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Adult Age-Related Changes in the Specificity of Episodic Memory Representations: A Review and Theoretical Framework

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We provide a comprehensive review describing research on the qualitative representational nature of older adults' episodic memories. Our review considers several broad theoretical frameworks and decades of research converging on a universal principle of adult aging: Episodic memory in older adulthood is characterized as being less specific in nature than in younger adulthood. Going beyond earlier specific reviews on related topics in the false memory, neuroscience, and reading comprehension literatures, our review synthesizes findings from these fields with more recent research from the precision literature, along with several new studies on age differences in the specificity of associative aspects of episodic memory, where age deficits have long been reported. We also sketch a new theoretical framework as inspiration for future research that can better elucidate the mechanisms underpinning age differences in the specificity of memory representations, including reduced attentional resources and slower speed of processing.

Public Significance Statement
Age-related declines in episodic memory, or memory for past events occurring in a specific time and place, are well-documented. However, these declines appear to be underpinned by changes in the representational quality of episodic memories in older adulthood, where memories are less specific in nature but still retain the gist, or essence, of past experiences. We review decades of research on this topic and propose some mechanisms for why the representations of episodic memories change as we age.

Keywords: aging, episodic memory, specificity, gist

Adult age-related deficits in episodic memory have been widely reported (Light, 1991; Naveh-Benjamin & Old, 2008; Salthouse, 1991; Zacks et al., 2000). Numerous theoretical accounts have been proposed to explain why these deficits occur, including age-related reductions in attentional resources (Craik & Byrd, 1982; Rabinowitz et al., 1982), impairments in associative binding of components of an episode (Naveh-Benjamin, 2000), slowed processing speed (Salthouse, 1996), impairments in recollection (Jennings & Jacoby, 1997), declines in inhibitory processes (Hasher & Zacks, 1988), and contemporary views attributing these deficits to a combination of factors impacting encoding and retrieval (Healey & Kahana, 2016).

Most inferences about age-related deficits in episodic memory occur at the level of task performance (Salthouse, 2000; for recent evidence, see Greene & Rhodes, 2022), such as older adults recalling or recognizing fewer studied items than younger adults. Although informative, age differences in task performance on traditional tests of recall or recognition (e.g., whether older adults can recall the same number of items as younger adults) do not speak as much to the qualitative nature of the underlying memory representations that may differ between young and older adults (cf. Benjamin, 2010). Performance on recall and recognition generally relies on participants' abilities to remember specific representations of previously studied items. If older adults lack such representations, they will perform worse on these tasks, but little will be learned about whether older adults might remember information at less specific levels of representation.

However, several methods have been developed across a rich variety of content areas (see Table 1) that provide deeper understanding of adult age differences in episodic memory representations. Collectively, the evidence from these separate fields converges on a potential universal principle of episodic memory in the context of adult aging: Older adults possess less specific episodic memory representations than those of younger adults.

Goals of the Present Review and Connections to Past Reviews

Our first goal is to provide a comprehensive review of theories and studies attempting to understand the qualitative representational

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Table 1
Description of Paradigms and Representative Findings on Age Differences in Memory Specificity

