a retrieval orientation biased toward specificity enables participants to retrieve more past episodes that involve alternate uses of objects, more readily retrieve and recombine episodic details that support constructing entirely
new uses of objects, or both. Using a procedure in which participants label uses on the AUT as “old” or “new” ideas, other researchers (Benedek et al., 2014; Gilhooly et al., 2007) have obtained results indicating that new ideas arise from recombining semantic information and imagery. We collected preliminary data suggesting that the specificity induction may boost both old and new ideas (see Appendix) but the issue requires more systematic investigation.

More broadly, episodic specificity affects performance on tasks that tap imaginative functions beyond divergent thinking. We recently found that it increases the number of relevant steps that individuals generate when solving means-end problems concerning hypothetical social scenarios (Madore & Schacter, 2014). Future work should use the specificity induction as a tool to identify the contribution of episodic processes to performance of other cognitive tasks that are not usually thought of as episodic memory tasks, yet nonetheless rely on constructive uses of episodic retrieval.
Author Contributions

All three authors developed the study concept and contributed to the study design. K. P. Madore performed data collection and statistical analyses under supervision of D. R. Addis and D. L. Schacter. K. P. Madore and D. L. Schacter drafted the manuscript, and D. R. Addis provided critical revisions. All three authors approved the final version of the manuscript for submission.

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Declaration of Conflicting Interests

The authors describe that they had no conflicts of interest with respect to their authorship or the publication of this article.

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Paper 3:

Abstract

Recent behavioral work suggests that an episodic specificity induction – brief training in recollecting the details of a past experience – enhances performance on subsequent tasks that rely on episodic retrieval, including imagining future experiences, solving open-ended problems, and thinking creatively. Despite these far-reaching behavioral effects, nothing is known about the neural processes impacted by an episodic specificity induction. Related neuroimaging work has linked episodic retrieval with a core network of brain regions that supports imagining future experiences. We tested the hypothesis that key structures in this network are influenced by the specificity induction. Participants received the specificity induction or one of two control inductions and then generated future events and semantic object comparisons during fMRI scanning. After receiving the specificity induction compared with the control, participants exhibited significantly more activity in several core network regions during the construction of imagined events over object comparisons, including the left anterior hippocampus, right inferior parietal lobule, right posterior cingulate cortex, and right ventral precuneus. Induction-related differences in the episodic detail of imagined events significantly modulated induction-related differences in the construction of imagined events in the left anterior hippocampus and right inferior parietal lobule. Resting-state functional connectivity analyses with hippocampal and inferior parietal lobule seed regions and the rest of the brain also revealed significantly stronger core network coupling following the specificity induction compared with the control. These findings provide evidence that an episodic specificity induction selectively targets episodic processes that are commonly linked to key core network regions, including the hippocampus.

Keywords: episodic specificity induction, imagination, hippocampus, core network, fMRI
Significance Statement

Recent behavioral studies using an episodic specificity induction – training in recollecting details of past experiences – have suggested a role for episodic memory in imagining future events, solving problems, and thinking creatively. The present fMRI study examines the brain regions impacted by the specificity induction. The experiment shows that receiving a specificity induction led to increased activity in key brain regions previously implicated in detailed event construction, including the hippocampus and inferior parietal lobule, when participants imagined future events. These results provide insights into the influence of episodic memory beyond simple remembering, and may help to guide potential applications for individuals from populations characterized by overgeneralized memory and imagination, such as healthy aging and clinical depression.
Episodic Specificity Induction Impacts Activity in a Core Brain Network During Construction of Imagined Future Experiences

Numerous recent studies have revealed striking overlap in the neural and cognitive processes that support remembering past experiences and imagining future experiences or novel scenes (reviewed in Mullally & Maguire, 2014; Schacter et al., 2012). According to the constructive episodic simulation hypothesis (Schacter & Addis, 2007), similarities between remembering and imagining reflect to a large extent the contributions of episodic memory to both processes (Tulving, 2002). However, some evidence indicates that these similarities can also reflect the influence of nonepisodic processes, such as descriptive ability or narrative style, that influence remembering and imagining (Gaesser, Sacchetti, Addis, & Schacter, 2011).

We recently developed an experimental approach to distinguishing episodic and nonepisodic influences on remembering and imagining that we refer to as an episodic specificity induction: brief training in recollecting episodic details of recent experiences (reviewed in Schacter & Madore, 2016). After receiving an episodic specificity induction (vs. a control induction), participants subsequently remembered past and imagined future experiences with increased episodic but not semantic detail, and the specificity induction had no effect on details generated during tasks that do not draw on episodic memory, such as describing a picture (Madore, Gaesser, & Schacter, 2014) or defining and comparing words (Madore & Schacter, 2016). We have also shown that the specificity induction boosts performance on such tasks as means-end problem solving (Jing, Madore, & Schacter, 2016; Madore & Schacter, 2014) and divergent creative thinking (Madore, Addis, & Schacter, 2015) that have also been linked previously to episodic memory. Based on these results, we have proposed that the specificity induction biases participants to adopt a specific retrieval orientation – i.e., to focus on episodic
details related to places, people, or actions – and that this heightened focus on episodic details impacts performance on tasks that involve constructing mental events or scenes containing details like those emphasized during the specificity induction (Schacter & Madore, 2016).

Although our previous work has examined the cognitive processes impacted by the specificity induction, our characterization of those processes, together with previous research concerning the neural underpinnings of remembering and imagining, leads to predictions regarding the neural processes that should be influenced by the induction. Previous studies have indicated that remembering and imagining rely on a common core network of brain regions (Benoit & Schacter, 2015; Schacter, Addis, & Buckner, 2007) that overlaps substantially with the default network (Andrews-Hanna, Reidler, Sepulcre, Poulin, & Buckner, 2010; Andrews-Hanna, Saxe, & Yarkoni, 2014; Buckner, Andrews-Hanna, & Schacter, 2010; Yeo et al., 2011).

According to a recent meta-analysis (Benoit & Schacter, 2015), this core network includes regions within all of the key segments of the default network, including its medial temporal lobe (MTL) subsystem (hippocampus, parahippocampal and retrosplenial cortex, inferior parietal lobe, ventromedial prefrontal cortex), which has been linked with the construction of imagined events or scenes, and its dorsomedial prefrontal subsystem (dorsomedial prefrontal cortex, dorsolateral prefrontal cortex, lateral temporal cortex), which has been linked with social components of events (Andrews-Hanna et al., 2010).

In light of our behavioral characterization of the specificity induction, we hypothesize and test here that (i) this induction should impact primarily structures within the MTL subsystem, in particular those regions – the hippocampus and inferior parietal lobule – that have been linked previously to detailed episodic retrieval and to imagining of specific (vs. general) future events (Addis, Cheng, Roberts, & Schacter, 2011; Addis & Schacter, 2008; Guerin,
Robbins, Gilmore, & Schacter, 2012). Moreover, our behavioral characterization of the specificity induction as affecting primarily participants’ retrieval orientation when they construct mental events or scenes leads us to predict that (ii) these effects will be observed mainly during the initial construction of an event. We adopted a construction-elaboration paradigm used in previous studies of remembering and imagining (Addis, Wong, & Schacter, 2007) to test this hypothesis, whereby an initial phase of event construction is distinguished from later event elaboration. To maximize our power to detect possibly subtle effects of the specificity induction, we replaced the remembering condition with additional imagining trials. We also hypothesized that (iii) induction-related differences in the episodic detail of imagined events from a postscan interview would modulate induction-related differences in neural activity in the construction of imagined events during scanning in the hippocampus and inferior parietal lobule. Resting-state functional connectivity analyses with hippocampal and inferior parietal lobule seed regions and the rest of the brain were also performed to test whether (iv) stronger coupling between these regions and other core network areas would be observed following the specificity relative to control induction.

To address our predictions, participants completed a within-subjects fMRI paradigm in one session (Appendix Figure 3.1). In each segment in the scanner, participants (i) viewed one of two short videos, completed a short filler task, and then received either the episodic specificity induction or one of two control inductions; (ii) viewed 36 object cues after receiving an induction, and, for each cue, generated an imagined event or an object size sentence and definitions (i.e., the main tasks); and (iii) completed a resting-state scan. Different stimuli were used in each segment for the induction and main tasks (counterbalanced across participants). For each of the main task scanning trials, we collected reaction time to construct, and detail and
engagement ratings. Following scanning, participants verbally generated their thoughts for each main task cue and completed additional ratings. A similar approach was tested in a behavioral pilot in which induction effects were observed (Madore & Schacter, 2016).

Results

Main Task Results

Imagining Future Events

Behavioral variables collected in the scanner (reaction time and subjective ratings for detail and engagement; Appendix Table 3.1) did not vary as a function of induction ($F_{1,31} \leq 1.82$, $P$ values $\geq 0.19$). Critically, generative responses (Appendix Table 3.2) collected in the postscan interview indicated that participants generated significantly more total details for imagined events – but not object comparisons – that followed the specificity induction compared with the control ($F_{1,31} = 8.87$, $P = 0.006$; $\eta_p^2 = 0.22$); critically, this increase in total details for imagined events was driven by a selective and significant boost in the production of episodic details – but not semantic details – following the specificity induction relative to the control ($F_{1,31} = 24.12$, $P < 0.001$; $\eta_p^2 = 0.44$). No induction-related differences were exhibited for any type of detail generated on object comparisons ($F_{1,31} \leq 1.05$, $P$ values $\geq 0.31$). Results of the postscan ratings appear in Appendix Table 3.3.

Following both inductions, participants exhibited significant and broad core network activation for imagining events over object comparisons during the construction phase and elaboration phase ($P < 0.001$, uncorrected and $k \geq 65$ voxels, yielding a corrected threshold of $P < 0.05$; Figure 3.1 and Appendix Table 3.4). These findings replicate previous work (Addis, Cheng et al., 2011; Addis et al., 2007; Benoit & Schacter, 2015) and indicate that participants were completing the main tasks in the scanner as expected.
Figure 3.1. Main task results for (A) constructing and (B) elaborating on imagined events (relative to the semantic object task) following the control induction and following the specificity induction at the threshold of \( P < 0.001 \), uncorrected (with an extent threshold of 65 voxels, yielding a corrected threshold of \( P < 0.05 \)). This pattern of findings closely parallels that of the core network, which overlaps with the default network (Andrews-Hanna et al., 2010, 2014; Benoit & Schacter, 2015; Buckner et al., 2008; Yeo et al., 2011).

Critically, participants exhibited significantly greater activation in several core network regions following the specificity induction compared with the control for constructing imagined events over object comparisons (\( P < 0.001 \), uncorrected and \( k \geq 65 \) voxels, yielding a corrected threshold of \( P < 0.05 \); Figure 3.2 and Appendix Table 3.5). These included several core network regions (Benoit & Schacter, 2015): the left anterior hippocampus, right inferior parietal lobule, right posterior cingulate cortex, and right ventral precuneus. To further characterize the results, descriptive plots for percent signal change in these regions and the others that emerged are presented in Figure 3.2. Note that error bars are not plotted as a result of potential noise, and significance tests were not run on these data (Kriegeskorte, Simmons, Bellgowan, & Baker, 2009; Vul, Harris, Winkielman, & Pashler, 2009).
Figure 3.2. MTL subsystem regions (and other regions within and outside of the core network) with stronger recruitment for constructing imagined events (relative to the semantic object task) following the specificity induction compared with the control at the threshold of $P < 0.001$, uncorrected (with an extent threshold of 65 voxels; yielding a corrected threshold of $P < 0.05$). The $y$ axis of each chart depicts percent signal change (extracted from the region’s peak voxel); the red bars depict imagine construction and the blue bars depict object construction. L, left; R, right.

To further link the key induction-related behavioral and brain results, the detail scores obtained from the postscan interview were entered as a modulator of interest during the construction phase of imagined events and object comparisons in the scanner. For the detail index, episodic details on the imagine task and on-topic, factual information on the objects task were used. Critically, induction-related differences in detail were significantly related to induction-related differences in neural activity during the construction of imagined events over object comparisons following the specificity induction compared with the control; these parametric modulation effects were evident in the left anterior hippocampus, right inferior parietal lobule, and right ventral precuneus, as well as the right anterior hippocampus and other regions ($P < 0.005$, uncorrected and $k \geq 10$ voxels; further details regarding thresholding are
provided in *Materials and Methods*). This analysis (Appendix Figure 3.2 and Appendix Table 3.6) indicates that the key induction-related behavioral effect (i.e., greater episodic details for imagined events following specificity vs. control) modulated the key induction-related neural effect (i.e., greater activation in the left anterior hippocampus and right inferior parietal lobule for imagined events following the specificity vs. control).

The induction-related results were selective to the construction phase; no significant activations in any direction were evident for elaboration. There were also no significant activations for the opposite contrasts of task and induction.

