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Memory Errors and Distortion

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Abstract

Human memory is prone to various kinds of errors and distortions, including misattribution (assigning a memory to the wrong source, resulting in such phenomena as false recognition), and suggestibility (memories that are implanted as a consequence of leading questions or misinformation). Here we review research on memory errors conducted during the past two decades. We organize our discussion around six major themes that we believe have emerged from, or have been strengthened by, recent research: 1) susceptibility to different kinds of memory distortions involves some common but largely distinct processes; 2) it is important to characterize subjective experiences associated with memory distortions; 3) sensory reactivation can distinguish between true and false memories under limited conditions; 4) memory specificity has multiple effects on memory distortion; 5) reactivation, recombination, and simulation processes can contribute to memory distortion; and 6) evidence is mounting in support of an adaptive perspective on memory distortion. We focus mainly on cognitive studies, but also discuss neuroimaging research when it is relevant to one of our main themes. We argue that the study of memory errors has made significant advances during the past two decades, and that these advances have contributed importantly to our understanding of memory as a fundamentally constructive process.

Keywords
memory distortion, memory error, misattribution, suggestibility, false recognition, false recall

Introduction

It has long been recognized that memory is an imperfect process, subject to a variety of errors and distortions that have important theoretical implications and practical consequences (e.g., Bartlett, 1932; Brainerd & Reyna, 2005; Gallo, 2006; Loftus, 1979, 2003; Neisser, 1967; Schacter, 1995). Schacter (1999, 2001) proposed that memory errors could be classified into seven basic categories or "sins". The first three are sins of omission that refer to different forms of forgetting: *transience* (loss of retention over time), *absentmindedness* (failures of attention that result in memory loss), and *blocking* (inability to retrieve information that is available in memory). The other four are sins of commission, where some form of memory is present but is either wrong or unwanted. These sins include three kinds of memory distortion: *misattribution* (attributing memory to an incorrect source), *suggestibility* (implanted memories resulting from suggestion or misleading information), and *bias* (distorting effects of current knowledge, beliefs, and feelings on memory). The final sin is *persistence* (intrusive, unwanted recollections that people cannot forget).

In the present chapter, we review findings and ideas regarding the nature of the distortion-related sins, focusing primarily on misattribution and suggestibility (for detailed discussion of recent findings concerning various forms of retrospective bias, see Bernstein, Aßfalg, Kumar, & Ackerman, 2016; Levine, Lench, Karnaze, & Carlson, 2018; Lotterman & Bonanno, 2014; Van Boekel, Varma, & Varma, 2017). We discuss mainly research that has been reported during the past two decades, following publication of both the seven sins of memory framework (Schacter, 1999, 2001) and the previous edition of the *Oxford Handbook of Memory* (Tulving & Craik, 2000). That edition contained excellent chapters by Roediger and McDermott (2000) on distortions of memory and by Mitchell and Johnson (2000) on source monitoring that cover much of the foundational research that has led to the recent developments we focus on here.

We will organize the chapter according to six key themes that we believe have emerged from, or been strengthened by, research on memory distortions during the past two decades: 1) *susceptibility to different kinds of memory distortions involves some common but largely distinct processes*; 2) *it is important to characterize subjective experiences associated with memory distortions*; 3) *sensory reactivation can distinguish between true and false memories under limited conditions*; 4) *memory specificity has multiple effects on memory distortion*; 5) *reactivation, recombination, and simulation processes can contribute to memory distortion*; and 6) *evidence is mounting in support of an adaptive perspective on memory distortion*.

We will focus mainly on cognitive/behavioral studies, but we will also draw on neuroimaging findings when they are relevant to our key themes (for detailed reviews of neuroimaging studies of memory distortion, see Dennis, Bowman, & Turney, 2015; Kurkela & Dennis, 2016; Schacter, Chamberlain, Gaesser, & Gerlach, 2012; Schacter & Slotnick, 2004). Moreover, we will also focus mainly on young adult populations, and refer the reader elsewhere for detailed reviews of false memories in aging (Devitt & Schacter, 2016), clinical populations (Schnider, 2018), and children (Lawson, Rodriguez-Steen, & London, 2018; Melnyk, Crossman, & Scullin, 2007). Thus, we do not attempt a comprehensive overview of the vast literature on memory errors and distortions that has been published since the previous edition of the *Oxford Handbook of Memory*, but instead provide a more focused discussion of what we believe are some key findings and ideas that have emerged during the past two decades.

Susceptibility to Different Kinds of Memory Distortions Involves Some Common but Largely Distinct Processes

A fundamental tenet of the seven sins framework is that there are different kinds of memory distortions, which are typically linked with the use of specific experimental paradigms. For example, one of the most intensively studied experimental paradigms for investigating misattributions was developed initially by Deese (1959) and later revived and extended by Roediger and McDermott (1995). In what is now called the Deese-Roediger-McDermott or "DRM" paradigm, participants are exposed to lists of semantically associated words, and subsequently exhibit robust levels of false recall and false recognition of a nonstudied "critical lure" word that is strongly associated with the studied target items (for detailed reviews, see Gallo, 2006, 2010). Misattributions have also been studied using an "imagination inflation" procedure, where imagining the occurrence of a past event boosts confidence that the event actually occurred (Garry, Manning, Loftus, & Sherman, 1996). A classic procedure for studying suggestibility is the misinformation paradigm, where after viewing a target event, participants are given misleading suggestions about what happened in that event, often leading them to claim that the misinformation was a part of the original event (e.g., Loftus, Miller, & Burns, 1978; for review, see Loftus, 2005). Related procedures have been developed using elements of both suggestion and imagination to implant so-called "rich false memories" of entire events that never occurred, typically focused on childhood and adolescence (e.g., Loftus, 2003; Shaw & Porter, 2015). Research on retrospective bias has used a variety of paradigms to examine specific forms of bias, including consistency and change biases, where current knowledge and beliefs lead people to recollect the past as overly similar to or different from the present (e.g., Wilson & Ross, 2003), and hindsight bias, where knowledge of the outcome of an event leads people to believe that they "knew it all along" (e.g., Guilbault, Bryant, Brockway, & Posavac, 2004).

Given the variety of memory distortions that have been documented, a fundamental question concerns whether or not they reflect the operation of a generalized tendency for memory distortion or false memories. There has been extensive research on individual differences in susceptibility to specific kinds of memory distortion (e.g., DRM false memories and misinformation effects; for review, see Nichols & Loftus, 2019), but less research regarding possible relations among types of memory distortions. Nonetheless, some relevant evidence does exist.

Clancy, Schacter, McNally, and Pitman (2000) reported increased DRM false recognition in women claiming to recover repressed memories of childhood sexual abuse, compared with women who reported abuse and always remembered it, women who believed they had been abused as children but had no memory of it, and a non-abused control group. If the recovered memories were false, then the increased DRM false recognition would constitute evidence for a relation between different kinds of memory distortions, but as Clancy et al. (2000) noted, it is entirely possible that the recovered memories of abuse were accurate. To investigate the issue further, Clancy, McNally, Schacter, Lenzenweger, & Pitman (2002) studied individuals who claimed to recover memories of a highly improbable event that is extremely unlikely to have occurred, abduction by space aliens. Clancy et al. found that people who "remembered" abduction by aliens showed higher levels of DRM false recall and recognition compared to a matched control group. Note, however, that Clancy et al. also reported a similar pattern in individuals who *believed* that they had been abducted but had not developed a full-blown false memory. In a later study, Meyersburg, Bogdan, Gallo, & McNally (2009) found heightened DRM false recall and false recognition in individuals who claimed to remember another highly improbable event - a past life – compared with controls who did not claim any such memory.

If the improbable events in the foregoing studies never occurred, then the findings suggest that a common underlying factor links DRM false memories and susceptibility to everyday "rich" false memories (and false beliefs). Qin, Ogle, and Goodman (2008) examined this issue by comparing performance on DRM false recall and recognition tasks with a "lost-in-the-mall" paradigm that elicits false memories of childhood events in a minority of participants (Loftus & Pickrell, 1995). Qin et al. reported mixed results: levels of DRM false memories did not predict susceptibility to false childhood memories, but the use of an overall liberal criterion on the DRM task was associated with increased susceptibility to false childhood memories. In a related study of children, Otgaar, Verschure, Meijer, and van Oorsouw (2012) found a modest positive correlation between DRM false recall and susceptibility to false memory for a suggested everyday event, and Zhu, Cheng, Loftus, Lin, and Dong (2013) reported a weak but significant positive correlation between susceptibility to post-event misinformation effects and DRM false recognition in a study using a large sample size (N=432).