Paradigm	Description	Representative cognitive aging findings	Similar paradigms
Word recognition with rhyme or synonym lures as distractors at test	Method to assess whether false recognitions of words is driven by perceptual or semantic similarity; lures at test are either rhymes (shared perceptual overlap with target words) or synonyms (shared conceptual/semantic overlap with target words). Higher rates of false alarms to lures (e.g., synonyms) suggest reduced memory specificity.	Older adults more susceptible to false recognitions of rhymes and synonyms (Rankin & Kausler, 1979), suggesting shallower processing at both perceptual and conceptual levels of analysis	Levels of processing manipulations to encourage shallow or deep processing of items (Craik & Lockhart, 1972); conjoint recognition (Brainerd et al., 1999)
Cued recall with specific versus general retrieval cues	Paradigm to assess whether participants' cued recall is enhanced when specific retrieval cues are provided compared to when general retrieval cues are provided. Retrieval cues are either (a) specific associates that participants generated at encoding or (b) general category labels. Ability to use specific retrieval cues (a) to aid with recall of targets from the list is suggested to reflect that an individual's memory is more specific/detailed in nature	Older adults do worse at cued recall when given specific retrieval cues, but perform comparable to young adults when given general category labels as retrieval cues (Rabinowitz et al., 1982)	Levels of processing manipulations (Craik & Lockhart, 1972)
Narrative recognition	Method to determine whether participants can retain the surface form (i.e., verbatim representation) of a passage of text or rely on situation models (i.e., gist representation of a text's core meaning); participants read a story and later complete a recognition test on sentences that are (a) old sentences, (b) paraphrases of old sentences, (c) new sentences that make inferences that are logically consistent with the passage of text, or (d) new sentences that make inferences that are logically inconsistent with the passage of text	Older adults rely less on surface levels of representation and more on situation models than younger adults do, as exhibited by poorer veridical recognition for old and paraphrase sentences but high rates of recognition for logically consistent meaning sentences (Radvansky et al., 2001)	Situation models in memory retrieval (Radvansky & Zacks, 1991)
False memory: Deese–Roediger–McDermott paradigm	False memory paradigm used to elicit false recall or recognition of unpresented lures. Participants study a list of related items (usually semantically related word lists, e.g., "bed," "rest," and "dream") that are related to an unpresented critical lure (e.g., "sleep").	Older adults far more likely to endorse the unpresented lure as having been studied (Norman & Schacter, 1997), even for visually presented items (Koutstaal & Schacter, 1997), suggesting a greater reliance on gist processing in older adulthood	Misinformation and suggestibility paradigms (Loftus, 1975)
Visual mnemonic discrimination or behavioral pattern separation tasks	Paradigm in which participants are tasked with discriminating old studied items from similar lures (sharing semantic or perceptual overlap with target items) and new, unrelated items.	Older adults endorse lure items as "old" far more likely than younger adults (Koutstaal, 2003), indicating a greater reliance on gist processing, especially semantic gist memory (Koutstaal et al., 2003)	Simplified conjoint recognition (Stahl & Klauer, 2008); associative recognition specificity paradigm (Greene & Naveh-Benjamin, 2020)
Memory precision tasks	Method to measure the representational precision of memory. Participants are tasked with reproducing some aspect of a studied item, such as the color of the item from a color wheel, or the angular orientation of the item.	Older adults' exhibit greater recall error in reproducing features (e.g., color, location) of studied items than younger adults do, indicating less precise memory in older adulthood (Peich et al., 2013)	N/A

(*table continues*)

Table 1 (*continued*)

Paradigm	Description	Representative cognitive aging findings	Similar paradigms
Autobiographical memory tasks	Participants are asked to recall personal experiences from their lives. Participants may be provided with prompts to constrain the discussion to a specific episode or to more general episodes.	Older adults' autobiographical memories are more categorical in nature (capturing details shared across many experiences); older adults may recall vivid details of a specific experience when given focused prompts, but only for recent memories (Levine et al., 2002)	N/A
Associative recognition with schematic support	Variety of methods used to assess whether participants can better remember associations between two items when those associations make use of preexisting schematic support, such as grocery items with realistic prices (Castel, 2005) or use of semantically related rather than unrelated word pairs (Naveh-Benjamin et al., 2003)	Older adults' associative memory deficits are reduced when schematic support is available (e.g., Naveh-Benjamin et al., 2003), and older adults can remember more general information about an association when they can make use of preexisting knowledge (Castel, 2005)	Associative recognition specificity paradigm (Greene & Naveh-Benjamin, 2020)
Associative recognition specificity paradigm	Participants study associations for which preexisting schematic support would be of little advantage (e.g., pictures of faces paired with scenes, as multiple different sources of preexisting knowledge could cause conflict, such as memory for seeing young women vs. young men at gyms) and are administered associative recognition tests requiring discrimination between intact/old pairs (e.g., same face with the same scene) and foils that vary in how similar they are to originally studied pairs (e.g., an old man paired with one garden at study but a different garden [similar] or a kitchen [dissimilar] scene at test).	Older adults' associative memory deficits are most pronounced when discriminating foils that are highly similar to originally studied pairs, sharing a gist level of representation, but not for foils that are completely dissimilar, sharing no gist level of representation with originally studied pairs, suggesting that age deficits in associative memory scale with how much specificity one needs to remember (Greene & Naveh-Benjamin, 2020)	Associative recognition with schematic support paradigms (Castel, 2005); specific and partial source memory paradigms (Dodson et al., 1998; Simons et al., 2004)
Remember/know procedure	Method to separate recollection and familiarity judgments; participants make "R" (remember) or "K" (know) responses to recognition probes they deem to be old	Older adults rely more on "K" than "R" judgments, indicating a greater reliance on familiarity than recollection (Prull et al., 2006)	Process-dissociation procedure (Jacoby, 1991; Jacoby et al., 1993)