**Resting-state Analyses**

To more fully characterize the influence of the induction manipulation, we examined its effects on subsequent resting-state connectivity of key core network regions that emerged from the main task analyses: the left anterior hippocampus ($xyz$, -34, -16, -12) and right inferior parietal lobule ($xyz$, 38, -32, 36). Following the specificity induction relative to the control (Figure 3.3 and Appendix Table 3.7), the left anterior hippocampal seed served to significantly boost connectivity with the right parahippocampal gyrus, and the right inferior parietal lobule seed served to significantly boost connectivity with the left parahippocampal gyrus, left superior medial frontal gyrus, and left anterior cingulate cortex ($P < 0.001$, uncorrected and $k \geq 38$ voxels, yielding a corrected threshold of $P < 0.05$). These results suggest short-term, functional reorganization in the core network as a function of induction. No activations survived the opposite induction contrast.
Figure 3.3. Resting-state functional connectivity results following the specificity compared with the control induction for (A) a left anterior hippocampal seed region (extracted from a peak voxel \(xyz\) of \(-34, -16, -12\)) and (B) a right inferior parietal lobule seed region (extracted from a peak voxel \(xyz\) of \(38, -32, 36\)) and the rest of the brain at a threshold of \(P < 0.001\), uncorrected (with an extent threshold of 38 voxels, yielding a corrected threshold of \(P < 0.05\)).

Discussion

In the present fMRI study, we established the neural signature of an episodic specificity induction for imagining future events. Previous research has suggested that a core network of brain regions comes online when individuals remember past and imagine future events (Benoit & Schacter, 2015), and that this network can be segmented into a MTL subsystem linked to the construction of events or scenes and a dorsomedial prefrontal subsystem linked to the social and self-referential components of these events or scenes (Andrews-Hanna et al., 2010). We found that participants did indeed activate the core network when generating imagined future events over semantic object comparisons after receiving the specificity and control inductions. Critically, and as hypothesized, receiving the specificity induction compared with either control also led to significantly increased activity in key regions of the MTL subsystem of the core network, including the hippocampus and inferior parietal lobule, when generating future events relative to object comparisons. Postscan responses suggested that the specificity induction was operating as expected in the scanner: significantly more episodic but not semantic details were generated for imagined events following the specificity induction compared with the control, with no differences in any type of detail for object comparisons. This pattern of behavioral
results replicates and extends previous work (Madore & Schacter, 2016), and confirms that differential neural patterns of activity were linked to the experimental manipulation participants received. Further support for a behavior-brain link was established via a parametric modulation analysis, which indicated that induction-related differences in episodic detail in imagined events from the postscan interview significantly modulated induction-related neural activity in the left anterior hippocampus and right inferior parietal lobule (and other regions) during imagine trials in the scanner. This latter finding should be taken as preliminary, however, as it did not emerge with more conservative statistical thresholds (corrected for multiple comparisons; Materials and Methods).

The finding that neural induction effects were limited to the construction phase of imagining future events and did not extend to elaboration is also in line with our hypotheses. We have previously suggested (Schacter & Madore, 2016) that the specificity induction leads individuals to focus on episodic details related to places, people, and actions of an event or scene and thus targets the process of retrieval orientation – a goal-directed strategy for retrieving an episode in a more or less specific way when presented with a cue (Morcom & Rugg, 2012). The neural induction effects we observed in the MTL subsystem during construction – but not elaboration – suggest that the specificity induction may help participants to adopt a specific retrieval orientation that is used on later tasks that also require participants to construct a mental event or scene that contains details like those emphasized during the induction. This account of the data can also be situated under the theoretical framework of an event model, which is composed, in part, of elements of episodic memory that are bounded in space and sequential time involving physical and figural entities (Radvansky & Zacks, 2014). The induction, by facilitating a specific retrieval mode, may help individuals to internally trigger the construction or assembly
of a mental event model that is filled with specific details. This notion of construction in an event model also fits with the recent idea that the hippocampus supports the encoding and retrieval of temporal sequences that constitute an event (Davachi & DuBrow, 2013; Eichenbaum, 2013; Ranganath & Hsieh, 2016).

In support of this view, we found increased activity in the left anterior hippocampus during the construction phase of imagination following the specificity induction relative to the control. This finding converges with evidence suggesting that the anterior hippocampus supports the relational processing of elements of an encoded memory at retrieval (Giovanello, Schnyer, & Verfaellie, 2009; Nielson, Smith, Sreekumar, Dennis, & Sederberg, 2015), as well as the flexible recombination of previously learned elements into a novel representation (Preston, Shrager, Dudukovic, & Gabrieli, 2004). Evidence has also indicated that the anterior hippocampus tracks the content (vs. the temporal ordering) of imagined events (D’Argembeau, Jeunehomme, Majerus, Bastin, & Salmon, 2015) and the specificity (vs. abstractness) of imagined events (Addis, Cheng et al., 2011; Addis & Schacter, 2008) and autobiographical plans (Spreng, Gerlach, Turner, & Schacter, 2015). The constructive episodic simulation hypothesis (Schacter & Addis, 2007) posits that imagining future events involves extracting and recombining elements of previous memories into a novel scenario, and that these cognitive processes are in part dependent on the hippocampus. Under this framework, the induction may lead to increased anterior hippocampal activity when participants imagine future events by ramping up processes involved in the extraction and relational recombination of elements of previous memories into a novel scenario.

Nonetheless, we are cautious in interpreting too heavily the precise location of increased induction-related activity within the hippocampus. Several factors can influence the location of
hippocampal activity (reviewed in Viard, Desgranges, Eustache, & Piolino, 2012), and work from the spatial cognition domain on the anterior-posterior hippocampal axis suggests that the anterior hippocampus supports coarse-grained (vs. fine-grained) representations, at least those that are spatial (Zeidman, Lutti, & Maguire, 2015; Zeidman, Mullally, & Maguire, 2015; reviewed in Poppenk, Evensmoen, Moscovitch, & Nadel, 2013). The anterior hippocampus has also been associated with the encoding of novel simulations into memory (Martin, Schacter, Corballis, & Addis, 2011). However, if the induction simply helped participants to encode novel representations into memory, we would have expected to observe increases in details generated in the postscan for cues involving imagined events and object definitions following the specificity induction, but we found effects only for imagined events. Future work should continue to identify subregions of the hippocampus that map onto subcomponents of imagining events or scenes using high-resolution fMRI (discussed in Addis & Schacter, 2012), as well as the role of lateralization in the hippocampus and other brain regions during simulation (Arzy, Molnar-Szakacs, & Blanke, 2008).

We also found increased induction-related neural activity in the right inferior parietal lobule when participants constructed imagined future events. Like the anterior hippocampus, the inferior parietal lobule has been implicated in studies in which participants imagine events in more specific (vs. more general) detail (Addis, Cheng et al., 2011), particularly during the construction phase (Addis et al., 2007). The inferior parietal lobule is also part of the MTL subsystem that is thought to track with episodic memory, event imagination, and scene content (Andrews-Hanna et al., 2010), and activity in this region has been associated with the successful retrieval and integration of perceptual details from memory (Guerin et al., 2012). In a related topic, we found evidence that activity in the right ventral precuneus increased following the
specificity induction relative to the control for imagined events. The inferior parietal lobule and ventral precuneus have recently been linked to mental orientation in space, time, and person (Peer, Salomon, Goldberg, Blanke, & Arzy, 2015). We have also previously found that the right ventral precuneus exhibits increased activity during repeated future simulations (e.g., Szpunar, St. Jacques, Robbins, Wig, & Schacter, 2014) but it is unclear whether these changes are specifically related to changes in event detail.

In addition, we found preliminary evidence suggesting that the specificity induction may impact the processing of contextual scene details and more self-relevant, social details into a novel simulation. Following the specificity induction compared with the control, resting-state functional connectivity analyses showed stronger coupling between the left anterior hippocampal seed and a key region linked with scene processing (i.e., right parahippocampal gyrus; Benoit, Szpunar, & Schacter, 2014; Hassabis, Kumaran, & Maguire, 2007; Szpunar et al., 2014), and between the right inferior parietal lobule seed and both scene (i.e., left parahippocampal gyrus) and social regions (i.e., left superior medial frontal gyrus; Andrews-Hanna et al., 2010; Szpunar et al., 2014), as well as the left anterior cingulate cortex. The anterior cingulate cortex is part of the frontoparietal control network (Vincent, Kahn, Snyder, Raichle, & Buckner, 2008) that has been associated with emotional processing and executive functions including cognitive control. However, because resting-state analyses involve measuring neural activity in the absence of task demands, we are cautious about interpreting these induction-related findings too heavily. Because the induction affected neural functioning during task performance that immediately preceded the resting-state scans, it is unclear whether the short-term reorganization of functional networks in the absence of task demands is due to (i) the induction manipulation or (ii) the specific neural processing that emerged as a result of the induction during the main tasks.
Although the specific processing that emerged as a result of the induction could plausibly have the same effect as the induction itself, future work should investigate this issue more systematically by having participants perform the resting-state scans immediately after receiving an induction.

Another caveat of the present study is that we did not obtain differences in detail ratings in the scanner as a function of induction. Participants could have plausibly rated their simulations as more detailed in the scanner following the specificity induction compared with the control. Nonetheless, previous work has suggested that subjective rating scales may not be the most sensitive measure of episodic detail. Studies have found that subjective ratings of detail and vividness for episodic simulations are higher in older adults than in young adults or are similarly rated (Addis, Musicaro, Pan, & Schacter, 2010; Addis, Roberts, & Schacter, 2011; Addis, Wong, & Schacter, 2008; Cole, Morrison, & Conway, 2013), yet objective scoring measures routinely show that older adults produce fewer episodic details in their narratives compared with young adults (Addis et al., 2010; Cole et al., 2013). Despite the complexities associated with measuring event detail, this outcome allows us to interpret the data patterns knowing that the imagined events after both inductions were, at least subjectively, matched on features that can contribute to the behavioral and neural expressions of simulation.

Taken together, the results suggest that the cognitive processes that are isolated and enhanced via the episodic specificity induction behaviorally are linked to key neural regions in the core network implicated in remembering and imagining events, including the hippocampus. Future work should continue to investigate the contributions of episodic memory, from both behavioral and neural perspectives, to cognitive tasks that could involve episodic elements of past experiences, such as imagination, problem-solving, and creativity. These findings may also
help to guide interventions for individuals from populations characterized by overgeneralized memory and imagination, such as healthy aging (Addis et al., 2008) and clinical depression (Hach, Tippett, & Addis, 2014; MacLeod & Conway, 2007; Williams et al., 1996), that have been shown to benefit from specificity inductions in previous behavioral research (Madore et al., 2014; Neshat-Doost et al., 2013).

**Materials and Methods**

**Participants**

Thirty-two young adults (mean age, 21.0 y; SD, 2.38; 20 female) participated in the study, recruited via advertisements at universities in Boston, MA. All participants were right-handed and fluent in English and had normal or corrected-to-normal vision and no history of neurological or psychological impairment. They all gave written informed consent and were treated in a manner approved by Harvard University’s ethics committee. An additional seven participants were excluded for excessive movement or task noncompliance.

**Induction Materials and Procedure**

An overview of the scanning and postscan design is provided in Appendix Figure 3.1. To begin each of the two main segments in the scanner, participants received an induction after viewing a ~2-min video of a man and woman performing kitchen activities and completing a 2-min number judgment filler task on a computer screen. Participants viewed the computer screen via a mirror attached to the scanner head coil and scanner-compatible headphones. All participants received the episodic specificity induction in one of the two segments; for the other segment, half of the participants were randomly assigned to receive the impressions control induction and half received the math control induction. Participants were randomly assigned to receive the specificity induction first or one of the two control inductions first, and induction
order was counterbalanced across participants. Participants were in the scanner for this portion of the study but were not scanned, heard induction questions over a loud speaker, and responded out loud. Inductions with interviews were audio-recorded (Madore et al., 2014, includes full scripts); all inductions took on average 5 min and did not differ significantly in length.

The episodic specificity induction consisted of a question set based on the cognitive interview (Fisher & Geiselman, 1992), a forensic protocol that boosts accurate details associated with eyewitness events. Participants were told that they were the chief expert about the video, and then responded to three mental imagery probes to report everything about the video’s setting, people, and actions as specifically and in as much detail as possible. Open-ended follow-up questions were used to probe generated details. Information on the control inductions is provided in Appendix.

fMRI Materials and Procedure

In each of the two segments following the induction, participants completed four runs of functional neuroimaging: three task runs during which they viewed 36 total object cues of the main tasks in an event-related design and one resting-state run. Three practice trials of each main task were completed to ensure understanding.

Main Tasks

Each main task run was 7 min, 34 s in duration and began and ended with 16 s of fixation. Within each run, six imagined event trials and six object comparison trials were randomly presented with the construction-elaboration paradigm for 20 s each (Addis, Cheng et al., 2011; Addis et al., 2007). Following each trial, two ratings appeared (4 s each), and then a rest period during which a basic odd/even number judgment task was performed (mean, 6 s; jittered at 4 s, 6
s, or 8 s). Participants made responses during the main tasks via an MR-compatible five-button response box in their right hand.