By contrast, several studies have reported null correlations between susceptibility to misinformation and DRM false recall or recognition (Calvillo & Parong, 2016; Monds, Paterson, & Kemp 2017; Ost, Blank, Davies, Jones, Lambert, & Salmon, 2013), and one study reported a negative correlation between susceptibility to misinformation effects and hindsight bias (Calvillo, 2014). More recent studies using very large sample sizes (i.e., N=200-500) have all reported weak-to-null correlations among paradigms that elicit different kinds of memory distortions: DRM false recall/recognition, misinformation, false event suggestions, inference-based integration, and imagination inflation (Bernstein, Scoboria, Desjarlais, & Soucie, 2018; Calvillo, Vasquez, & Pesavento, 2019; Patihis, Frenda, & Loftus, 2018; Nichols & Loftus, 2019; Varga, Gaugler, & Talarico, 2019). These findings led Bernstein et al. (2018), Patihis et al.

(2018), and Nichols and Loftus (2019) to conclude that there is no single false memory "trait" that predicts susceptibility to memory distortion across paradigms. Of course, this conclusion need not imply that no common mechanisms operate across types of memory distortion. For example, as discussed by Nichols and Loftus (2019), source misattributions play some role in each of the memory errors they investigated. Indeed, an earlier analysis by Mazzoni and Vannucci (2007) proposed that source misattribution and other metacognitive judgments contribute to memory distortions observed in the misinformation paradigm, false autobiographical memories, and hindsight bias (see also, Varga et al., 2019).

Overall, there may be some mechanistic overlap among types of memory distortion that contributes to the modest positive correlations across paradigms that are occasionally reported. However, the bulk of the evidence suggests that specific kinds of memory distortions also recruit largely independent, domain-specific processes, e.g., semantic/associative processes in the case of DRM false recall and recognition, imaginative construction in the case of imagination inflation, and vulnerability to suggestion in the case of misinformation effects and false event suggestions. However, it seems clear that more research is needed to elucidate similarities and differences among mechanisms that underpin specific types of memory distortions.

It is Important to Characterize Subjective Experiences Associated with Memory Distortions

A compelling aspect of memory distortions concerns the strong subjective experiences that can be associated with them. In this section we consider four areas in which assessment of subjective experience has implications for understanding the nature or significance of a particular kind of memory error. We begin by considering research using the DRM paradigm, where characterization of subjective experiences that accompany false recognition has had significant theoretical ramifications. We then turn our attention to studies that have developed experimental methods for characterizing subjective experiences associated with the compelling but poorly understood experience of déjà vu. We conclude by considering two lines of research in which the nature of subjective experience has significant implications for understanding memory errors in real-world settings: the distinction between false memories and false beliefs, and eyewitness memory.

DRM false recognition One of the striking aspects of DRM false recognition, originally reported by Roediger and McDermott (1995) and subsequently replicated many times, is that participants express high confidence when they claim that a related lure word appeared on the list, at a level similar to the confidence expressed in study list items. Functional magnetic resonance imaging (fMRI) evidence reveals indistinguishable neural correlates of confidence for DRM studied items and critical lures (Moritz, Gläscher, Somner, Büchel, Braus, 2006). Moreover, Roediger and McDermott (1995) observed that a majority of studied items and critical lures judged as old were accompanied by "remember" responses (i.e., participants recollect specific details associated with prior presentation) rather than "know" responses (i.e., the item seems familiar but lacking in specific details; Tulving, 1985). This result, too, has since been replicated many times (for review, see Gallo, 2010). Bypassing reliance on introspective reports, Brainerd, Wright, Reyna, and Mojardin (2001) developed a modeling approach to demonstrate the existence of what they termed "phantom recollection" in the DRM and related paradigms: false recognition associated with illusory conscious experience. Other studies have shown that false alarms to critical lure items are often accompanied by misattributions of illusory perceptual, contextual, and associative details, ranging from the voices or sensory modality in which studied words were spoken during initial presentation (O'Neill & Diana, 2017; Roediger, McDermott, Pisoni, & Gallo, 2004) to associations that participants generated during encoding of study list items (Lampinen, Meier, Arnal, & Leding, 2005).

These observations are important because they indicate that false recognition in the DRM paradigm is not simply the product of a criterion shift or biased guessing strategy (e.g., Miller & Wolford, 1999; cf., Wixted & Stretch, 2000). Rather, converging evidence from the foregoing and other studies justify the characterization of “old” responses to DRM critical lures as “false memories” because they are accompanied by subjective experiences comparable to those associated with true memories.

Déjà vu Déjà vu refers to the illusory subjective experience that an objectively novel situation is familiar. Numerous theories concerning the origins of déjà vu have been put forward (for detailed reviews, see Brown, 2003, 2004; Moulin, 2018), but progress in understanding the basis of déjà vu has been hampered by the lack of controlled experimental paradigms for inducing and exploring the phenomenon. However, that situation has begun to change, as researchers have begun to develop laboratory analogues of déjà vu to explore both cognitive (e.g., O’Connor, Barnier, & Cox, 2008) and neural (e.g., Urquhart, Sivakumaran, Macfarlane, & O’Connor, 2018) characteristics of the phenomenon. Cleary et al. (2012) developed a virtual reality procedure in which participants viewed a series of scenes and later tried to remember them. Cleary et al. found that when participants were presented with a novel scene that was configurally similar to a previously viewed but unrecalled scene, there was an increased likelihood that they would report an experience of déjà vu. Building on this procedure, Cleary and Claxton (2018) used a modified version of the virtual reality paradigm to examine another subjective experience commonly reported during déjà vu states: the feeling that one knows what is going to happen next. When participants were tested on novel scenes, they were instructed that: “Without knowing why, you may also feel a sense of which way to turn next. Indicate which way to turn. Press L for Left and R for Right.” They found that participants claimed to have a feeling of which way to turn next more frequently when they reported an experience of déjà vu to a novel, configurally similar scene than when they did not report an experience of déjà vu. Despite this subjective conviction, however, participants were unable to predict with above-chance accuracy what the next turn would be. These findings led Cleary and Claxton (2018) to characterize déjà vu as an “illusion of prediction” and to link the phenomenon with research demonstrating a close connection between memory and future thinking (Schacter, Addis, & Buckner, 2007).

False memories and false beliefs Research on memory distortion during the 1990s was fueled, in part, by controversies concerning the accuracy of repressed and subsequently recovered memories of childhood sexual abuse (e.g., Loftus, 1993; Patihis, Ho, Tingen, Lilienfeld, & Loftus, 2014; Patihis & Pendergrast, 2019). Standard laboratory procedures for studying memory distortions, such as the post-event misinformation paradigm, typically elicited errors regarding only relatively minor details of target items (e.g., remembering a suggested yield sign instead of a perceived stop sign; Loftus et al., 1978). As such, intense interest emerged as to whether it was possible to implant false memories of entire events, including traumatic ones, that resemble more closely the kinds of repressed memories allegedly recovered in therapy. Loftus (1993) reported a case study of an adolescent named Chris who was asked by his older brother to try to recall the time he had been lost in a shopping mall as a five-year old child – an event that, according to his brother and other family members, never occurred. Chris initially failed to recall this event, but after several days of probing, generated a detailed but false recollection of it. Loftus and Pickrell (1995) extended this basic procedure by asking 24 participants to recall three actual events provided by relatives, along with the false "lost in the mall" event, and they found that 25% of participants eventually generated and retained a false memory of being lost in a mall or similar public place. Using variations of this basic "familial-informant false narrative" procedure, subsequent studies revealed that roughly 25%-40% of participants developed false memories of various mildly traumatic childhood events, including spilling punch at a wedding (Hyman, Husband, & Billings, 1995), a serious animal attack (Porter, Yuille, & Lehman, 1999), and being pulled out of water by a lifeguard (Heaps & Nash, 2001).

Using a modified version of the familial-informative false narrative paradigm, Shaw and Porter (2015) subsequently reported what appeared to be a substantial increase in false memories among college students for an extremely serious and relatively recent event: committing a crime as an adolescent. Questionnaires were sent to primary caregivers of 126 undergraduates asking about 3 negative emotional non-criminal events (accident, animal attack, losing a lot of money) and criminal events (assault, assault with a weapon, theft) that occurred during a student's adolescence. The study ultimately included sixty individuals who met participation criteria: the caregiver provided at least one emotional non-criminal event that had occurred, indicated none of the criminal events had occurred, and that the student never had police contact. Subsequently, students completed three 40-minute interviews at approximately one-week intervals in which they were first asked about the true event, which all of them recalled. For the false event, half of the participants were told that they had committed a crime resulting in police contact (either an assault, assault with a weapon, or theft) and the other half were told that they had experienced an emotional but non-criminal event (either an injury, dog attack, or lost a large sum of money). None of the participants initially recalled any of the false events. The experimenter then applied social pressure (e.g., your parents said the event happened; most people can recall such events if they try hard enough; other rapport building techniques) and encouraged the involvement of imagination by asking participants to visualize the event at home during the week between experimental sessions.