Eighteen total imagined event trials were included per segment. For each trial, the word “imagine” appeared on one line of the screen, followed by the instruction “near future event” on the next line, followed by the cue in capital letters on the third line. As in previous work (Addis, Cheng et al., 2011; Addis et al., 2007; Madore & Schacter, 2016), participants were instructed to silently generate a novel future event or scenario that could happen to them within the next few years in as much detail as possible that was somehow related to the cue, plausible, new, viewed from a field perspective, and specific to one time and place. By using the construction-elaboration paradigm, participants were instructed that they should press their thumb when they had constructed each imagined event, and, after pressing their thumb, should elaborate or fill in all the details of the event until the trial was over. At the end of each trial, the screen changed and participants rated (i) how detailed the mental image of their imagination was (from 1 to 5, with 1 indicating no/few details and least vivid to 5 indicating many details and most vivid) and (ii) whether they stayed engaged on task (either 1 indicating yes or 2 indicating no). Eighteen total object comparison trials were also included per segment and matched with imagined events for task structure and response mode (see Appendix). Although both main tasks required generative search and retrieval (Conway & Pleydell-Pearce, 2000), only the imagine task required generating episodic content.

**Resting-state**

In each of the two segments following the main task runs, participants completed a resting-state scan for 7 m, 13 s in which they viewed a black background with a white fixation cross.
**Postscan Interview**

Immediately after scanning, participants completed a postscan interview (Addis, Cheng et al. 2011; Addis et al., 2007). Participants viewed each object cue from the scanner (in the same order to reduce cognitive load) and verbally reported whatever they had thought about (without adding new details). Each trial was completed in a self-paced manner without input or probing from the experimenter, and following each trial, participants completed four ratings for imagined events and two for object comparisons (Appendix provides information on additional ratings). Pilot testing before the study commenced ($n = 2$) showed that participants could describe what they had silently generated.

Participants’ actual verbal reports for imagined events and object comparisons were audio-recorded for later transcription and scoring with the autobiographical interview procedure (Levine, Svoboda, Hay, Winocur, & Moscovitch, 2002). For imagined events, bits of information contained in these verbal reports were segmented. Each detail was classified as either episodic or semantic to the main event described. Episodic details included the who, what, where, and when elements of the central event specific in time and place; semantic details included factual information, off-topic and repetitive information, and commentary. For object comparisons, bits of information were also segmented and scored into detail subcategories (as in Madore & Schacter, 2016). The main measure of interest was elements of the central object definitions that were on-task and meaningful; extraneous details included elements of the reports that were off-topic, repetitive, not meaningful, or commentary. Two independent raters blind to all experimental hypotheses and the induction conditions scored the verbal reports after completing an interrater reliability assessment of 20 trials of imagined events and object comparisons from the pilot subjects not included in the main study. Reliability was high across
scored measures (Cronbach’s standardized $\alpha \geq .90$). Additional information on scoring is provided in Appendix.

**fMRI Acquisition, Preprocessing, and Analysis Parameters**

**Main Task Approach**

Scanning and preprocessing parameters for the main tasks are provided in Appendix. Preprocessed data were statistically analyzed by using the general linear model (examples of this approach are provided in Addis, Cheng et al., 2011; Addis et al., 2007). Each participant’s blood oxygen level-dependent (BOLD) response for (i) construction and (ii) elaboration were modeled separately for each imagined event trial and each object comparison trial by using SPM12’s canonical hemodynamic response function (hrf) with first-level fixed-effects models. One first-level model was created for the control induction runs and one for the specificity induction runs. The hrf for construction (i.e., regressors for imagine and object construction) was applied 2 s after cue onset, and the hrf for elaboration (i.e., regressors for imagine and object elaboration) was applied 2 s after the participant made a button press (mean elaboration [jittered] = 8.65 s across tasks). The entire 20-s duration of each trial was not modeled to reduce contamination effects. The BOLD response for the rating phase of each trial was also modeled at the rating onset (i.e., regressors for imagine and object rating), and subject-specific movement parameters for each run were added as covariates of no interest.

To examine whether participants displayed typical neural patterns of performance on the imagined event and object comparison tasks and to test for any induction-related effects, we computed contrasts for (i) imagine construction > object construction and (ii) imagine elaboration > object elaboration. At the second level, we entered the contrast images into random-effects one-sample $t$ tests for each induction separately for (i) construction and (ii)
elaboration to ensure that typical neural patterns of core network recruitment were observed after each induction and phase (Addis, Cheng et al., 2011; Addis et al., 2007; Benoit & Schacter, 2015). Critically, at the second level, we also entered contrast images into random-effects paired t tests whereby each pair of scans included the respective control induction contrast image and specificity induction contrast image for each participant separately for (i) construction and (ii) elaboration. An interaction effect was also computed (Appendix).

The significance threshold and minimum cluster size ($P < 0.001$, uncorrected and $k \geq 65$ voxels), equivalent to $P < 0.05$ corrected for multiple comparisons, was determined via Analysis of Functional NeuroImages’ (AFNI) 3dClustSim program (in June 2015) by using a Monte Carlo simulation (10,000 iterations) within the 3D whole-brain search volume (179,380 2-mm$^3$ voxels) to estimate the overall probability of false positives (as in Gaesser, Spreng, McClelland, Addis, & Schacter, 2013; Martin et al., 2011). To minimize the possibility of false positives with cluster thresholding in functional neuroimaging analyses (Eklund, Nichols, & Knutsson, 2016), we used a version of the 3dClustSim program that is free from technical problems uncovered in previous versions, and that incorporated the correct smoothing value (i.e., derived from the group residual mean-square images) with a conservative cluster-defining threshold (i.e., $P < 0.001$ versus $P < 0.01$).

Next, we performed a parametric modulation analysis in SPM by including regressors in the first-level models outlined earlier for control and specificity runs separately (as in Addis & Schacter, 2008). Although we used a cognitive experimental manipulation – a feature of the methodological design that should pinpoint in a systematic way the impact of the behavioral induction on neural performance – we took this additional step to relate behavioral and neural data. We entered, trial-by-trial, a detail score for each imagined event and object comparison.
obtained in the postscan interview as a covariate of interest for each respective imagine
construction and object construction trial (i.e., regressors for imagine detail and object detail).

We focused on the behavioral detail index and the construction phase fMRI data because results
indicated induction-related effects on these key outputs. The detail score covariate was modeled
linearly, represented the orthogonal contribution of detail in the absence of any other covariates,
and was mean-centered according to SPM algorithms. We contrasted the modulatory effects of
imagine detail covariate > object detail covariate during the construction phase at the first level.
At the second level, we entered these first-level contrast images into a random-effects paired t
test whereby each pair of scans included the respective control induction contrast image and
specificity induction contrast image for each participant. This analysis allowed us to identify
which regions during construction showed differential activity following the specificity induction
compared with the control as modulated by an index of detail for imagined events over object
comparisons.

A significance threshold of $P < 0.005$, uncorrected with an extent threshold of 10
contiguously activated voxels (2-mm$^3$) was applied for whole-brain testing of the parametric
modulation (the same or similar thresholds were used for parametric modulation analyses in
Addis & Schacter, 2008; De Brigard, Addis, Ford, Schacter, & Giovanello, 2013; Holland,
Addis, & Kensinger, 2011). Although the results of this particular analysis did not survive more
stringent corrected thresholds, we included it as preliminary induction-related evidence of a
behavior-brain link (a theoretical and quantitative justification of the threshold is provided in
Lieberman & Cunningham, 2009).

**Resting-state Approach**
For the resting-state scans, we performed a series of preprocessing steps (including global signal regression) on the raw data followed by a series of functional connectivity-specific preprocessing steps (Appendix). For the analyses (based on Biswal, Yetkin, Haughton, & Hyde, 1995; Van Dijk et al., 2010), seed regions in the hippocampus and inferior parietal lobule (i.e., a 6-mm sphere centered on the region’s peak voxel) were selected on the basis of results from the main task analyses and in line with a priori hypotheses. To create whole-brain correlation images, the averaged time series across all voxels comprising a seed region of interest (ROI) was used as the variable of interest with the time series corresponding to each voxel across the brain via Pearson’s product moment correlation. Comparisons of connectivity strength with seed regions across specificity and control inductions were made by using a pairwise t test in AFNI. All statistical analyses of correlation data were performed on Fisher z-transformations (Zar, 1996), which are approximately normally distributed. Results involve those voxels that survived a statistical threshold of \( P < 0.001 \), uncorrected with an extent threshold of 38 contiguously activated voxels applied for whole-brain testing (search volume of 266,816 2-mm\(^3\) voxels) using 3dClustSim and equivalent to a significance threshold of \( P < 0.05 \), corrected for multiple comparisons. Note that the cluster extent required to achieve a corrected \( \alpha \) of 0.05 with a voxelwise threshold of \( P < 0.001 \) here was smaller than the extent required in the main task analysis due to differences in EPI acquisition and the smoothness of the data.

Visualization and localization steps for the main tasks and resting-state analyses are in Appendix. All data and materials are available upon request.
Author Contributions


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Declaration of Conflicting Interests

The authors declare no conflict of interest.

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General Discussion

The three papers of the dissertation aimed to address the outstanding issue of episodic memory’s contribution to a range of cognitive tasks beyond remembering of past events and imagining of future events (see Schacter & Addis, 2007, 2009), and the neural signature associated with this contribution. We initially developed and used an experimental tool – the episodic specificity induction – to dissociate the contributions of episodic processes to remembering the past and imagining the future from non-episodic processes like semantic memory, descriptive ability, and inhibitory control (Madore, Gaesser, & Schacter, 2014; Madore & Schacter, 2016). Having established the efficacy of the induction, Paper 1 (Madore & Schacter, 2014) and Paper 2 (Madore, Addis, & Schacter, 2015) of the dissertation use the tool to identify the involvement of episodic memory on two cognitive tasks that have been studied sparingly but where kernels of evidence suggest episodic processes may play a role: means-end problem solving (e.g., Sheldon, McAndrews, & Moscovitch, 2011; Sheldon et al., 2015) and divergent creative thinking (e.g., Addis, Pan, Musicaro, & Schacter, 2016; Gilhooly, Fioratou, Anthony, & Wynn, 2007). With the cognitive signature of the specificity induction identified, Paper 3 (Madore, Szpunar, Addis, & Schacter, 2016) assesses the neural signature of the manipulation.

In line with our hypotheses, Paper 1 (Madore & Schacter, 2014) indicates that episodic memory is involved in means-end problem solving in young and older adults. After receiving the specificity induction compared with a control, both young and older adults exhibited boosts in performance on an index of problem solving thought to draw on episodic memory – relevant steps – without a boost in performance on an index thought to measure semantic memory – other steps. Following the specificity induction, young and older adults also generated more
internal/episodic details in their solution steps relative to the control with no increase in external/semantic details.

Relatedly, Paper 2 (Madore et al., 2015) extended this logic to divergent creative thinking in young adults and indicates that episodic memory also contributes to this task. In two experiments, we examined whether performance on a divergent thinking task thought to at least nominally draw on episodic processes would be affected by the specificity induction. In support of our hypotheses, Experiment 1 indicated that participants exhibited a boost in divergent thinking performance following the specificity induction relative to a control but did not exhibit changes on a more semantic object association task as a function of induction. Experiment 2 furthered these results by showing that the specificity induction enhanced divergent thinking but did not affect performance on a task which involved solving semantic creative riddles, a measure of convergent creative thinking. It should be noted that the results of Paper 2 have been further replicated and extended in a sample of young and older adults, and with a second index of divergent thinking, in two additional experiments (Madore, Jing, & Schacter, 2016).

Having established a cognitive signature of the specificity induction on several tasks that may index episodic memory, Paper 3 (Madore, Szpunar et al., 2016) addressed the outstanding issue of the neural signature of the induction. This question is an important one because a manipulation that targets episodic processes on means-end problem solving and divergent thinking should also affect neural activity in brain regions during an imagined future events task that likewise is thought to draw on episodic processes. In support of our hypotheses, participants exhibited significantly greater neural activity in several medial temporal lobe subsystem regions of the core network, including the left anterior hippocampus and right inferior parietal lobule, when imagining future events compared with a semantic object task, particularly after receiving
the specificity induction compared with a control. This induction-related effect was restricted to the construction phase of imagining future events, and did not extend to the elaboration phase. Moreover, induction-related differences in neural activity during the construction of imagined future events in the left anterior hippocampus and right inferior parietal lobule were significantly modulated by induction-related differences in the episodic – but not semantic – details of generated content from the imagined future event trials collected during a post-scan interview. Details generated for the semantic control trials did not vary as a function of induction in the post-scan interview.

While the critical analyses of the study involved neural comparisons from the main tasks in the scanner and cognitive comparisons from the post-scan session, resting-state functional connectivity analyses with left anterior hippocampal and right inferior parietal lobule seed regions and the rest of the brain also revealed stronger core network coupling following the specificity induction relative to the control. Induction-related differences were observed in the strength of coupling between the left anterior hippocampal seed and the right parahippocampal gyrus, and the right inferior parietal lobule seed and the left parahippocampal gyrus, anterior cingulate cortex, and superior medial frontal gyrus.

Collectively, the results indicate that an episodic specificity induction targets brain structures of the core network linked to episodic detail in the medial temporal lobe subsystem, including the hippocampus and inferior parietal lobule (e.g., Addis, Cheng, Roberts, & Schacter, 2011; Addis, Wong, & Schacter, 2007; Andrews-Hanna, Reidler, Sepulcre, Poulin, & Buckner, 2010; Guerin, Roberts, Gilmore, & Schacter, 2011). Tentative evidence from the resting-state scans also suggests that the induction can affect coupling of particular seed regions with additional event- and social-processing hubs of the brain (Andrews-Hanna et al., 2010; Szpunar,
St. Jacques, Robbins, Wig, & Schacter, 2014). The findings of Paper 3 strengthen the theoretical account of the specificity induction as affecting episodic retrieval orientation. The induction-related neural effects were restricted to the construction – but not elaboration – phase of imagining future events. Episodic retrieval orientation should have its greatest effects when a cue is initially viewed and an event has to be subsequently constructed (for further elaboration, see Schacter & Madore, 2016). The findings also address the outstanding issue of the specificity induction’s neural signature, and can be situated in current theoretical accounts regarding episodic memory.

In particular, in line with the constructive episodic simulation hypothesis (Schacter & Addis, 2007, 2009), the findings of the three papers indicate that the retrieval and reconstruction of episodic details from past experiences can play a role in additional cognitive tasks that may require episodic processes for completion, such as imagining future events, solving means-end problems, and thinking creatively. From the three papers, the cognitive signature of the specificity induction on key indices of these tasks was established, as was the neural signature of the specificity induction on activity in particular core network regions linked to episodic detail in the medial temporal lobe subsystem. The findings of the three papers also add support to frameworks that highlight how flexible mental representations (Rubin, Watson, Duff, & Cohen, 2014) and open-ended and generative tasks (Sheldon & Levine, 2016) may draw on episodic processes and recruit the hippocampus in particular (for further review, see Moscovitch, Cabeza, Winocur, & Nadel, 2016).

Having summarized the dissertation papers and delineated how their findings address outstanding issues, the theoretical and functional implications of the body of work will be presented next. Then, future directions of the research program will be discussed.
Theoretical Implications

Based on the body of work on the specificity induction, we have hypothesized (Madore et al., 2014) that episodic retrieval orientation is a key process that underlies remembering the past, imagining the future, solving social open-ended problems, and generating creative responses on divergent thinking, but does not play a major role in describing pictures, comparing, defining, and generating associations of words, and solving semantic creative riddles. The results indicate that biasing a specific retrieval orientation with an induction focused on filling in the many details related to an event and its people, settings, and actions may also assist on additional cognitive tasks that rely on this sort of mental event or scene building for completion. In addition, we have recently suggested (Schacter & Madore, 2016) that triggering a specific retrieval mode may facilitate a more general process of event construction (Romero & Moscovitch, 2012) that may be recruited for memory, imagination, social problem solving, and divergent creative thinking. Event construction, the assembly of an event bound in space and time with details related to settings, people, and actions, may be facilitated by a retrieval mode that focuses on assembling an event with these kinds of specific details. This point also fits under the theoretical framework of an event model (Radvansky & Zacks, 2014), which is constructed, at least in part, of elements of previous episodic memories that are situated in a specific place and time related to physical entities and action sequences. While event construction may comprise both episodic and non-episodic components, a specificity induction focused on episodic details should target the episodic component of this process and likewise affect performance on subsequent tasks that involve this sort of mental event building.

In a related vein, Maguire and colleagues have suggested that scene construction, a type of event construction focused on the spatial coherence of a scene in particular, may underlie
commonalities observed in memory, imagination, and related constructs (Hassabis, Kumaran, & Maguire, 2007; Hassabis, Kumaran, Vann, & Maguire, 2007; Hassabis & Maguire, 2007; Palombo, Hayes, Peterson, Keane, & Verfaellie, 2016). According to this view, the process of scene construction is involved in but not restricted to episodic memory (Mullally & Maguire, 2014; Rubin & Umanath, 2015), and in specificity induction studies could potentially be facilitated by retrieval attempts that focus on filling a mental scene with specific details that are generic, rather than episodic, in the sense that they are not associated with a particular past or future event. Findings from future experiments will help to characterize the processes targeted by the specificity induction and in turn help to characterize the common processes underlying similarities observed in memory, imagination, and related constructs like means-end problem solving and divergent creative thinking. In particular, testing whether the specificity induction impacts key measures of scene construction such as spatial coherence would identify whether the induction affects this process specifically or a more general event construction process that involves scene processing as well as the processing of other kinds of elements, some drawn from episodic memory, that comprise an event or scene (see Future Directions below for further elaboration).

Cognitive and neural evidence for the idea of a general event construction process that includes but is not limited to scene processing, and that may underlie commonalities observed on episodic memory and related tasks, comes from several studies and theoretical accounts. These pieces of evidence support the notion that the hippocampus – a key brain structure implicated in episodic memory and tasks thought to draw on episodic details – involves the processing of spatial information as well as other types of information, including temporal information (Davachi & DuBrow, 2015; Deuker, Bellmund, Navarro Schroder, & Doeller, 2016;
Eichenbaum, 2013; Eichenbaum & Cohen, 2014; Ranganath & Hsieh, 2016; Rosenbaum, Gilboa, Levine, Winocur, & Moscovitch, 2009). This point is important because it underscores that an induction that has been found to impact neural activity in the hippocampus may likely be related to a cognitive process that the hippocampus supports, in this case a retrieval mode that facilitates a general event construction process.

Having outlined a key theoretical implication of specificity induction studies, a few functional implications of the body of work will be discussed next, followed by future aims for the research program.

**Functional Implications**

The specificity induction represents a useful tool for examining theoretical issues regarding episodic memory, as well as functional issues that individuals experience in everyday life. For example, specificity trainings for episodic memory (e.g., Moradi et al., 2014; Neshat-Doost et al., 2013) and simulation (Williams et al., 1996) have been found to improve clinical symptoms of depression and posttraumatic stress disorder compared with control trainings (for a recent clinical meta-analysis, see Hitchcock, Werner-Siedler, Blackwell, & Dalgleish, 2016; for a related review, see MacLeod, 2016). Our own specificity induction has also been found to reduce anxiety and negative affect ratings in healthy college students about personally worrisome future events (Jing, Madore, & Schacter, 2016). The specificity induction developed and examined in the dissertation adds to this body of work because it indicates that episodic processes, rather than non-episodic processes like descriptive ability and inhibitory control, may be targeted by specificity trainings and can be enhanced.

While we now know that specificity trainings can be effective in clinical and non-clinical samples focused on depression, anxiety, and stress, one functional implication of induction-
related work is the training’s impact on other samples that have documented deficits in episodic processing. Recent work has suggested that individuals who exhibit symptoms of alcoholism (e.g., Snider, LaConte, & Bickel, 2016), chronic smoking (e.g., Stein et al., 2016), and obesity (e.g., O’Neill, Daniel, & Epstein, 2016) may not spontaneously engage episodic processing during tasks that invoke and measure memory-related constructs such as delay discounting (the ability to devalue short-term, immediate rewards for long-term, larger rewards). In such studies, these individuals benefit after receiving variants of future thinking manipulations that focus on generating detailed episodic events. For example, Stein et al. (2016) found that cigarette smokers who received an episodic future thinking manipulation exhibited reduced delay discounting and smoking behavior (i.e., puffs from cigarettes) compared with those who received a control manipulation. Thus, one broad implication of induction-related work may be the opportunity to assist individuals with difficult experiences in everyday life that may at least in part have an episodic memory component that can be targeted by a specificity training. While the specificity induction we have developed is brief for lab-based purposes, trainings that are longer in duration and have multiple sessions may be the most effective in everyday life (for an example, see Neshat-Doost et al., 2013).

While much of the dissertation has focused on adaptive boosts in performance and potential benefits following a specificity induction, another functional implication of the body of work is the flipside of this effect: memory distortion. The constructive process of memory that allows for extraction and recombination of disparate elements of prior experiences into novel events and ideas for tasks like imagination, social problem solving, and divergent creative thinking may also contribute to false memories and errors. According to Schacter, Guerin, and St. Jacques (2011), the very processes underlying an adaptive and flexible memory system can
also contribute to different kinds of memory distortions (for recent examples, see Carpenter & Schacter, 2016; Dewhurst, Anderson, Grace, & van Esch, 2016; for further theoretical elaboration, see Schacter & Addis, 2007, 2009). Thus, there may be instances where ramping up the specificity and detail of memories, imaginations, solution steps, and creative ideas via a specificity induction has downsides. As Schacter et al. (2011) note, one sort of memory distortion, imagination inflation, results in individuals believing a novel event has actually occurred as a result of simulating the experience. In support of this view, ongoing research in the lab indicates that receiving a specificity induction can increase imagination inflation in an autobiographical memory paradigm (for a related paradigm, see Devitt, Monk-Fromont, Schacter, & Addis, 2015) and false lures in the DRM paradigm (for a related paradigm, see McCabe & Smith, 2006; Thakral, Madore, & Schacter, in prep) if given before certain critical phases in the respective study. Therefore, while induction-related work has focused on the functional benefits of episodic memory in terms of simulating future experiences, solving social problems, thinking creatively, and regulating emotions more successfully, another functional ramification of the research is the potential for memory distortion and error, in line with the processes engaged for an adaptive memory system (e.g., Schacter et al., 2011).

Having outlined potential functional implications of the body of work, directions for future work will be presented next followed by a brief conclusion.

**Future Directions**

The body of work in the dissertation represents a first step in identifying contributions of episodic memory to tasks beyond simple remembering using an experimental induction technique that isolates episodic from non-episodic processes. Based on the papers of the dissertation, future work can continue to identify the 1) cognitive and 2) neural processes that
Contribute to episodic memory and related constructs using the specificity induction and main task measures delineated in the dissertation papers, as well as different sorts of inductions that target different sorts of processes and are measured on new main tasks of interest.

**Cognitive Processes**

One question that emerges from the cognitive papers in the dissertation is what process episodic retrieval orientation facilitates. We have recently suggested (Schacter & Madore, 2016) that the specificity induction, by focusing an individual on filling in a mental event or scene with many specific details related to people, settings, and actions, may likewise facilitate performance on subsequent tasks that rely on this sort of mental event or scene building for completion. Thus, the specificity induction may make specific a retrieval orientation that facilitates a general event construction process (Radvansky & Zacks, 2014; Romero & Moscovitch, 2012). A related, though not mutually exclusive, idea is that the specificity induction facilitates scene construction, a type of event construction that focuses on the spatial coherence of a scene; in this body of work, scene construction is thought to underlie cognitive and neural commonalities observed in episodic memory, simulation, and related tasks like spatial navigation (e.g., Hassabis & Maguire, 2007; Mullally & Maguire, 2014; Palombo et al., 2016; Rubin & Umanath, 2015).

To test the idea that the specificity induction affects scene construction specifically, we recently completed a study with young adults where induction-related effects on indices of scene construction were measured. We used the scene construction materials developed by Hassabis, Maguire, and colleagues, which include several prompts focused on filling in the contents of a given atemporal scene (e.g., a jungle, a marketplace, a castle, etc.) with verbal generations. A key index of scene construction – spatial coherence – was also measured after each trial by ratings from participants. If the specificity induction affects the process of scene construction in
particular, then it should lead participants to have higher spatial coherence ratings – a key index of scene construction – after this induction is received compared with a control; if the specificity induction affects a more general event construction process, then it should lead participants to generate more details in their scene constructions from all categories that are scored – spatial references, entities present, sensory descriptions, and thoughts/emotions/actions – compared with a control. As hypothesized, participants did not exhibit significant differences in spatial coherence ratings as a function of induction; the same finding was observed when blind raters scored the constructions for spatial coherence. Nonetheless, participants did generate significantly more details from all categories measured in the paradigm following the specificity induction compared with a control. These results indicate that the specificity induction may not target the process of scene construction specifically but a more general event construction process that involves filling in an event or scene with details including but not limited to spatial information.

We recently completed a second experiment in this series with young adults that converges with the idea that the induction facilitates event construction. In the study, participants received a memory specificity induction about a past event (as in previous work), an imagination specificity induction about a novel future event, or a control induction, and then completed subsequent memory, imagination, and picture description tasks (as in Madore et al., 2014). If a specificity induction facilitates a general event construction process, then it should affect detail production whether the induction is focused on a specific past event or a specific future event; both sorts of specificity inductions involve filling in a mental event or scene with many specific details, at least some retrieved and reconstructed from episodic memories. As hypothesized, the two specificity inductions produced significant and indistinguishable increases in the number of
episodic – but not semantic – details generated during the subsequent memory and imagination tasks compared with the control induction. By contrast, the two specificity inductions did not affect any details generated on picture description compared with the control. Taken together, the results suggest that the specificity induction may facilitate an event construction process that underlies similarities observed in memory, imagination, and related tasks that draw on this process for completion, and in particular may target the episodic component of this process. We predict that the imagination specificity induction used in the experiment will boost performance on key indices of means-end problem solving and divergent creative thinking affected in previous work by the memory specificity induction as well.