In a final interview, 70% of participants in the criminal conditions and just over 76% of participants in the non-criminal conditions met criteria for false memory, which included both believing that the event occurred, and providing a detailed account of it that included false information suggested by the interviewer. Although Shaw and Porter (2015) characterized their criteria for false memory as "conservative", Wade, Garry, and Pezdek (2018) questioned this claim and carried out a re-analysis of Shaw and Porter's data using both Shaw and Porter's criteria for false memories, and also criteria from Lindsay, Hagen, Read, Wade, and Garry (2004) and Scoboria et al. (2017) that distinguish false *memories* from false *beliefs*, where false beliefs involve accepting a suggestion, speculating about what happened, and generating mental images, but do not reflect a subjective experience of remembering. When using Shaw and Porter's criteria, two independent raters blind to conditions and hypotheses replicated their finding that 70% of participants developed false memories for committing a crime. But when applying the more stringent criteria from Lindsay et al. (2004) and Scorboria et al. (2017) to Shaw and Porter's data, the blind raters judged that only 26-30% of participants developed false memories, far short of Shaw and Porter's estimate, but in line with previous studies that used the familial informant false narrative procedure. The remaining reports were classified as false beliefs. Wade et al. (2018) also conducted experiments in which laypeople evaluated the reports from Shaw and Porter's participants, and they found that these assessments aligned much more closely with the Lindsay et al. and Scoboria et al. criteria for false memories than with Shaw and Porter's criteria (for a response to these points, see Shaw, 2018).

These findings underscore the importance of distinguishing false memories from false beliefs. It remains to be determined precisely which criteria are most appropriate and why. However, the criteria-dependent conclusions concerning Shaw and Porter's data indicate that this is a critical task for future research (for related controversies regarding the prevalence of false memories for real-world events, see Brewin & Andrews, 2017; Nash, Wade, Garry, Loftus, & Ost, 2017).

Eyewitness memory In 1984, a 22-year-old college student named Jennifer Thompson was raped by a man that she incorrectly identified as Ronald Cotton. Thompson developed such high confidence in her inaccurate memory that even when the actual rapist, Bobby Poole, was brought to trial in 1987 after confessing his culpability to Ronald Cotton when both were in prison, Thompson asserted that she had never seen Poole before and persisted in claiming that Cotton was the rapist. Cotton remained in prison until 1995, when DNA evidence showed conclusively that Poole, not Cotton, committed the rape. Thompson and Cotton subsequently became friends, co-authored a book about the case (Thompson-Cannino, Cotton, & Torneo, 2009), and began lecturing together about the dangers of eyewitness misidentifications.

Strong subjective experiences associated with eyewitness misidentification are not uncommon, and are frequently implicated in wrongful convictions reversed by DNA evidence (Garrett, 2011; see Chapter X on Eyewitness Memory). These kinds of findings fit well with the consensus view in the field prior to the past decade that memory confidence and accuracy are at best weakly related (e.g., Wells & Murray, 1984; Penrod & Cutler, 1995), which has important implications for the legal system because high confidence identifications have a strong impact on jurors (Cutler, Penrod, & Stuve, 1988). However, our understanding of the relation between memory confidence and accuracy has undergone a major change in recent years. One problem is that much of the early research on confidence-accuracy relations relied on the point-biserial correlation, despite a paper by Juslin, Olson, and Winman (1996) showing that the point-biserial correlation can greatly underestimate the extent to which confidence and accuracy are related (for detailed discussion, Wixted, Mickes, Clark, Gronlund, & Roediger, 2015; Wixted & Wells, 2017). More recent research that relies on more appropriate measures such as calibration curves has shown a robust positive relationship between confidence and accuracy (e.g., Palmer, Brewer, Weber, & Nagesh, 2013).

What, then, explains the existence of so many cases of confident but inaccurate eyewitness memories? According to Wixted et al. (2015, p. 522), the malleability of memory is to blame: high-confidence but inaccurate identifications implicated in wrongful convictions often begin as hesitant, low-confidence identifications – which is appropriate because in these cases the suspect did not commit the crime – and only later morph into high-confidence identifications as a result of feedback, repeated testing, and suggestion. Thus, post-event processes of the kind associated with the misinformation effect likely play an important role in this transformation of subjective experience associated with an inaccurate memory. Indeed, this is precisely what happened in the Jennifer Thompson case: she was initially extremely uncertain about her identification and only became confident after the police provided confirmatory feedback (Thompson-Canninio et al., 2009, p. 33; for discussion, see Wixted et al., 2015, Wixted & Wells, 2017). Thus, it seems clear that careful analysis of the nature and source of subjective experiences associated with eyewitness memories is a critical task that requires further attention, along with a change in practice such that only eyewitness confidence statements from the original identification are proffered as evidence (National Academies of Sciences, 2014).

Sensory Reactivation Can Distinguish between True and False Memories under Limited Conditions

The strong subjective experiences that often accompany memory errors and distortions can make it difficult to distinguish between true and false memories. After reviewing the available literature a decade ago, Bernstein and Loftus (2009, p. 373) concluded that "it might be virtually impossible to tell reliably if a particular memory is true or false without independent corroboration." However, they also noted that *on average* true memories contain more sensory and perceptual detail than false or imaginary memories, a point that had been established by behavioral research using the misinformation paradigm (e.g., Schooler, Gerhard, & Loftus, 1986), reality monitoring paradigms (e.g., Johnson, Foley, Suengas & Raye, 1988), and the DRM paradigm (e.g., Norman & Schacter, 1997). Moreover, several early neuroimaging studies provided evidence that regions associated with sensory/perceptual processing showed increased activity for true versus false memories (for detailed review, see Schacter & Slotnick, 2004). Here we consider evidence bearing on whether sensory/perceptual reactivation can distinguish true from false memories at the group level, and also ask whether any progress has been made in our ability to distinguish whether a particular memory is true or false.

Sensory reactivation hypothesis Early evidence favoring the sensory reactivation hypothesis came from neuroimaging studies of the DRM paradigm. Following auditory study of DRM lists, neuroimaging evidence revealed increased activation during true relative to false recognition in areas associated with auditory/phonological processing (Abe et al., 2008; Cabeza et al., 2001; Schacter et al., 1996). Similarly, using a visual analog of the DRM paradigm in which participants encoded variations of a prototypical novel visual shape, and on a subsequent recognition test made frequent false alarms to the prototype, Slotnick and Schacter (2004) observed true>false activation in early visual processing regions (i.e., Brodmann area (BA) 17, 18) but not in late, higher-order visual processing regions (i.e., BA 19, 37). Slotnick and Schacter (2006) reported similar findings with the same visual stimuli in a priming paradigm focused on implicit retrieval, suggesting that sensory reactivation need not involve conscious or explicit retrieval.

Kim and Cabeza (2007) examined encoding contributions to true and false memories using a modified DRM paradigm in which participants studied a series of visually presented 4-word DRM lists. Kim and Cabeza used a subsequent memory approach (e.g., Wagner et al., 1998) in which they attempted to identify regions in which encoding-related activity was associated with subsequent true recognition of studied words vs. false recognition of related lure words. Encoding-related activity in late visual regions predicted subsequent true and false recognition, whereas encoding-related activity in early visual regions predicted only true recognition. Kim and Cabeza noted that these findings support a sensory reactivation interpretation of the earlier findings from Slotnick and Schacter.

Extending this line of research to the domain of post-event suggestion, Stark, Okado, and Loftus (2010) used a modified version of the misinformation paradigm in which they presented original event information visually and post-event misinformation auditorily. During a subsequent test phase, they found true>false memory activity in early visual regions overlapping with those reported by Slotnick and Schacter (2004). A variety of other neuroimaging studies have reported similar findings of true>false early visual area activations with visual objects and words (e.g., Dennis, Bowman, & Vandekar, 2012; Dennis, Johnson, & Peterson, 2014; Okado & Stark, 2003) and with unfamiliar faces in which a morphing procedure was used to create lure items (Turney & Dennis, 2017). However, this pattern is not always observed. For example, in a study using categorized visual objects (e.g., participants viewed multiple exemplars of chairs, umbrellas, etc.), Gutchess and Schacter (2012) found that during false recognition, activity in BA 17 modulated as a function of how many related exemplars had been studied previously.