These two recent experiments, and the induction-related body of work, are important because they highlight how component processes involved in cognitive tasks can be identified via an induction procedure. Future work could design and evaluate other sorts of inductions focused on semantic memory or scaffolding (e.g., Irish & Piolino, 2016), description or narrative style (e.g., Rudoy, Weintraub, & Paller, 2009), motivation (e.g., Castel et al., 2011), strategic search (e.g., Addis, Hach, & Tippett, 2016), or cognitive flexibility (e.g., El Haj, Antoine, & Kapogiannis, 2015; Roberts et al., 2017) to probe how these sorts of processes contribute to the overlap observed in episodic memory, simulation, social problem solving, and divergent thinking, as well as differences observed among the tasks. Research in this area may also help to explain conflicting findings in the literature regarding the common underlying processes that contribute to episodic memory and related tasks (e.g., Dede, Wixted, Hopkins, & Squire, 2016; Kirwan, Ashby, & Nash, 2014; Klein, 2013, 2016; Zeidman & Maguire, 2016).

Neural Processes
A related question that emerges from the neural paper on simulation in the dissertation is how the processes targeted by the specificity induction affect neural activity in and connectivity between key brain structures during other tasks with known induction effects, such as means-end problem solving and divergent creative thinking. We have recently completed data collection for another fMRI study with 32 young adults focused on how the specificity induction affects divergent creative thinking in particular (for a related training approach, see Fink et al., 2015). We used the same paradigm as reported in Paper 3 (Madore, Szpunar et al., 2016) but replaced the imagined future events task and object comparison task with the AUT (generating unusual and creative uses of everyday objects) and the OAT (generating typical associates of everyday objects). This research was motivated by prior work suggesting that the hippocampus, in particular, shows increased activity when participants perform divergent creative thinking tasks compared with various controls in the scanner. These divergent thinking tasks include the AUT (e.g., Beaty, Benedek, Kaufman, & Silvia, 2015; Benedek et al., 2014; Fink et al., 2009, 2012), a book illustration task (Ellamil, Dobson, Beeman, & Christoff, 2012), and creative writing tasks that involve generating novel stories (Shah et al., 2013) or poems (Liu et al., 2015) from various prompts.

We hypothesize that following the specificity induction compared with a control there should be particular patterns of cognitive and neural performance in support of the view that episodic processes contribute to divergent thinking. Cognitively, participants should exhibit enhanced performance on the AUT but not the OAT as indexed by the number of button presses in the scanner for the number of ideas generated in the trial window. Neurally, participants should also exhibit increased activation in the hippocampus and medial temporal lobe subsystem regions (Andrews-Hanna et al., 2010) involved in detailed mental event and scene building. We
hypothesize that this subset of core regions will be the most active during the AUT compared with the OAT following the specificity induction compared with a control based on 1) previous evidence for hippocampal involvement in generative divergent thinking tasks (e.g., Benedek et al., 2014); 2) our recent imaging work showing greater hippocampal recruitment for imagined events relative to a semantic object task following the specificity induction (Madore, Szpunar et al., 2016); and 3) our recent theoretical account that the induction and divergent thinking recruit episodic processes involved in detailed event and scene building (Schacter & Madore, 2016). We also aim to replicate and extend our previous finding that the specificity induction affects resting-state connectivity between core network regions (Madore, Szpunar et al., 2016).

This sort of neuroimaging work is important because it underscores how component processes can be identified via patterns of neural activity that have been previously linked to episodic memory. Relatedly, future fMRI work could focus on specificity induction paradigms with main tasks that resemble means-end problem solving (e.g., Gerlach, Spreng, Madore, & Schacter, 2014) or expand the work to other domains where previous cognitive and neural studies suggest a role for episodic processes (see Schacter, 2012), including prosocial intentions (e.g., Gaesser & Schacter, 2014), prospective memory (e.g., Reynolds, West, & Braver, 2009), spatial navigation (e.g., Brown et al., 2016), creative writing (Shah et al., 2013), and delay discounting (e.g., Benoit, Gilbert, & Burgess, 2011). Such work could also include connectivity approaches (e.g., Bellana, Liu, Diamond, Grady, & Moscovitch, 2016) to examine under what conditions brain networks activate or de-activate in support of the respective task.

Induction-related studies of neural and cognitive processes should continue to examine age-related questions as well. In particular, it will be critical to apply the neuroimaging work of the dissertation to paradigms appropriate for older adults to examine whether the specificity
induction can impact age-related performance on different tasks in the scanner, and the brain regions and networks that are activated or de-activated to complete such tasks (for a related example, see Addis, Roberts, & Schacter, 2011). Age-related questions could also focus on compensatory contributions of non-episodic processes for different tasks across adult development, with a focus on capitalizing on what is preserved versus what declines in aging (for a related example, see Leon, Altmann, Abrams, Gonzalez Rothi, & Heilman, 2014).

**Conclusion**

Research over the past decade has indicated that episodic memory retrieval is not just for remembering past events. An experimental tool, the episodic specificity induction, was developed and examined to identify episodic contributions to tasks that may involve episodic retrieval from non-episodic contributions in young and older adults. Future work should continue to investigate constructive uses of episodic retrieval on tasks that are not episodic memory tasks in the strict sense but may rely on this sort of processing for completion. The body of work in the dissertation is a starting point for continued development and evaluation of induction procedures targeting different processes in cognitive and neural studies, including event construction. Research in this area will shed light on component processes involved in episodic memory and related tasks, with an emphasis on commonalities and differences. Collectively, such work should strengthen our theoretical understanding of episodic memory and what it is for, and could have functional implications for individuals characterized by overgeneralized memory, such as aging, depression, and posttraumatic stress disorder.
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Appendix

Paper 1 (Madore & Schacter, 2014)

Means-End Problem Solving Task Instructions and Standard Story Stimuli

“In this part of the experiment you are going to be presented with the beginning and end of 5 stories. Each story has a beginning problem and an ending solution. You will be asked to create the middle of each story, i.e. the steps you would take to solve the problem in each story. You will have 5 minutes to write out as much detail as you can for each story.”

Problem 1: Mrs. A was listening to the people speak at a meeting about how to make things better in her neighborhood. She wanted to say something important and have a chance to be a leader too. The story ends with her being elected leader and presenting a speech. You begin the story at the meeting where she wanted to have a chance to be a leader.

Problem 2: H loved her boyfriend very much, but they had many arguments. One day the boyfriend left H. H wanted things to be better. The story ends with everything fine between H and her boyfriend. You begin the story with H’s boyfriend leaving her after an argument.

Problem 3: Mrs. P came home after shopping and found that she had lost her watch. She was very upset about it. The story ends with Mrs. P finding her watch and feeling good about it. You begin the story where Mrs. P found that she had lost her watch.

Problem 4: C had just moved in that day and didn’t know anyone. C wanted to have friends in the neighborhood. The story ends with C having many good friends and feeling at home in the neighborhood. You begin the story with C in her room immediately after arriving in the neighborhood.

Problem 5: During the war, a woman’s husband and children were tortured and killed by a soldier and the woman swore revenge. The story begins one day after the war, when the
woman enters a restaurant and sees the soldier. The story ends with the woman killing the soldier. You begin the story when the woman sees the soldier.

Problem 6: One day A saw a beautiful man she had never seen before while eating in a restaurant. She was immediately attracted to him. The story ends when they get married. You begin the story when A first notices the man in the restaurant.

Problem 7: B needed money badly. The story begins one day when she notices a valuable diamond in a shop window. B decides to steal it. The story ends when B succeeds in stealing the diamond. You begin the story when B sees the diamond.

Problem 8: J noticed that her friends seemed to be avoiding her. J wanted to have friends and be liked. The story ends when J’s friends like her again. You begin the story where J first notices her friends avoiding her.

Problem 9: One day G was standing around with some other people when one of them said something very nasty to G. G got very mad. G got so mad she decided to get even with the other person. The story ends with G happy because she got even. You begin the story when G decided to get even.

Problem 10: J is having trouble getting along with the boss on her job. J is very unhappy about this. The story ends with J’s boss liking her. You begin the story where J isn’t getting along with her boss.

Means-End Problem Solving Task Instructions and Self-Relevant Story Stimuli

“In this part of the experiment you are going to be presented with the beginning and end of 5 different stories. Each story has a beginning problem and an ending solution. You will be asked to create the middle of each story, i.e. the steps you would take to solve the problem in each story. People in your age group have reported that the problems you will see are ones that
they have personally had. You will have 5 minutes to write out as much detail as you can for each story.”

Problem 1: You would like to declutter your living space. The story ends with you decluttering your living space. The story begins with you wanting to declutter your living space.

Problem 2: You would like to eat better. The story ends with you eating better. The story begins with you wanting to eat better.

Problem 3: You would like to exercise more. The story ends with you exercising more. The story begins with you wanting to exercise more.

Problem 4: You would like to learn a new skill. The story ends with you learning a new skill. The story begins with you wanting to learn a new skill.

Problem 5: You would like to make more time for family. The story ends with you making more time for family. The story begins with you wanting to make more time for family.

Problem 6: You would like to manage your finances better. The story ends with you managing your finances better. The story begins with you wanting to manage your finances better.

Problem 7: You would like to plan a day trip. The story ends with you planning a day trip. The story begins with you wanting to plan a day trip.

Problem 8: You would like to schedule healthcare visits. The story ends with you scheduling healthcare visits. The story begins with you wanting to schedule healthcare visits.

Problem 9: You would like to stay mentally active. The story ends with you staying mentally active. The story begins with you wanting to stay mentally active.
Problem 10: You would like to volunteer/help others more. The story ends with you volunteering/helping others more. The story begins with you wanting to volunteer/help others more.

Coarse-Unit Scoring for Problem Solving

We conducted supplemental scoring for the means-end problem solving (MEPS) task based on work in the event segmentation literature (e.g., Zacks, Tversky, & Iyer, 2001) that suggests that participants’ parsing of events and descriptions of them can be segmented into more coarse- or fine-grained units. For example, when participants describe the steps involved in “fertilizing houseplants,” they might generate a step such as “adds water” (a coarse unit) or they might provide several sub-steps such as “turn faucet,” “turn off faucet,” “pick up plant,” and so on (fine units; Zacks et al., 2001).

This work has implications for our study because typical MEPS scoring uses a total fluency measure for steps without dividing them into more coarse- or fine-grained units. Previous research has suggested that older adults sometimes segment events into more coarse-grained units than young adults (Kurby & Zacks, 2011), possibly accounting for the age-related differences found in our study with relevant step fluency. It is also of functional value to determine whether the episodic specificity induction increases coarse-unit steps that other sub-steps fall under or just the total number of steps that participants generate.

To get at these issues, we developed a scoring scheme based on binning participants’ different steps into one of a few predetermined overarching categories. For the standard problem set, these categories were those referenced in Platt and Spivack’s (1975) manual and for the self-relevant problem set, these were the most typical categories that both young and older adults’ responses fell under in the Spreng and Schacter (2012) study which was the source of the self-
relevant problems. For example, in the standard problem story about C moving to a new neighborhood and wanting to make new friends, one of the overarching categories is “visit neighbors.” Any steps that participants generated that fit under this category, such as “walking out of the house,” “going down the street,” “knocking on neighbor’s door,” “introducing self,” and “talking with neighbor” would all be binned as 1 step under the overarching category of “visit neighbors.” With this scoring scheme, providing multiple instances of a step under the same category was also given credit just once (e.g., C knocking on one door and talking with one neighbor, and then knocking on another door and talking with another neighbor, would be binned as 1 step under the “visit neighbors” category). Binning sub-steps under overarching categories maps fairly well onto Zacks et al.’s (2001) distinction between coarse- and fine-unit event segmentation and description.

Because some of the problems had more step categories than others, we calculated a proportion for the number of step categories that participants fulfilled across stories over the total number of possible step categories. The pattern of results was the same whether we used this proportion or the raw number of step categories as the main variable, which was not surprising since the problem sequence was randomized across participants. Induction order (i.e., carryover) also had no impact on the results.