In more recent work using a variant of the abstract shape paradigm developed by Slotnick and Schacter (2004), Karanian and Slotnick (2017) showed that false memories produce robust activation in the lateral occipital complex, but consistent with earlier work, found even greater activation in this area for true recognition. Karanian and Slotnick (2018) tested memory for the spatial location of abstract shapes, and similar to Karanian and Slotnick (2017), found both robust false memory-related activity in an early visual processing region (BA 17) together with true>false activity. Importantly, Karanian and Slotnick (2018) applied transcranial magnetic stimulation (TMS) to this region and found a significant TMS-induced reduction in high-confidence false memories but not high-confidence true memories (compared with control stimulation to the vertex). These findings suggest that early visual regions are not exclusively associated with true memories and can play a causal role in the generation of false memories. Consistent with these findings, a recent meta-analysis of fMRI studies of false memory by Kurkela and Dennis (2016) concluded that visual processing plays a role in retrieving false memories under conditions in which lure items are perceptually similar to targets. These kinds of findings indicate the need for further study of the role of perceptual processing in the genesis of false memories (for relevant behavioral evidence, see Doss, Bluestone, & Gallo, 2016; Lyle & Johnson, 2006), and also indicate that the sensory reactivation hypothesis requires some modification to account for the evidence linking perceptual processing and false memories. Nonetheless, the overall thrust of the neuroimaging evidence is still broadly consistent with the sensory reactivation hypothesis, i.e., the idea that activity in sensory/perceptual regions can distinguish true from false memories.

Particular true and false memories All of the foregoing studies involved averaging across multiple participants and items, so they do not address the question posed by Bernstein and Loftus (2009) concerning whether it is possible to tell if a particular memory is true or false. This question is especially important in legal contexts, where there has been much discussion about the appropriateness of using neuroimaging to determine whether a particular memory of a witness, defendant, or victim is true or false (Schacter et al., 2012; Schacter & Loftus, 2013; see also, Farah, Hutchinson, Phelps, & Wagner, 2014; Lacy & Stark, 2014). Making such a distinction requires the ability to distinguish a true from a false everyday, autobiographical memory for a *single* event in a *single* individual. Recently, progress has been made in using fMRI pattern classification techniques to decode individual memories in the hippocampus (Chadwick, Hassabis, Weiskopf, & Maguire, 2010), study the neural signatures of real-world autobiographical memories using camera technology that allows assessment of memory accuracy (e.g., Chow, Westphal, & Rissman, 2018; Rissman, Chow, Reggente, & Wagner, 2016; for review, see Chow & Rissman, 2017), and determine with considerable accuracy whether an individual subjectively experiences a previously encountered face as old or new (Rissman, Greeley, & Wagner, 2010). Rissman et al. (2010) also showed that a classifier could distinguish to a moderate degree between true and false recognition of a face in single participants, but only for items assigned low confidence responses, and this discrimination was not nearly as robust as that between faces that were subjectively experienced as "old" vs. "new". Nonetheless, we are not aware of any evidence beyond this study that has established that pattern classification or other neuroimaging techniques can be used to distinguish a true from a false memory for a single event in a single individual. Addressing this issue is an important task for future neuroimaging studies of memory distortion.

Memory Specificity has Multiple Effects on Memory Distortion

Evidence supporting the idea that reactivation of sensory/perceptual information can distinguish true from false memories implies that access to specific, detailed mnemonic information can help to avoid or reduce memory distortions. There is abundant support for this hypothesis in the literature. For example, in a classic study of the misinformation effect, Lindsay (1990) exposed participants to a slide sequence depicting a theft followed by a post-event narrative that included several misinformation items. Using the logic of opposition (e.g., Jacoby, Woloshyn, & Kelley, 1989), Lindsay informed participants that any information from the post-event narrative was incorrect, such that when participants did report information from the post-event narrative, a failure of source memory could be inferred. Lindsay compared performance in a low-discriminability condition in which it was difficult to recall the source of the misinformation with a high-discriminability condition in which it was easy to remember the source of the misinformation. In the low-discriminability condition, participants frequently claimed that misleading items were part of the original slide sequence, thereby indicating a failure of source memory. By contrast, in the high-discriminability condition, they successfully avoided falsely recalling the misleading information, thereby indicating successful source memory. Thus, conditions that promoted specific memories of the original event, distinct from the misinformation items, allowed participants to avoid memory errors.

Related phenomena have been observed with the DRM paradigm. Simply repeating DRM study lists several times, and thereby allowing participants to develop more detailed and specific memories of the words that were actually presented, produces significant decreases in subsequent false recall and false recognition of critical lure items (e.g., Benjamin, 2001; Kensinger & Schacter, 1999; McDermott, 1996; Schacter, Verfaellie, Anes, & Racine, 1998). Similarly, research on the *distinctiveness heuristic* (Schacter, Israel, & Racine, 1999) has shown that conditions that promote encoding of specific, distinctive details of list items significantly reduce DRM false recall and false recognition by inducing participants to demand access to specific information before concluding that an item was previously encountered on a study list (e.g., Israel & Schacter, 1997; McCabe & Smith, 2006; Schacter et al., 1999).

These converging lines of evidence from the DRM paradigm support the general idea that memory specificity helps people to avoid memory errors. By contrast, other evidence from the DRM paradigm indicates that conditions exist in which enhanced memory specificity can *increase* susceptibility to memory distortion. Dewhurst, Anderson, Berry, and Garner (2018) administered a DRM paradigm to participants who also completed the Sentence Completion for Events from the Past Test (SCEPT; Raes, Hermans, Williams, & Eelen, 2007), in which people complete 11 sentence stems that refer to past experiences (e.g., "Last week I…"). Each response is then coded for the extent to which it represents a specific memory, with a view toward assessing each individual's habitual retrieval style. Dewhurst et al. found that participants characterized by a specific retrieval style on the SCEPT were more susceptible to false recognition of critical lures in the DRM paradigm.

Converging evidence on this point comes from a study that examined the effects of an Episodic Specificity Induction (ESI) on DRM true and false recall (Thakral, Madore, Devitt, & Schacter, 2019). The ESI involves brief training in recollecting specific details of a recent experience via administration of an adapted version of the Cognitive Interview (CI; initially developed by Fisher & Geiselman, 1992). Studies typically focus on the downstream consequences of administering this ESI on subsequent tasks: if a cognitive task draws on episodic retrieval, then performance on that task should improve following ESI compared with a control induction, whereas tasks that do not draw on episodic retrieval should not benefit from a prior ESI (Madore, Gaesser, & Schacter, 2014). Numerous studies have shown that, compared with a control induction, ESI selectively boosts performance on a variety of subsequent tasks hypothesized to draw on episodic retrieval, including future imagining, means-end problem solving, and divergent creative thinking, while having no effect on tasks that do not draw on episodic retrieval (e.g., describing a picture or defining words; for review, see Schacter & Madore, 2016).

The study by Thakral et al. (2019) contrasted two hypotheses concerning possible mechanisms of ESI. According to the *constructive retrieval* hypothesis, ESI biases the adoption of a retrieval orientation to focus on episodic details, and this retrieval orientation impacts an *event construction* process, i.e., assembling a mental event with details related to places, people, objects, and actions (Schacter & Madore, 2016). According to the *reproductive retrieval* hypothesis, ESI effects may depend on verbatim or reproductive retrieval processes. During ESI, participants typically accurately remember details of the recent video, and the CI on which ESI is based was designed to increase accurate retrieval. Therefore, downstream effects of ESI could depend on such reproductive retrieval, rather than an event construction process. With respect to the DRM paradigm, the constructive retrieval hypothesis predicts that ESI should primarily impact false recall, whereas the reproductive retrieval hypothesis predicts that ESI should impact primarily true recall.

In three separate experiments in which ESI was administered after study and before recall of DRM lists, Thakral et al. (2019) reported that ESI produced significant increases in false recall compared with control inductions, together with no effect on true recall (in a fourth experiment in which ESI was administered before encoding of DRM lists, there were no effects on either true or false recall; see Thakral et al. for discussion). These results clearly support the constructive retrieval hypothesis. Particularly compelling evidence comes from an experiment in which one group of participants received a single exposure to DRM lists followed by ESI or control inductions just prior to a recall test, and a second group received three exposures to the DRM lists followed by ESI or control inductions prior to the recall test, which should increase the impact of reproductive retrieval. As shown in Figure 1, false recall was significantly higher

--Insert Figure 1 about here--

following ESI than the control induction in the single exposure condition, but the impact of ESI on false recall was eliminated in the three-exposure condition. These findings strongly support the idea that ESI engages constructive retrieval processes.

The findings that increased DRM false memories are associated with a specific retrieval style (Dewhurst et al., 2018) and boosted by the ESI manipulation (Thakral et al., 2019) may reflect a tendency for a specific retrieval style or orientation to produce increased reliance on illusory episodic details. As discussed earlier, prior research has established that DRM false memories are sometimes accompanied by illusory recollection of perceptual and contextual details (O'Neill & Diana, 2017; Roediger et al., 2004), which in some cases participants had initially provided as associative responses to list items during study ("content borrowing"; Lampinen et al., 2005). Dewhurst et al. (2018) proposed that a specific retrieval style is associated with increased willingness to rely on such illusory details, and Thakral et al. similarly suggested that ESI enhances the retrieval of episodic details that had been incorrectly linked to critical lure items. Future studies will be needed to assess whether individual differences in memory specificity and experimental manipulations such as ESI are associated with increased susceptibility to other kinds of memory distortions.

Reactivation, Recombination, and Simulation Processes Can Contribute to Memory Distortion

It is well-established that reactivating or retrieving information can be a powerful tool for increasing subsequent memory for the retrieved information, as illustrated by the well-known testing effect (Roediger & Karpicke, 2006; see Chapter X by Pan and Bjork). However, it has become increasingly clear that conditions exist in which various forms of retrieval can increase memory distortion. We consider two broad lines of evidence focused on 1) reactivation and reconsolidation effects, and 2) recombination processes associated with simulation, inference, and future thinking.

Reactivation and reconsolidation effects One line of evidence implicating retrieval and reactivation processes in memory distortion comes from the misinformation literature, where various studies during the past decade or so have established a phenomenon known as *retrieval-enhanced suggestibility* (RES; Chan, Thomas, and Bulevich, 2009). Here, testing information from the original event just prior to presenting misinformation can enhance subsequent acceptance of misinformation items. The initial demonstration of RES was surprising because 1) the phenomenon contrasts sharply with the aforementioned evidence that retrieval practice enhances subsequent retention (Roediger & Karpicke, 2006), and 2) in the context of the misinformation paradigm, RES contradicts the expectation that retrieving information regarding the original event should help to protect against (rather than facilitate) the corrupting influence of misinformation. Nonetheless, RES has since been documented across a range of tasks and conditions (for review, see Butler & Loftus, 2018; LaPaglia & Chan, 2019). However, it is not an inevitable consequence of testing prior to the presentation of misinformation. For example, RES can be eliminated by warning participants about potential inaccuracies in the post-event narrative (Thomas, Bulevich, & Chan, 2010), and testing can either increase or decrease suggestibility in the misinformation paradigm depending on other details of experimental conditions (LaPaglia & Chan, 2012, 2019; Thomas, Gordon, Cernasov, & Bulevich, 2017).

Chan et al. (2009) originally proposed a dual mechanism account of RES, where retrieving event information both enhances learning of the misinformation and also reduces accessibility of the original event by making it more vulnerable to interference from misinformation. Although there is some evidence supporting both possibilities, recent experiments raise questions about whether RES impacts the accessibility of the original event memory (Rindal, DeFranco, Rich, & Zaragoza, 2016). Using procedures similar to those developed by McCloskey and Zaragoza (1985) to critique a memory impairment account of the classic misinformation effect, Rindal et al. (2016) provided evidence against the idea that RES (as observed in a version of the experimental paradigm developed by Chan and LaPaglia, 2013) results in overwriting or destruction of the original event memory: they found no evidence for impairment of the original memory on a modified recognition test in which the misinformation is not presented, and participants instead choose between studied and entirely novel information. They suggest that the reactivation manipulation increased participants' willingness to discount their original memories because of social psychological factors such as trusting experimenter-provided misinformation as necessarily true. Chan, Manley, and Lang (2017) provide useful discussion of these and other accounts of RES.

Nonetheless, the idea that RES might be attributable in part to increased interference from misinformation when the original event is tested led Chan et al. (2009), Chan and LaPaglia

(2013) and others to relate RES to the phenomenon of *reconsolidation*, where reactivation of a memory renders it temporarily vulnerable to disruption (Dudai, 2012; Nader & Einarsson, 2010; see also Chapter X by Nadel & Sederberg). Reconsolidation was established initially in the animal literature by experiments showing that reactivating a memory made it susceptible to disruption by protein synthesis inhibitors that also inhibit the initial consolidation of the memory (Nader, Schafe, & LeDoux, 2000). Since that time, a number of researchers have attempted to establish human analogues of reconsolidation and have proposed that some memory distortions, including RES, may be attributable to reconsolidation processes (for a detailed review, see Elsey, Van Ast, & Kindt, 2018). By this view, reactivating an original memory in the misinformation paradigm produces a labile state in which the memory needs to be reconsolidated and can be more easily impacted by post-event misinformation. The results of Rindal et al. (2016) provide evidence against a strong version of this hypothesis, although as noted by Elsey et al. (2018, p. 831), neither the Rindal et al. experiments nor the Chan and LaPaglia (2013) experiments on which they are based meet all the experimental design criteria typically required of reconsolidation experiments. For example, whereas classical animal studies of reconsolidation follow a 3-day design in which learning occurs on Day 1, memory reactivation on Day 2, and testing on Day 3, the experiments by Chan and LaPaglia and Rindal et al. were conducted within a single day. According to Elsey et al. (2018), this departure from a standard reconsolidation design does not allow sufficient time for the initial consolidation and subsequent reconsolidation of a memory. Thus, additional studies will be needed to further assess a reconsolidation account of RES.

Hupbach and colleagues (Hupbach, Gomez, Hardt, and Nadel, 2007; Hupbach, Gomez, & Nadel, 2009) devised a related experimental paradigm that reveals contributions of retrieval and reactivation processes to memory distortion, and that they interpreted as an example of reconsolidation. In their paradigm, participants encoded a series of objects (List 1) and after a 48-hour delay encoded another series of objects (List 2). For one group, the List 2 objects were preceded by a reminder (i.e., reactivation) of the earlier set of objects, and for a separate group, no reminder was provided. Two days later, participants were asked to recall the List 1 objects. Hupbach and colleagues found that there were more intrusions from List 2 objects in the reminder condition than in the no reminder condition. Although the reminder increased misattribution of List 2 items to List 1, an additional experiment showed no corresponding increase of List 1 items into List 2; this asymmetrical pattern of errors suggests that the intrusion of List 2 objects into List 1 does not simply reflect source memory confusion. Instead, Hupbach et al. interpreted the results as evidence for a reconsolidation effect: reactivation of List 1 items via the reminder rendered memories of List 1 items unstable and susceptible to the incorporation of new information (i.e., List 2 items). Related experiments replicated the basic effect and revealed several of its properties and boundary conditions (Hupbach, 2015; Hupbach, Gomez, & Nadel, 2011).

Sederberg, Gershman, Polyn, & Norman (2011) challenged the reconsolidation interpretation of the asymmetric misattribution errors documented by Hupbach and colleagues by invoking the well-established temporal context model (Howard & Kahana, 2002). Specifically, Sederberg et al. argued that providing a reminder of List 1 prior to List 2 reinstates the List 1 temporal context, which is incorporated with the subsequently learned List 2 items. Thus, List 1 context shares associations with both List 1 items and some List 2 items, whereas List 2 context only has associations with List 2 items. These ideas lead to the prediction that cuing List 1 context at retrieval will trigger both the correct recall of items from List 1 but also the List 2 items (i.e., the intrusions). By contrast, cuing the List 2 context at test would only cue the recall of List 2 items. Based on these and some further ideas from the temporal context model, Sederberg et al. were able to show that this model indeed can account for the key asymmetric intrusion effects reported by Hupbach and colleagues (for related findings, see Klingmüller, Caplan, & Sommer, 2017). In a subsequent study, Gershman, Schapiro, Hupbach, and Norman (2013) used an fMRI pattern classification approach and provided neural evidence that List 1 contextual reinstatement during study of List 2 predicts subsequent misattribution errors (for related evidence, see Kim, Norman, & Turk-Browne, 2019).