Two raters who were separate from the five main raters of the study completed training on this category scoring. The two raters were blind to all hypotheses of the experiment and to which inductions the participants had received. Before examining the main experimental trials, the raters scored 20 practice responses independently and had high inter-rater reliability (standardized Cronbach’s $\alpha = .95$, bivariate $r = .91$). They then completed category scoring separately for the main experimental trials for the 96 participants in the two sessions.
To analyze the scoring, we used a mixed-factorial ANOVA that was similar to those used in the main text with the between-subjects factors of Age (Young vs. Older) and Problem Set (Standard vs. Self-Relevant MEPS) and the within-subjects factor of Induction (Control vs. Specificity). The main output variable was the proportion of step categories fulfilled. We found a significant main effect of Age, $F(1, 92) = 6.00, p < .05, \eta^2_p = .06$, and a significant main effect of Induction, $F(1, 92) = 10.31, p < .01, \eta^2_p = .10$. These variables did not interact with each other or with the Problem Set variable in any form ($Fs < 0.41, ps > .53$), though the Problem Set main effect was also significant, $F(1, 92) = 82.23, p < .001, \eta^2_p = .47$. As in our main results with relevant step fluency, older adults fulfilled a significantly lower proportion of step categories ($M = 0.25, SE = 0.02$) compared with young adults ($M = 0.29, SE = 0.02$), $d = 0.37$. Likewise, participants in both age groups fulfilled a significantly higher proportion of step categories when they received the specificity induction ($M = 0.29, SE = 0.01$) compared with the control induction ($M = 0.25, SE = 0.01$), $d = 0.33$.

These findings have important implications because they indicate that our main age-related findings and induction findings are the same whether scoring is completed in a more coarse- or fine-grained fashion. The age-related results and the induction results cannot be explained by differences in scoring used: older adults fulfilled a lower proportion of step categories than young adults and also generated fewer relevant steps overall, and participants in both age groups fulfilled a higher proportion of step categories when they received the specificity induction compared with the control induction and also generated more relevant steps overall when they received the specificity induction.

**Paper 2 (Madore, Addis, & Schacter, 2015)**

**Experiment 1 Method**
Along with categories of appropriate uses, AUT responses were scored for total fluency, appropriateness, flexibility, elaboration, and creativity (Addis, Pan, Musicaro, & Schacter, 2016; Benedek et al., 2014; Guilford, 1967). Total fluency reflects the total number of uses generated excluding repetitions. Appropriateness reflects whether each use could actually work. Flexibility reflects the number of categories the uses fell under for each cue (irrespective of appropriateness). Elaboration reflects how detailed each use was (rating of 0 = brief to 2 = more detailed). Creativity reflects how original and unusual each use was (rating of 1 = uncreative to 4 = very creative), with the highest ratings reserved for uses that raters judged that only a few people could come up with. Raters had high inter-rater reliability across these measures (Cronbach’s αs ≥ .86). Raters did not score for total fluency, which reflects raw responses.

**Experiment 1 Results**

Our main analysis of divergent thinking focused on categories of appropriate uses, the most stringent definition of a use (see main text). We also examined total uses, appropriate uses, and categories of uses (i.e., flexibility) against total objects in a series of 2x2 repeated-measures ANOVAs, and found the same pattern of results as in the primary analysis of categories of appropriate uses.

There were no main effects of Induction ($Fs \leq 0.54$, $ps > .250$, $\eta^2p$s ≤ .02), main effects of Task ($Fs \geq 23.07$, $ps \leq .001$, $\eta^2p$s ≥ .51), and interactions between Induction and Task ($Fs \geq 7.05$, $ps \leq .014$, $\eta^2p$s ≥ .24). Participants generated more total uses ($M_{control} = 32.61$, $SE = 2.86$; $M_{specificity} = 38.61$, $SE = 3.96$), appropriate uses ($M_{control} = 32.09$, $SE = 2.96$; $M_{specificity} = 38.22$, $SE = 3.85$), and categories of uses ($M_{control} = 29.00$, $SE = 2.65$; $M_{specificity} = 34.87$, $SE = 3.66$) after the specificity induction than the control, smallest $t(22) = 2.24$, $p = .035$, mean difference = 6.00,
95% CI = [0.45, 11.55], \(d = 0.47\). Appendix Figure 2.1 depicts the difference score for each measure.

Appendix Figure 2.1. Mean difference for each output variable as a function of induction. Error bars represent 95% confidence interval on the mean difference.

We also examined whether uses varied on elaboration and creativity as a function of induction. We focus here on categories of appropriate uses (similar results were found for these ratings with the other use measures). Participants were rated as similarly detailed (\(M_{\text{control}} = 0.90, SE = 0.08; M_{\text{specificity}} = 0.89, SE = 0.07\)) and creative (\(M_{\text{control}} = 1.77, SE = 0.08; M_{\text{specificity}} = 1.78, SE = 0.09\)) following both inductions, largest \(t(22) = -0.25, p > .250\), mean difference = -0.01, 95% CI = [-0.11, 0.08], \(d = 0.05\).

**Experiment 2 Method**

Raters had high reliability for AUT measures (Cronbach’s \(\alpha \geq .91\)).

**Experiment 2 Results**

When total, appropriate, and categories of uses rather than categories of appropriate uses were entered into the ANOVA model against RAT triad solutions, the pattern of results
looked similar. There were main effects of Induction ($F$s $\geq 7.66$, $ps \leq .011$, $\eta_p^2$s $\geq .26$) and Task ($F$s $\geq 62.63$, $ps \leq .001$, $\eta_p^2$s $\geq .74$), and marginal interactions between Induction and Task ($F$s $\geq 2.99$; $p = .096$ and $\eta_p^2 = .12$ for total, $p = .038$ and $\eta_p^2 = .18$ for appropriate, and $p = .098$ and $\eta_p^2 = .12$ for categories). Participants generated more total ($M_{control} = 32.74$, $SE = 3.64$; $M_{specificity} = 36.52$, $SE = 3.30$), appropriate ($M_{control} = 31.39$, $SE = 3.49$; $M_{specificity} = 35.57$, $SE = 3.21$), and categories of uses ($M_{control} = 24.17$, $SE = 2.20$; $M_{specificity} = 27.48$, $SE = 2.02$) after the specificity induction than the control, smallest $t(22) = 2.58$, $p = .017$, mean difference = 3.78, 95% CI = [0.74, 6.82], $d = 0.54$. Appendix Figure 2.2 depicts the difference score for each measure.

![Appendix Figure 2.2](image)

*Appendix Figure 2.2.* Mean difference for each output variable as a function of induction. Error bars represent 95% confidence interval on the mean difference.

We also replicated findings from Experiment 1 for elaboration and creativity with categories of appropriate uses (and with the other use measures). Participants were rated as similarly detailed ($M_{control} = 0.53$, $SE = 0.10$; $M_{specificity} = 0.56$, $SE = 0.10$) and creative ($M_{control} = 2.23$, $SE = 0.07$; $M_{specificity} = 2.29$, $SE = 0.05$) following both inductions, largest $t(22) = 0.79$, $p > .250$, mean difference = 0.05, 95% CI = [-0.09, 0.20], $d = 0.14$. 
**Exploratory Analyses for Old/New Ideas**

At the end of the second session participants also rated each use they had generated during the experiment as either an *old idea* or a *new idea* (Benedek et al., 2014). Old ideas were ones that participants had experienced or knew about before the study, and new ideas were ones that emerged for the first time during the study.

We included this old/new measure for exploratory purposes, and examined the total number of old and new uses that participants generated as a function of induction in both experiments with 2 (Induction: control vs. specificity) x 2 (Idea type: old vs. new) repeated-measures ANOVAs. Three uses were excluded in Experiment 1 and two uses in Experiment 2 for being unmarked. In both experiments, we found main effects of Induction ($F_s \geq 4.73, ps \leq .041, \eta^2 ps \geq .18$), no main effects of Idea type ($F_s \leq 2.88, ps \geq .104, \eta^2 ps \leq .12$), and no interactions between Induction and Idea type ($F_s \leq 1.97, ps \geq .175, \eta^2 ps \leq .08$). This pattern suggests that after the specificity induction, participants generated more uses that were both old (Expt 1: $M_{control} = 17.26, SE = 1.72$ and $M_{specificity} = 20.21, SE = 1.59$; Expt 2: $M_{control} = 13.43, SE = 1.66$ and $M_{specificity} = 16.57, SE = 1.93$) and new (Expt 1: $M_{control} = 15.35, SE = 2.35$ and $M_{specificity} = 18.26, SE = 3.82$; Expt 2: $M_{control} = 19.30, SE = 2.62$ and $M_{specificity} = 19.87, SE = 2.63$).

Note, however, that there are concerns related to collecting these old/new measures. First, participants were asked to mark all uses at the end of the second session, rather than at the end of each session, to avoid potential biases about what kinds of uses they should generate during the experiment. It is unclear how well participants are able to make judgments about uses that they generated a week before (but it is also unclear whether asking participants to make judgments either after each use generated or at the end of each session is much better; source confusions
could arise during any of these instances). Second, the specificity manipulation itself is thought to affect episodic retrieval and thus could bias how well participants are able to remember whether the source of a use is old or new.

**Induction Scripts**

See below for the episodic specificity induction script (Experiments 1 and 2), and impressions induction script (Experiment 1).

**Episodic Specificity Induction Script**

**Introduction** So now I’m going to ask you a few questions about the video you watched. I haven’t seen the video myself, so you’re the expert on that. I’m also going to use the audio-recorder and write down what you say to keep track if that’s okay. How does that sound to you?

**Mental imagery about the surroundings** Okay, so first I want you to close your eyes and get a picture in your head about the surroundings of the video you watched. I want you to think about what types of things were in the environment and how they were arranged and what they looked like. Once you have a really good picture in your head I want you to tell me everything you remember about the surroundings. Try to be as specific and detailed as you can.

**General probing about the surroundings**

- Tell me more about… (details mentioned)
- Tell me more about how the kitchen was arranged.
- Tell me more about what was in the kitchen.
- Were there any other rooms?

**Mental imagery about the people** Now I want you to close your eyes and get another picture in your head, this time about the people in the video you watched. I want you to think about what the people looked like and what they were wearing. Once you have a really good picture in your
head I want you to tell me everything you remember about the people in the video. Again, try to be as specific and detailed as you can.

**General probing about the people**

- Tell me more about… (details mentioned)
- Tell me more about the man/woman’s outfit.
- Tell me more about the man/woman’s face.
- What color hair did the man/woman have?

**Mental imagery about the actions** Now I want you to close your eyes and get a picture in your head about the actions in the video you watched. I want you to think about what the people were actually doing in the video and how they did these things. Once you have a really good picture in your head I want you to tell me everything you remember about the actions starting with the first one and ending with the last one. Try to be as specific and detailed as you can.

**General probing about the actions**

- Tell me more about… (action mentioned)

**Follow-up and repeat for actions**

*only do this if participant doesn’t give sequence of actions first time around*

- What happened after that?
- What was the next thing?
- What was the last thing that happened?

**Impressions Induction Script**

**Introduction** So now I’m going to ask you a few questions about the video you watched. I’m also going to use the audio-recorder and write down what you say to keep track if that’s okay.
How does that sound to you? First I want you to tell me what you thought about the video. Just tell me what your thoughts and opinions of it were. What were your general impressions of the video?

**Question bank**

- What adjectives would you use to describe the setting of the video? The people? The actions?
- Did you have any other opinions about the setting of the video? Did you have any other opinions about the people? The actions?
- Can you describe the whole video in one or two words? What one or two words would you use?
- Did you like the video?
- When do you think the video was made?
- How do you think it was made? (what equipment do you think they used?)
- Did the video remind you of anything? (from your own life)
- Can you guess how big the place was based on the video?
- Can you guess the people’s occupations based on the video?

**Concluding remarks** Were there any other thoughts or opinions you had about the video? Is there anything else you wanted to say about it?

Paper 3 (Madore, Szpunar, Addis, & Schacter, 2016)

Supporting Information (SI) Materials and Methods

**Induction Phase and Main Tasks**

*Control inductions.* To parallel the structure of the specificity induction, the impressions control induction was a question set that required reflecting back on and speaking about the viewed video, but not retrieving specific episodic details. Participants were asked about their global impressions of the video, and then stated their general opinions about other aspects of the video’s
setting, people, and actions as elicited via a question bank. The other control induction, the math control, was completing basic math problems. Because the impressions control focuses on global opinions and could bias individuals towards adopting a gist-like retrieval orientation on subsequent tasks we used the math control as a neutral baseline. Although previous work has revealed a boost in episodic detail after the specificity induction irrespective of which control induction is the comparison (Madore et al., 2015; Madore, Gaesser, & Schacter, 2014; Madore & Schacter, 2016), we included both to ensure the generality of any observed effects. No mental imagery probes were used in either control induction.

**Cues.** The object cues (as listed later) were high in concreteness (mean = 6.88, SD = 0.16), “imageability” (mean = 5.84, SD = 0.34), and Thorndike-Lorge frequency (mean = 1.65, SD = 0.27) as normed in Clark and Paivio (2004). They were drawn from previous work on imagined events (Addis, Cheng, Roberts, & Schacter, 2011; Addis, Wong, & Schacter, 2007). The cues were divided into 4 lists of 18 cues each, and did not differ in respect to these characteristics; the order of lists was fully counterbalanced across induction sequence and control induction used, and participants were randomly assigned to one of the orders (as in Addis et al., 2011, 2007). None of the cues were related to the content of the induction videos.

**List of cues.** The cues (from Clark & Paivio, 2004) used in the main tasks for imagined events and object comparisons were: apple, beaver, bird, book, bottle, bowl, butter, butterfly, candy, car, claw, clock, coffee, coin, corn, cotton, diamond, doll, dollar, dress, elephant, engine, fireplace, flag, fork, fox, frog, fur, hammer, horse, instrument, iron, jelly, lemon, letter, lime, lobster, meat, microscope, nail, newspaper, palace, peach, pencil, pepper, photograph, piano, pipe, pole, potato, rattle, rock, salad, ship, shoe, slipper, snake, stain, star, strawberry, string, sugar, tablespoon, ticket, toast, tool, tower, toy, tree, truck, umbrella, and wine.
Object comparison task. Eighteen total trials were included per segment (as with imagined events). For each trial, the word “objects” appeared followed by the instruction “size and define” followed by the cue in capital letters. As in previous work (Addis et al., 2011, 2007; Hach, Tippett, & Addis, 2014; Madore & Schacter, 2016), participants were instructed to silently generate two objects that were somehow factually related to each object cue and put them in a sentence focused on the physical sizes of the objects from largest to smallest (i.e., “X is larger than Y is larger than Z”). Participants were told that the object cue itself could be first, second, or last in the size sentence. By using the construction-elaboration paradigm as in the imagined event task, participants were told to press their thumb when they had constructed the size sentence, and to then elaborate on a semantic definition of each object until the trial was over. Participants were told to generate everything they could for the object definitions in as much detail as possible, including typical functions, attributes, and characteristics of the objects. Participants were instructed to not think about the objects in relation to themselves or their own lives, but to focus on generating objects and definitions as if they came from a dictionary or Wikipedia page. Following each trial, participants rated (i) how detailed they thought their definitions were (from 1 indicating no/few details and least vivid to 5 indicating many details and most vivid) and (ii) whether they were engaged on task (1 indicating yes or 2 indicating no). This task was used as the comparison for imagined events because it requires searching for, integrating, and generating information related to a given cue, but does not involve elements of episodic experience for completion (further details are provided in Addis et al., 2011, 2007).

Postscan ratings. Participants completed additional phenomenological ratings for imagined events and object comparisons following their verbal generation of content for each cue. For imagined events, participants rated (i) how difficult it was to imagine the event in the scanner,
(ii) how similar the imagined event was to an experience from their own life, (iii) how plausible the event was to occur (all from 1 indicating least to 5 indicating most), and (iv) whether the event was imagined within the next few years (yes or no). For object comparisons, participants rated (i) how difficult it was to complete the task in the scanner and (ii) how familiar the objects were to them (both from 1 indicating least to 5 indicating most). These ratings were included to ensure that any performance differences across the inductions would not be the result of these particular features of generated content. As predicted, ratings on the two tasks did not differ as a function of induction.

**Postscan scoring.** Because the critical detail indices for imagined events and object comparisons were not necessarily equated, and to ensure that any related effects of the specificity induction do not depend on the scoring criteria used, we computed a total detail score and adopted this score as our main dependent variable (Madore & Schacter, 2016). We also examined the details split separately as in our previous work on the induction (Madore et al., 2015, 2014; Madore & Schacter, 2016) and in the standard autobiographical interview (Levine, Svoboda, Hay, Winocur, & Moscovitch, 2002) to confirm the induction operated as expected.

**fMRI main task acquisition.** Neuroimaging data were collected via a 3-T Siemens Magneton Tim Trio MRI scanner with a 32-channel head coil. Anatomical images were collected via a T1-weighted magnetization-prepared rapid gradient multiecho sequence [176 sagittal slices; repetition time (TR) = 2,530 ms; echo times (TEs) = 1.64, 3.50, 5.36, and 7.22 ms; flip angle = 7°; 1-mm³ voxels; field of view (FoV) = 256 mm]. All BOLD data were collected via a T2*-weighted multiband EPI pulse sequence that employed multiband radiofrequency (RF) pulses and simultaneous multislice acquisition (Moeller et al., 2010; Setsompop et al., 2012). For the six (three per segment) BOLD main task runs, the EPI parameters were as follows: 69
interleaved axial-oblique slices, TR = 2,000 ms, TE = 30 ms, flip angle = 80°, 2-mm³ nominal voxels, 6/8 partial Fourier, FoV = 216 mm, SMS = 3. For the two (one per segment) BOLD resting-state runs, the EPI parameters were as follows: 72 interleaved axial-oblique slices, TR = 755 ms, TE = 30 ms, flip angle = 58°, 2-mm³ nominal voxels, 6/8 partial Fourier, FoV = 216 mm, SMS = 8. The SMS-EPI acquisitions used a modified version of the Siemens WIP 770A.

**fMRI main task preprocessing.** Imaging data were preprocessed by using SPM12 (Wellcome Department of Imaging Neuroscience, London, United Kingdom) to account for noise and artifacts from scanning. The first four functional images were discarded to account for T1-saturation effects. Slice-timing correction, realignment, spatial normalization to the Montreal Neurological Institute (MNI) template (resampled at 2-mm³ voxels), and spatial smoothing [using an 8-mm full-width half maximum (FWHM) Gaussian kernel] were also completed.

**fMRI main task analyses.** On average, 15 imagined event and 17 object comparison trials per induction were analyzed (out of 18). Type of control induction and order of induction manipulation did not affect behavioral or neural outcomes.

**fMRI main task interaction effect.** For the main task analyses, we also computed an interaction effect of imagine construction + object elaboration > object construction + imagine elaboration at the first level for each participant for control runs and for specificity runs separately. At the second level, we entered these contrast images into a random-effects paired t test with pairs corresponding to the specificity induction image and control induction image for each participant. The same statistical thresholding ($P < 0.001, k \geq 65$ voxels) was used as in the main task analyses. A significant pattern of activation was observed in the right inferior parietal lobule ($xyz, 36, -30, 36$) for this contrast, indicating that following the specificity induction compared with the control participants exhibited greater activity in this region for imagined events over
object comparisons during the construction phase selectively. No significant activity emerged for
the opposite task or induction contrast.

**fMRI main task visualization and localization.** Peak coordinates of active regions are reported
in MNI space and were localized with xjView 8 ([www.alivelearn.net/xjview](http://www.alivelearn.net/xjview)). The same
parameters were used for the parametric modulation and resting-state analyses. Percent signal
change was extracted from activations of interest for the imagined event and object comparison
conditions for the induction-related, main-task contrasts by using the MarsBaR SPM toolbox
(Brett, Anton, Valbregue, & Poline, 2002).

**Resting-state Acquisition and Preprocessing**

The acquisition parameters are listed earlier. For preprocessing, a series of steps were
first performed on the raw data. To ensure stabilization of the BOLD signal, the first four time
points of each functional run were removed. A rigid-body correction within and across runs
accounted for head motion (FSL 4.1.7; FMRIB). In addition, a nonlinear registration of the
functional data to a T2*-weighted MNI template (SPM2; Wellcome Department of Imaging
Neuroscience, London, United Kingdom) yielded images re-sampled at 2-mm³ voxels. Next, a
series of functional connectivity-specific preprocessing steps were carried out (based on Biswal,
Yetkin, Haughton, & Hyde, 1995; Van Dijk et al., 2010). Specifically, data within each session
were first concatenated and spatially smoothed by using a 6-mm FWHM kernel. These images
were then temporally filtered (low-pass) to retain frequencies below 0.08 Hz. A series of
nuisance regressors reflecting spurious noise or systematic variance associated with nonneural
sources were created and removed by using partial regression. These nuisance regressors
included the six parameters computed from the rigid-body motion correction and their
derivatives, the averaged signal within the lateral ventricles, an ROI within the deep white
matter, and an ROI comprising the whole brain (i.e., global signal regression). We included each regressor’s first temporal derivative due to temporal shifts in BOLD signal. It should be noted that the merits of using global signal regression have been debated (an alternative is provided in Murphy, Birn, Handwerker, Jones, & Bandettini, 2009, and an example of justification for the adopted technique is provided in Fox, Zhang, Snyder, & Raichle, 2009).

Appendix Figure 3.1. Participants completed a within-subjects, event-related design in a single fMRI scanning session. (Top) Scanning procedure. In segment one of scanning, participants viewed a short video followed by a brief filler task, and then received either a control induction (focused on general impressions of the video or math problems) or the episodic specificity induction (focused on specific features of the video). After the induction phase, participants
completed three runs of functional neuroimaging for the main tasks in which they viewed 36 object cues (12 per run) and generated an imagined event related to the cue or a semantic object comparison and definitions related to the cue. Following these runs of scanning, participants completed one resting-state scan, and then a brief filler task before beginning segment two (involving whichever video and induction were not received in the first segment, and new main task cues). (Middle) Sample trial cycle during the 3 fMRI task runs. Participants viewed a screen for 20 s with the phrase “imagine” or “objects” followed by the instruction “near future event” or “size and define” followed by an object cue (e.g., CLOCK). Participants pressed a button when they had initially constructed an imagined event or size sentence for the object cue, and then elaborated on the contents of the imagined event or semantic definitions for the objects from the size sentence until the trial was over. Two ratings for 4 s each for detail and task engagement then appeared, followed by an odd/even jittered baseline task for 4, 6, or 8 s. (Bottom) Postscan procedure. After completing the two segments in the scanner, participants again viewed the cues they had seen for the main tasks outside the scanner, verbally stated what they had thought about for each one, and completed additional ratings to ensure task compliance. Individual difference questionnaires for creativity, personality, and memory were also collected (which are not included in this report). Participant responses to the cues were audio-recorded. After the scanning session and postscan, the responses were transcribed and scored by raters blind to hypothesis and induction for different details.

Appendix Figure 3.2. MTL subsystem regions (and the precuneus) with stronger recruitment for constructing imagined events (relative to the semantic object task) with higher detail following the specificity induction compared with the control at the threshold of $P < 0.005$, uncorrected (with an extent threshold of 10 voxels).
Appendix Table 3.1

**fMRI Main Task Reaction Times and Ratings**

<table>
<thead>
<tr>
<th>Rating</th>
<th>Control induction</th>
<th>Specificity induction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Imagine construction, s</td>
<td>5.74 (3.04)</td>
<td>5.63 (2.81)</td>
</tr>
<tr>
<td>Object construction, s</td>
<td>7.75 (2.57)</td>
<td>7.48 (2.32)</td>
</tr>
<tr>
<td>Imagine detail rating</td>
<td>3.70 (0.61)</td>
<td>3.75 (0.52)</td>
</tr>
<tr>
<td>Object detail rating</td>
<td>3.49 (0.65)</td>
<td>3.53 (0.63)</td>
</tr>
<tr>
<td>Imagine on-task (out of 18)</td>
<td>17.50 (1.32)</td>
<td>17.41 (1.50)</td>
</tr>
<tr>
<td>Object on-task (out of 18)</td>
<td>17.66 (0.60)</td>
<td>17.72 (0.58)</td>
</tr>
</tbody>
</table>

*Note.* Values are presented as mean (SD). Detail ratings range from 1 (least) to 5 (most). No significant differences emerged in output variables as a function of induction. As in previous work (Hach et al., 2014), objects took longer to construct than imagined events. They were also rated as less detailed.