The studies by Sederberg et al. (2011) and Gershman et al. (2013) indicate that a reconsolidation interpretation is not necessary to explain the key memory errors initially documented in the Hupbach et al. experiments. However, these findings are consistent with and indeed strengthen the more general idea that reactivating memories can contribute to subsequent distortions and errors, here via contextual reinstatement. Consistent with this general interpretation, St. Jacques and Schacter (2013) provided evidence from a naturalistic memory paradigm that the strength or quality of reactivation for a recent experience can contribute to memory errors. Participants took a guided tour of a museum comprised of multiple stops while wearing a camera that recorded what they saw at each stop. Two days later, memories of the tour were reactivated by showing participants images of what they had seen, along with related images from an alternate version of the tour that they had not seen. On a recognition test given two days after the reactivation session, reactivation boosted true recognition of studied items but also increased false recognition of the related lure images. Moreover, subsequent true and false recognition were increased for memories that were highly reactivated (i.e., retrieval cues during the reactivation session matched those from the encoding experience) than for memories that were reactivated at a lower level (i.e., retrieval cues during reactivation mismatched those from the encoding experience). In a subsequent fMRI study using an adapted version of this museum tour paradigm, St. Jacques, Olm, and Schacter (2013) found that neural recruitment during the reactivation sessions in regions previously linked to autobiographical recollection, including the posterior inferior parietal cortex, bilateral retrosplenial cortex, and left posterior hippocampus, predicted both subsequent true recognition of studied items and false recognition of lures presented initially during the reactivation session. These results converge with the previous findings reviewed in this section in showing that retrieval and reactivation processes can contribute to subsequent memory misattribution errors.

Flexible recombination processes that support simulation, future thinking, and inference can produce memory errors During the past decade, a growing number of studies have demonstrated striking neural and cognitive similarities between remembering past experiences and imagining or simulating future or other hypothetical experiences (for a recent review, see Schacter, Benoit, & Szpunar, 2017). According to the constructive episodic simulation hypothesis (Schacter & Addis, 2007, 2020), these similarities reflect, in part, the contribution of episodic retrieval processes to both remembering and imagining. By this view, episodic retrieval enables the flexible recombination of details from past experiences into simulations of possible future scenarios. Because the future is not an exact repetition of the past, it is important that stored information can be accessed flexibly and recombined across past experiences to form simulations of novel future events that are informed by relevant past events. Critically, however, the constructive episodic simulation hypothesis holds that these same flexible retrieval processes can produce memory errors that result from miscombining elements of past experiences.

Some evidence broadly consistent with this perspective comes from observations of memory conjunction errors (Reinitz, Lammers, & Cochran, 1992) for autobiographical events. In a study by Odegard and Lampinen (2004) participants recorded in a diary one event that happened every few days for several weeks, including a variety of event details (e.g., people, locations, and actions). The experimenters later recombined some of these details across events to produce conjunction lures. For example, if a participant recorded in their diary that they went to the dance with Richard and the masquerade with Tom, a conjunction lure would indicate that the participant went to the dance with Tom. When given a recognition test six weeks after completing their diaries, participants falsely endorsed some conjunction lures as actual events recorded in their diaries. Moreover, in a follow-up experiment where participants were asked to make remember/know judgments, most conjunction lures were assigned "remember" responses. Burt, Kemp, and Conway (2004) reported similar results in a study where they recombined person, place, and activity details from diaries in which participants had recorded events approximately 13 years earlier.

More recently, Devitt, Monk-Fromont, Schacter, and Addis (2016) examined a similar phenomenon in a laboratory study that adapted an experimental recombination procedure previously developed for use in studies of future imagining (Addis, Pan, Vu, Laiser, & Schacter, 2009). In an initial session, participants generated person-place-object autobiographical memories. The experimenter subsequently recombined elements of these memories into lure items that were either partial recombinations (one element of a memory changed) or full recombinations (two elements changed). In a second session, participants were instructed to imagine the recombined items as events that might have occurred in the past. In a third session, they judged whether these recombined detail sets and the previously remembered person-place-object combinations constituted 1) a real event, 2) an imagined event, or 3) a novel recombination they had not seen previously. In two experiments, Devitt et al. (2016) found that imagining partial or full recombinations boosted the number of "real" judgments assigned to recombined events, compared to recombinations that were not imagined. Although these autobiographical memory conjunction errors were relatively infrequent, they were more frequent for partial than full recombinations, probably reflecting greater similarity of imagined past events to an actual event for the partial recombinations.

Carpenter and Schacter (2017) recently developed another approach to investigating the relation between flexible recombination processes and memory errors produced by miscombining elements of events, by modifying procedures previously developed to study associative inference (e.g., Zeithamova & Preston, 2010). In this adapted version of the associative inference paradigm, participants view scenes depicting a person, an object, and a background setting. They are instructed to remember each scene and also to infer the connection between people in different background settings who are linked to one another because each is paired with the same object (e.g., a man holding a toy in a room with a white couch and a boy holding the same toy in a different room with a brown couch). Across four experiments, Carpenter and Schacter (2017) consistently found that participants made more memory errors that were attributable to mistakenly combining contextual details from related scenes (e.g., mistakenly recalling that the man was in a room with a brown couch) when they made *correct* inferences about the relations between the people in these scenes than when they made *incorrect* inferences (e.g., when they correctly inferred that the man and boy were linked via the toy vs. when they did not). Moreover, this increase in memory errors for correct inferences occurred only when contextual details were probed *after* the associative inference test; there was no difference in memory errors for correct vs. incorrect inferences when memory for contextual details was probed *before* the associative inference test (see Figure 2 for data from a representative experiment). This latter result is crucial theoretically because the associative inference test is thought to engage flexible recombination processes that are needed to link the two scenes and make the correct inference.

--Insert Figure 2 about here--

Carpenter and Schacter (2018) used a similar paradigm to test whether flexible recombination also boosts memory errors associated with value/reward details. In this paradigm, as in Carpenter and Schacter (2017), people are linked to one another because each is paired with the same object, but here they were also assigned designations of high, low, or no value. Participants were instructed to try to remember the people, objects, and values. Carpenter and Schacter (2018) found that participants were more likely to mistakenly attribute high- or low-value to a no-value individual when they correctly inferred the relationships between these individuals (i.e., judged correctly that the individuals were linked by a common object) than when they failed to make such inferences (for related research, see Wimmer & Shohamy, 2012). As in Carpenter and Schacter (2017), this increase in memory errors was observed when memory for value details was probed *after* but not *before* the associative inference test that engaged flexible recombination processes. In both sets of experiments, the flexible recombination processes responsible for increased across-episode memory errors supported an adaptive function, associative inference, in line with the general tenets of the constructive episodic simulation hypothesis.

Although the foregoing studies do not specifically link future simulation with memory errors, other recent evidence does. In a study by Dewhurst, Anderson, Grace, and van Esch

(2016), separate groups of participants encoded a series of DRM word lists with reference to a future or past event, or by rating the pleasantness of each list item. There were two versions of the future and past conditions, one that involved planning (e.g., imagine a future holiday and plans you will make/remember a past holiday and plans you made, rate relevance of list items) and one that did not (imagine details of a future holiday/remember details of a past holiday, rate relevance of list items). On a subsequent free recall test, false recall of critical lure words was significantly higher following the two future encoding conditions than the two past encoding conditions or the pleasantness encoding condition, with no corresponding effect on true recall of presented list items. Additional experiments showed similar effects on false but not true recognition. Consistent with the general idea that flexible recombination processes associated with future thinking (during the encoding phase in these experiments) underpin the observed boost in false memories, Dewhurst et al. (2016, p. 1083) suggested that "the greater flexibility of future thinking may have enabled participants to think creatively about the possibility of encountering studied items in a hypothetical future event, thereby increasing the possibility of activating the critical lure."

Dewhurst, Anderson, Grace, and Howe (2019) extended this pattern of increased false recognition following future-related encoding to schema-related lure items. Using similar past and future encoding tasks to those reported by Dewhurst et al. (2016), as well as an atemporal visualization encoding task, participants rated schema-related words (e.g., for a holiday scenario, *sunblock* and *air tickets*) as well as schema-unrelated words (e.g., *hammer* and *telescope*). On a subsequent recognition test, participants made more false alarms to schema-related lures (e.g., *currency*) in the future condition than in either the past or visualization conditions. Dewhurst et al. noted the possible relevance of an experiment by Campbell, Benoit, and Schacter (2017) showing that when people simulate a future event, related information is automatically activated, whereas previous findings show that when people retrieve memories, related information is inhibited (e.g., Anderson, Bjork, & Bjork, 1994). Related information that becomes activated when people imagine a future event could include schema-related information, which is combined with list items. Thus, the studies by Dewhurst et al. (2016, 2019) are broadly consistent with a role for flexible recombination processes associated with future thinking in boosting memory errors.

Finally, we also note related research from Devitt and Schacter (2018) focused on the consequences of episodic future simulation for subsequent memory. In an initial experiment, participants simulated positive or negative outcomes of hypothetical future events before they learned the outcomes of those events. On a subsequent recognition test, positive simulation led to biased remembering: neutral outcome events were remembered positively, reflecting a liberal response bias for positive information and a conservative response bias for negative information

--Insert Figure 3 about here--

(see Figure 3). A second experiment revealed the same positivity bias after participants simulated positive outcomes to imagined past events, suggesting that biased remembering in this paradigm reflects the qualities of episodic simulations in either temporal direction. Thus, these findings add to the literature linking episodic simulation and memory distortion.

Evidence is Mounting in Support of an Adaptive Perspective on Memory Distortion

A key idea in the seven sins of memory framework is that memory distortions of the kind reviewed here, rather than constituting fatal flaws in the architecture of memory, reflect costs associated with beneficial features of memory that contribute to the adaptive functioning of the system (Schacter, 1999, 2001). For example, robust false recognition effects observed in the

DRM paradigm, though in part reflecting a failure of source monitoring processes (Gallo, 2010), also reflect the retention of the gist or general meaning of the items that were presented (e.g., Brainerd & Reyna, 2005; Schacter, Verfaellie, & Pradere, 1996). Retaining semantic gist information, in turn, is highly adaptive because it supports the ability to generalize based on experience (e.g., McClelland, 1995). Similarly, although misinformation effects indicate inappropriate incorporation of post-event suggestions into memory, they can also be viewed as reflecting the operation of an adaptive memory updating process (Loftus, 2005). Although this kind of adaptive perspective on memory distortion was initially based mainly on functional considerations and theoretical suggestions, during the past decade experimental evidence supporting this view has begun to mount (Howe, 2011; Schacter, Guerin, & St. Jacques, 2011).

We have already considered in this chapter recent evidence that supports this perspective. For example, the studies by Carpenter and Schacter (2017, 2018) showing that successful associative inference results in increased source memory errors following an inference test implicate flexible recombination processes in both an adaptive inferential process and a form of memory distortion. Studies by Dewhurst et al. (2016, 2019) and Devitt and Schacter (2018) have linked adaptive simulation processes with memory error and bias, and the experiments of Thakral et al. (2019) have shown that the ESI procedure, which enhances such adaptive processes as future simulation, problem solving, and divergent creative thinking, also increases susceptibility to DRM false recall. FMRI evidence from St. Jacques et al. (2013) revealed that reactivation-associated recruitment effects in regions linked to true autobiographical recollection also predicted subsequent false recognition of lure items that were presented for the first time during a reactivation session. Next we consider some additional recent developments that add to the emerging empirical picture of adaptive memory distortion.

As noted above, the idea that false recall and recognition in the DRM paradigm reflects retention of semantic gist information fits well with an adaptive perspective. A recent fMRI study by Chadwick et al. (2016) has added to this perspective by providing evidence that the left temporal pole, a brain region characterized as a "semantic hub" that is critical for conceptual processing and representation (Patterson, Nestor, & Rogers, 2007), is implicated in DRM false recognition. In this study, participants performed a semantic encoding task while viewing 40 sets of four DRM list words along with their associated critical lures, and Chadwick et al. measured neural pattern similarity between the four list words and the critical lure. Chadwick et al. examined whether the degree of similarity between the list items and their respective lure words is associated with the level of false recall of critical lures, based on canonical data from an entirely separate set of participants (Roediger, Watson, McDermott, & Gallo, 2001). This analysis revealed a significant positive correlation ($r = .40$) between the level of false recall and list/lure neural pattern similarity in only one region of the brain, the left temporal pole. Chadwick et al. also reported a positive association between temporal pole neural overlap and DRM false recognition of critical lures within the same sample of participants tested on two different occasions. These findings fit nicely with an adaptive perspective on DRM false memories because they show that the same brain region that is important for processing of semantic information and relations, a key adaptive process, is linked to false recall and recognition resulting from that process (for related observations concerning brain regions that support contextual processing and are also associated with subsequent false memories for contextually related items, see Aminoff, Schacter, & Bar, 2008).

Howe and colleagues have also relied on the DRM paradigm to develop an adaptive perspective on memory distortion. In their initial studies, Howe, Garner, Dewhurst, and Ball

(2010) exposed adults to DRM lists before asking them to solve a remote associate problem in which the participants attempt to come up with a single solution word that fits all three words in the problem (e.g., for the problem walk/beauty/over, the solution word is "sleep"). Studying DRM lists that prime the solution word (e.g., bed, rest, awake…), boosted performance on the remote associates task, but only when participants falsely recalled the critical lure word prior to the remote associates task. Howe, Garner, Charlesworth, and Knott (2011) extended this effect to children, and Howe and Garner (2018) showed that "false priming" biases participants' responses toward the dominant solution on remote associate problems in which there are two possible solutions (for additional evidence linking DRM false recognition and performance on the remote associates task, see Dewhurst, Thorley, Hammond, & Ormerod, 2011). Subsequent studies have further extended such false priming via recall of nonstudied DRM lures to analogical reasoning tasks in young adults (Howe, Garner, Threadgold, & Ball, 2015) as well as in older adults and patients with Alzheimer's disease (Akhtar & Howe, 2019). Taken together, these studies establish that false recall, at least as measured by the DRM paradigm, can have beneficial downstream consequences.

Another line of research that has produced evidence for an adaptive perspective on memory distortion comes from studies linking post-event misinformation with memory updating processes. For example, Edelson, Sharot, Dolan, and Dudai (2011) reported fMRI evidence that memory errors produced by misinformation attributable to social influence were associated with encoding-related medial temporal lobe activity that resulted in memory updating. These findings fit with the more general view that post-event misinformation effects and related phenomena may reflect the operation of reconsolidation processes whose primary adaptive function is to allow memory updating (Hardt, Einarsson, & Nader, 2010). However, as noted earlier the strength of evidence that reconsolidation processes are responsible for memory changes in humans is still actively debated (for review and meta-analysis, see Elsey et al., 2018; Scully, Napper, & Hupbach, 2017).

Overall, this body of evidence supports the idea that a variety of memory errors can be conceived as reflecting the operation of *adaptive constructive processes* (Schacter, 2012), that is, processes that play a useful, functional role in memory but create distortions or errors as a consequence of doing so. This general perspective dates at least to the pioneering studies of Bartlett (1932) and is highly relevant to the analysis of memory errors and distortions today.

Concluding Comments

The analysis of memory errors and distortion has progressed significantly during the past two decades. Here we have highlighted key themes that have emerged from or been strengthened by this research, and have noted various issues and questions that will require additional study. In addition to the specific points we have raised regarding experimental findings and theoretical interpretation, a more general point to highlight is that research on memory errors and distortion is increasingly relevant to a broad range of topics in cognitive psychology and neuroscience, including creative thinking, associative inference, episodic simulation, and semantic representation.

We think that this broad relevance is a natural consequence of the idea that memory errors reveal the operation of adaptive constructive processes in different domains. Moreover, the longstanding relevance of research on memory errors to crucial real-world issues such as the reliability of eyewitness memory and the accuracy of memories recalled in psychotherapy has only been heightened by developments during the past two decades. For example, recent research has linked memory distortion to the socially important topic of "fake news": A study of voters in the 2018 Irish referendum on abortion rights revealed that supporters and opponents of the referendum exhibited false memories for having previously seen fake news items that were generated by the experimenters, and to a greater extent for fake items that depicted the other side in a negative light (Murphy, Loftus, Grady, Levine, & Greene, 2019). In light of their broad theoretical relevance and everyday implications, we believe that a continued focus on the analysis of memory errors and distortion will prove to be a rich source of insight into the operation of memory and cognition during the upcoming decades.