Appendix Table 3.2

**Postscan Details Generated**

<table>
<thead>
<tr>
<th>Detail</th>
<th>Control induction</th>
<th>Specificity induction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Imagine total details</td>
<td>13.63 (7.12)</td>
<td>14.64 (7.49)</td>
</tr>
<tr>
<td>Object total details</td>
<td>12.91 (7.16)</td>
<td>12.17 (5.31)</td>
</tr>
<tr>
<td>Imagine episodic details</td>
<td>11.62 (5.58)</td>
<td>13.06 (5.98)</td>
</tr>
<tr>
<td>Imagine semantic details</td>
<td>2.00 (2.14)</td>
<td>1.58 (1.96)</td>
</tr>
<tr>
<td>Object main details</td>
<td>12.10 (7.01)</td>
<td>11.49 (5.25)</td>
</tr>
<tr>
<td>Object extraneous details</td>
<td>0.81 (0.96)</td>
<td>0.68 (0.96)</td>
</tr>
</tbody>
</table>

*Note.* Values are presented as mean (SD). Consistent with previous behavioral work (Madore & Schacter, 2016), imagined events following the specificity induction contained significantly more total details than those generated following the control. This increase was driven by a selective and significant increase in episodic details, but not semantic details. There was no difference in any sort of detail on object comparisons as a function of induction. There were also no differences in details generated across each task irrespective of induction. It should be noted that total time and total word count for task responses generated during the postscan likewise did not vary as a function of induction.
Appendix Table 3.3

Postscan Ratings

<table>
<thead>
<tr>
<th>Rating</th>
<th>Control induction</th>
<th>Specificity induction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Imagine difficulty</td>
<td>2.02 (0.52)</td>
<td>1.92 (0.48)</td>
</tr>
<tr>
<td>Object difficulty</td>
<td>2.52 (0.62)</td>
<td>2.53 (0.53)</td>
</tr>
<tr>
<td>Imagine similarity</td>
<td>2.76 (0.70)</td>
<td>2.88 (0.74)</td>
</tr>
<tr>
<td>Imagine plausibility</td>
<td>3.45 (0.73)</td>
<td>3.54 (0.69)</td>
</tr>
<tr>
<td>Object familiarity</td>
<td>3.92 (0.47)</td>
<td>3.93 (0.53)</td>
</tr>
</tbody>
</table>

Note. Values are presented as mean (SD). Scores on the Likert scale range from 1 (least) to 5 (most). No significant differences emerged in output variables as a function of induction. Object trials were rated as more difficult than imagine trials. Overall, imagined events were plausible and not very similar to past experiences, and object comparisons involved familiar enough objects.
Appendix Table 3.4

Regions with Peak Activation in Main Task Analyses During Imagine Construction > Object Construction and Imagine Elaboration > Object Elaboration for Each Induction

<table>
<thead>
<tr>
<th>Brain region</th>
<th>x</th>
<th>y</th>
<th>z</th>
<th>Z-score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Imagine construction &gt; object construction for control induction</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left medial prefrontal cortex/anterior cingulate cortex</td>
<td>−4</td>
<td>54</td>
<td>−2</td>
<td>6.84</td>
</tr>
<tr>
<td>Left parahippocampal gyrus</td>
<td>−24</td>
<td>−34</td>
<td>−14</td>
<td>6.37</td>
</tr>
<tr>
<td>Left posterior cingulate cortex</td>
<td>−4</td>
<td>−56</td>
<td>16</td>
<td>5.89</td>
</tr>
<tr>
<td>Right middle temporal gyrus</td>
<td>54</td>
<td>−4</td>
<td>−16</td>
<td>5.67</td>
</tr>
<tr>
<td>Right parahippocampal gyrus</td>
<td>26</td>
<td>−32</td>
<td>−14</td>
<td>5.31</td>
</tr>
<tr>
<td>Left middle temporal gyrus</td>
<td>−64</td>
<td>−6</td>
<td>−14</td>
<td>5.06</td>
</tr>
<tr>
<td>Right superior temporal gyrus</td>
<td>52</td>
<td>−58</td>
<td>18</td>
<td>4.44</td>
</tr>
<tr>
<td>Imagine construction &gt; object construction for specificity induction</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left medial prefrontal cortex</td>
<td>−2</td>
<td>50</td>
<td>−6</td>
<td>7.52</td>
</tr>
<tr>
<td>Right superior temporal gyrus</td>
<td>52</td>
<td>−60</td>
<td>22</td>
<td>6.69</td>
</tr>
<tr>
<td>Left inferior temporal gyrus</td>
<td>−60</td>
<td>−6</td>
<td>−18</td>
<td>5.88</td>
</tr>
<tr>
<td>Left angular gyrus</td>
<td>−46</td>
<td>−74</td>
<td>32</td>
<td>5.18</td>
</tr>
<tr>
<td>Left temporal pole</td>
<td>−48</td>
<td>18</td>
<td>−30</td>
<td>5.03</td>
</tr>
<tr>
<td>Right precentral gyrus</td>
<td>40</td>
<td>−12</td>
<td>52</td>
<td>4.63</td>
</tr>
<tr>
<td>Left cerebellum</td>
<td>−6</td>
<td>−52</td>
<td>−42</td>
<td>4.47</td>
</tr>
<tr>
<td>Right middle frontal gyrus</td>
<td>48</td>
<td>36</td>
<td>−2</td>
<td>4.34</td>
</tr>
<tr>
<td>Left cerebellum</td>
<td>−18</td>
<td>−84</td>
<td>−40</td>
<td>4.32</td>
</tr>
<tr>
<td>Left superior frontal gyrus</td>
<td>−20</td>
<td>34</td>
<td>46</td>
<td>3.96</td>
</tr>
<tr>
<td>Imagine elaboration &gt; object elaboration for control induction</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left medial prefrontal cortex</td>
<td>−6</td>
<td>20</td>
<td>−16</td>
<td>6.26</td>
</tr>
<tr>
<td>Left posterior cingulate cortex</td>
<td>−2</td>
<td>−54</td>
<td>18</td>
<td>5.04</td>
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<tr>
<td>Right middle occipital gyrus</td>
<td>46</td>
<td>−64</td>
<td>28</td>
<td>4.76</td>
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<tr>
<td>Right middle temporal gyrus</td>
<td>58</td>
<td>−4</td>
<td>−18</td>
<td>4.60</td>
</tr>
<tr>
<td>Right middle temporal pole</td>
<td>44</td>
<td>24</td>
<td>−34</td>
<td>4.51</td>
</tr>
<tr>
<td>Left parahippocampal gyrus</td>
<td>−24</td>
<td>−36</td>
<td>−14</td>
<td>4.46</td>
</tr>
<tr>
<td>Left angular gyrus</td>
<td>−42</td>
<td>−72</td>
<td>30</td>
<td>4.42</td>
</tr>
<tr>
<td>Left middle temporal gyrus</td>
<td>−60</td>
<td>−8</td>
<td>−14</td>
<td>4.10</td>
</tr>
<tr>
<td>Left inferior orbitofrontal cortex</td>
<td>−38</td>
<td>28</td>
<td>−16</td>
<td>3.71</td>
</tr>
<tr>
<td>Imagine elaboration &gt; object elaboration for specificity induction</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left medial prefrontal cortex</td>
<td>−10</td>
<td>46</td>
<td>−16</td>
<td>6.33</td>
</tr>
<tr>
<td>Left middle temporal gyrus</td>
<td>−66</td>
<td>−14</td>
<td>−16</td>
<td>5.93</td>
</tr>
<tr>
<td>Right middle temporal gyrus</td>
<td>62</td>
<td>−48</td>
<td>6</td>
<td>4.48</td>
</tr>
<tr>
<td>Left cerebellum</td>
<td>−28</td>
<td>−78</td>
<td>−34</td>
<td>4.38</td>
</tr>
<tr>
<td>Right paracentral lobule</td>
<td>4</td>
<td>−34</td>
<td>74</td>
<td>4.19</td>
</tr>
<tr>
<td>Left angular gyrus</td>
<td>−48</td>
<td>−74</td>
<td>34</td>
<td>4.09</td>
</tr>
</tbody>
</table>

Note. For each cluster of activation, the MNI coordinates of the maximally activated (i.e., peak) voxel are reported at the threshold of \( P < 0.001 \), uncorrected (with an extent threshold of 65 voxels, yielding in a corrected threshold of \( P < 0.05 \)).
Appendix Table 3.5

*Regions with Peak Activation in Main Task Analyses for Specificity Induction > Control Induction During the Construction Phase of Imagined Events > Object Comparisons*

<table>
<thead>
<tr>
<th>Brain region</th>
<th>x</th>
<th>y</th>
<th>z</th>
<th>Z-score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right inferior parietal lobule</td>
<td>38</td>
<td>-32</td>
<td>36</td>
<td>4.82</td>
</tr>
<tr>
<td>Right thalamus</td>
<td>12</td>
<td>-6</td>
<td>10</td>
<td>4.17</td>
</tr>
<tr>
<td>Left anterior hippocampus</td>
<td>-34</td>
<td>-16</td>
<td>-12</td>
<td>3.93</td>
</tr>
<tr>
<td>Right precentral gyrus</td>
<td>38</td>
<td>-10</td>
<td>46</td>
<td>3.91</td>
</tr>
<tr>
<td>Right posterior cingulate cortex</td>
<td>6</td>
<td>-34</td>
<td>24</td>
<td>3.76</td>
</tr>
<tr>
<td>Right supplementary motor area</td>
<td>2</td>
<td>-16</td>
<td>72</td>
<td>3.67</td>
</tr>
<tr>
<td>Right ventral precuneus</td>
<td>14</td>
<td>-58</td>
<td>46</td>
<td>3.65</td>
</tr>
<tr>
<td>Left caudate</td>
<td>-20</td>
<td>14</td>
<td>16</td>
<td>3.62</td>
</tr>
</tbody>
</table>

*Note.* For each cluster of activation, the MNI coordinates of the maximally activated (i.e., peak) voxel are reported at the threshold of $P < 0.001$, uncorrected (with an extent threshold of 65 voxels, yielding in a corrected threshold of $P < 0.05$).

Appendix Table 3.6

*Regions with Peak Activation in Parametric Modulation Analysis (of Detail) for Specificity Induction > Control Induction During the Construction Phase*

<table>
<thead>
<tr>
<th>Brain region</th>
<th>x</th>
<th>y</th>
<th>z</th>
<th>Z-score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left middle temporal gyrus</td>
<td>-44</td>
<td>-64</td>
<td>6</td>
<td>3.83</td>
</tr>
<tr>
<td>Right fusiform gyrus</td>
<td>42</td>
<td>-50</td>
<td>-16</td>
<td>3.78</td>
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<tr>
<td>Right precentral gyrus</td>
<td>32</td>
<td>-20</td>
<td>40</td>
<td>3.53</td>
</tr>
<tr>
<td>Right ventral precuneus</td>
<td>4</td>
<td>-56</td>
<td>46</td>
<td>3.49</td>
</tr>
<tr>
<td>Right cerebellum</td>
<td>22</td>
<td>-34</td>
<td>-24</td>
<td>3.43</td>
</tr>
<tr>
<td>Right cuneus</td>
<td>26</td>
<td>-62</td>
<td>20</td>
<td>3.33</td>
</tr>
<tr>
<td>Left cerebellum</td>
<td>-6</td>
<td>-50</td>
<td>-32</td>
<td>3.25</td>
</tr>
<tr>
<td>Left insula</td>
<td>-40</td>
<td>-10</td>
<td>12</td>
<td>3.23</td>
</tr>
<tr>
<td>Left caudate</td>
<td>-10</td>
<td>2</td>
<td>20</td>
<td>3.19</td>
</tr>
<tr>
<td>Left superior temporal pole</td>
<td>-38</td>
<td>18</td>
<td>-24</td>
<td>3.05</td>
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<td>-34</td>
<td>14</td>
<td>3.03</td>
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<tr>
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<td>-20</td>
<td>-16</td>
<td>3.00</td>
</tr>
<tr>
<td>Right caudate</td>
<td>14</td>
<td>2</td>
<td>12</td>
<td>2.88</td>
</tr>
<tr>
<td>Right inferior parietal lobule (posterior)</td>
<td>36</td>
<td>-76</td>
<td>44</td>
<td>2.86</td>
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<tr>
<td>Left anterior hippocampus</td>
<td>-36</td>
<td>-26</td>
<td>-14</td>
<td>2.83</td>
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</table>
Appendix Table 3.6 (Continued)

*Note.* For each cluster of activation, the MNI coordinates of the maximally activated (i.e., peak) voxel are reported at the threshold of $P < 0.005$, uncorrected (with an extent threshold of 10 voxels).

Appendix Table 3.7

*Regions with Peak Activation in Resting-state Functional Connectivity Analyses for Specificity Induction > Control Induction*

<table>
<thead>
<tr>
<th>Brain region</th>
<th>x</th>
<th>y</th>
<th>z</th>
<th>t-score</th>
</tr>
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<tbody>
<tr>
<td><strong>Specificity induction &gt; control induction for left anterior hippocampal seed</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right parahippocampal gyrus</td>
<td>20</td>
<td>−4</td>
<td>−26</td>
<td>3.84</td>
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<td>Right midbrain</td>
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<td>−26</td>
<td>−10</td>
<td>3.79</td>
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<tr>
<td>Right cerebellum</td>
<td>16</td>
<td>−48</td>
<td>−60</td>
<td>3.77</td>
</tr>
<tr>
<td>Left intraparietal sulcus</td>
<td>−28</td>
<td>−52</td>
<td>24</td>
<td>3.74</td>
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<td><strong>Specificity induction &gt; control induction for right inferior parietal lobule seed</strong></td>
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<td></td>
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<tr>
<td>Left parahippocampal gyrus</td>
<td>−32</td>
<td>−2</td>
<td>−26</td>
<td>4.43</td>
</tr>
<tr>
<td>Left anterior cingulate cortex</td>
<td>−20</td>
<td>−32</td>
<td>20</td>
<td>4.19</td>
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<td>Left inferior temporal gyrus</td>
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<td>−42</td>
<td>−22</td>
<td>4.16</td>
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<tr>
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<td>−4</td>
<td>4</td>
<td>4.08</td>
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<td>−16</td>
<td>34</td>
<td>3.88</td>
</tr>
<tr>
<td>Left superior frontal gyrus</td>
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<td>62</td>
<td>42</td>
<td>3.84</td>
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<td>Left superior medial frontal gyrus</td>
<td>−6</td>
<td>32</td>
<td>56</td>
<td>3.82</td>
</tr>
</tbody>
</table>

*Note.* For each cluster of activation, the MNI coordinates of the maximally activated (i.e., peak) voxel are reported at the threshold of $P < 0.001$, uncorrected (with an extent threshold of 38 voxels, yielding in a corrected threshold of $P < 0.05$).