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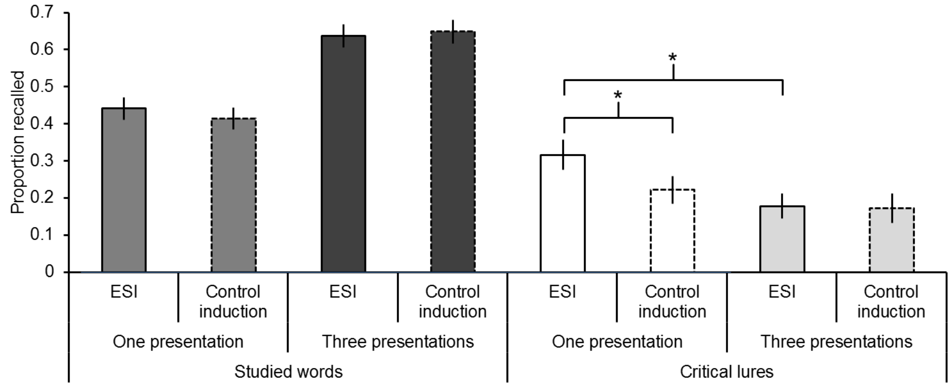
Figure Captions

Figure 1. Results from Experiment 5 of Thakral et al. (2019). Mean recall of studied words and critical lures as a function of presentation group (one presentation and three presentations) and induction (episodic specificity induction (ESI) and control induction). Error bars denote ± 1 standard error of the mean and asterisks indicate significant results (*$p < 0.05$). Adapted with permission from Thakral, P.P., Madore, K.P., Devitt, A.L., & Schacter, D.L. (2019). Adaptive constructive processes: An episodic specificity induction impacts false recall in the Deese-Roediger- McDermott paradigm. *Journal of Experimental Psychology: General*, *148*, 1480-1493.

Figure 2. Results from Experiment 2 of Carpenter & Schacter (2017). Mean false memories as a function of associative inference performance and time (i.e., before vs. after the test of inference and directly learned associations). Results revealed that false memories increased significantly only after successful inference and not after unsuccessful inference. Error bars denote ± 1 standard error of the mean. Adapted with permission from Carpenter, A.C. & Schacter, D.L. (2017). Flexible retrieval: When true inferences produce false memories. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 43,* 335-349.

Figure 3. Results from Experiment 1 of Devitt & Schacter (2018). Mean response bias (C) as a function of simulation valence (positive, negative, no simulation) and valence of detail presented at recognition (positive, negative). Higher C values indicate more conservative responses. Error bars denote ± 1 standard error of the mean and asterisks indicate significant results (**$p < .01$). Adapted with permission from Devitt, A.L. & Schacter, D.L. (2018). An optimistic outlook creates a rosy past: The impact of episodic simulation on subsequent memory. *Psychological Science, 29,* 936-946.



Proportion recalled
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
*
*
ESI
Control induction
ESI
Control induction
ESI
Control induction
ESI
Control induction
One presentation
Three presentations
One presentation
Three presentations
Studied words
Critical lures

Figure 1

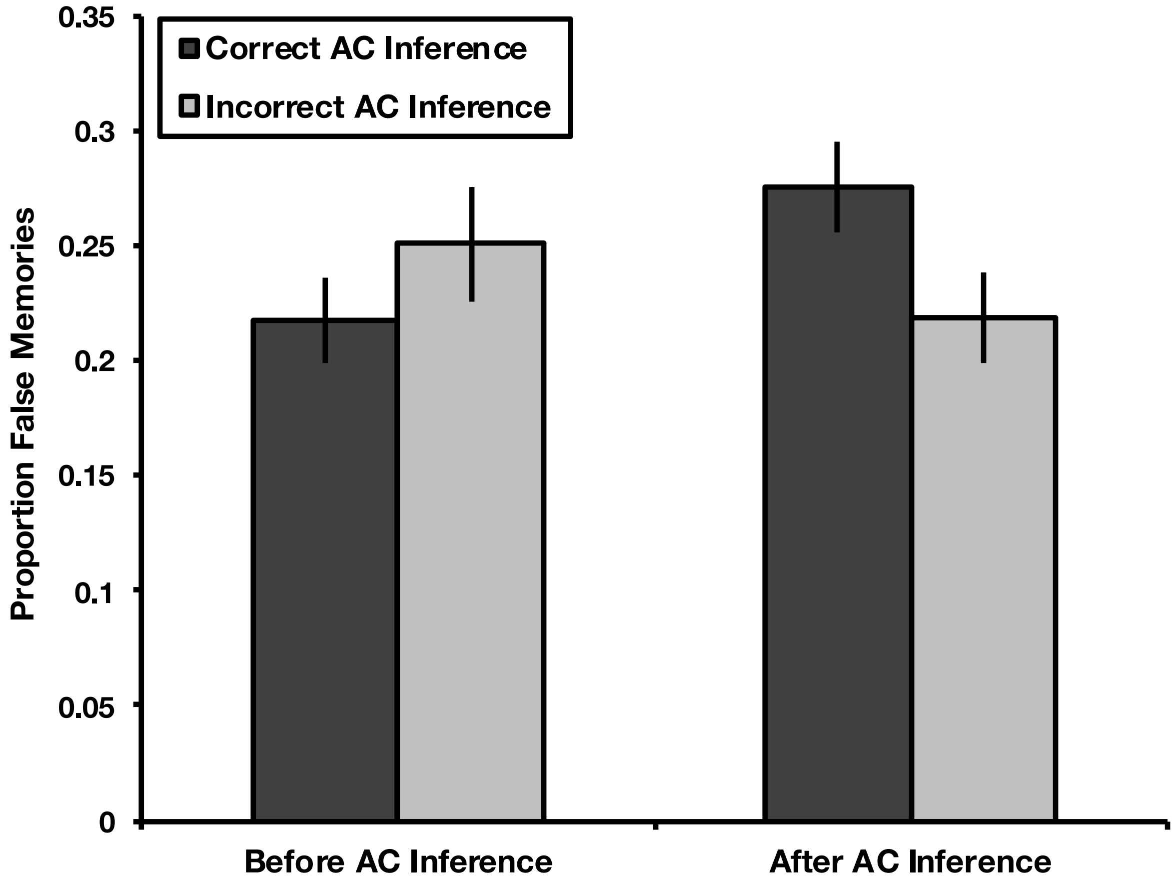
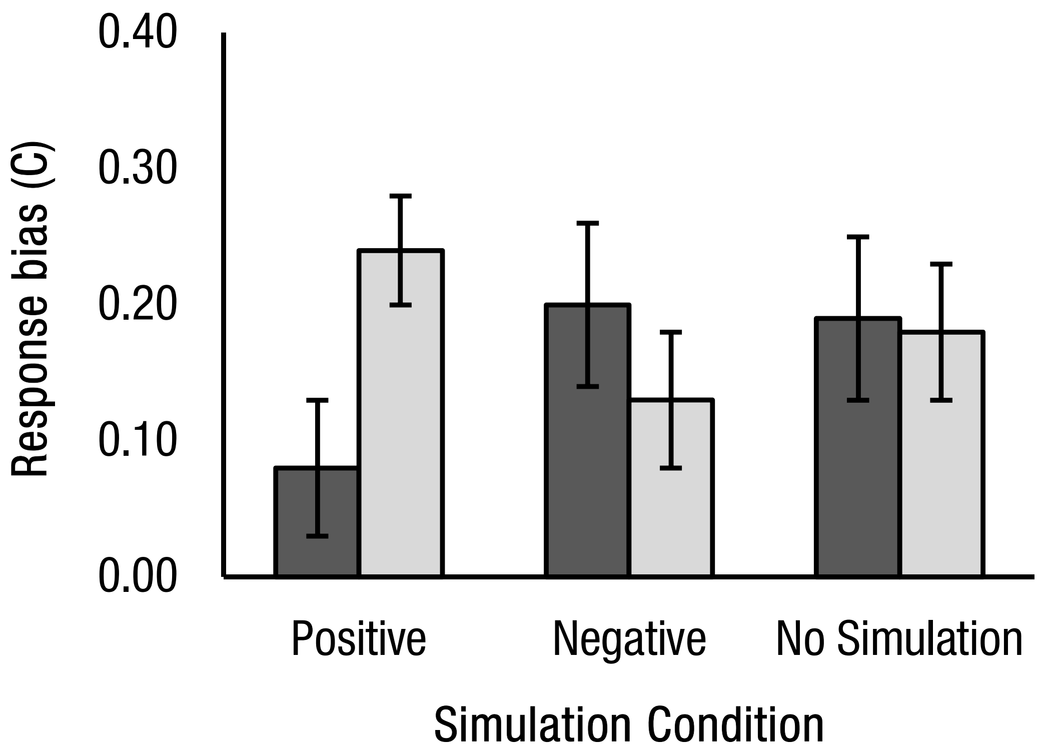

0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Proportion False Memories
Correct AC Inference
Incorrect AC Inference
Before AC Inference
After AC Inference

Figure 2

Figure 3


0.40
0.30
0.20
0.10
0.00
Response bias (C)
Positive
Negative
No Simulation
Simulation Condition