nature of older adults' episodic memories. Our second goal is to build an integrative, theoretical framework to explain *why* older adults' episodic memory representations are less specific in nature.

There are other related reviews, including those on age differences in false memory (Devitt & Schacter, 2016; Jacoby & Rhodes, 2006; Koutstaal & Schacter, 2001), free recall (Brainerd et al., 2009; Brainerd & Reyna, 2015), and reading comprehension (Radvansky & Dijkstra, 2007). Our review differs from these earlier reviews in several important ways. First, we focus on the qualitative representational nature of older adults' *episodic* memories, which was only briefly covered in the most recent reviews on false memory (Devitt & Schacter, 2016) and reading comprehension (Radvansky & Dijkstra, 2007). Second, our review considers evidence from a wider variety of areas, including recent research on tasks assessing precision of memory (e.g., Peich et al., 2013; Pertzov et al., 2015; Rhodes et al., 2020; Souza, 2016) and specificity of associative episodic memory (e.g., Greene & Naveh-Benjamin, 2020). Third, our review considers perspectives beyond those of fuzzy-trace theory (as reviewed in Brainerd & Reyna, 2015) by describing different theories that are often mentioned in the separate literatures. Fourth, we describe a theoretical modeling framework that can provide insight into the mechanisms underlying why older adults' episodic memories are less specific in nature.

We begin by describing a few theories that distinguish between specific and gist/general memory representations. We then review five decades of empirical work examining age differences in the specificity of episodic memory. Next, we sketch our theoretical framework and end by considering implications and directions for future research.

Theories on Levels of Representation in Episodic Memory

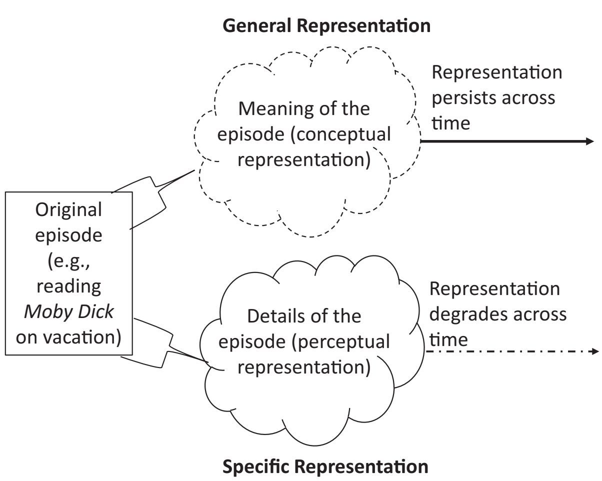
Several theories distinguish between different levels of memory representation (see Figure 1). These theories can be divided into those that originated in the cognitive psychology literature without attempting to localize the neural bases for different levels of representation, such as fuzzy-trace theory (Brainerd & Reyna, 1990) and hierarchical representation theory (Craik, 2002b), and those that originated in the cognitive neuroscience literature to link distinct levels of representation to underlying neural correlates. This latter group includes trace-transformation theory (Moscovitch et al., 2016; Robin & Moscovitch, 2017; Winocur et al., 2007, 2010; Winocur & Moscovitch, 2011) and theories of hippocampal pattern separation (Kirwan & Stark, 2007; Stark et al., 2013; Yassa et al., 2011). Despite some differences among the existing theories, they all share many common features that make them more *complementary* than opposing.

First, all theories of memory representation differentiate detailed or specific representations from less detailed and more general representations, though the terms used may differ depending on the theory adopted. For example, fuzzy-trace theory (Brainerd & Reyna, 1990) refers to specific representations as *verbatim representations*, whereas trace-transformation theory refers to these as *detailed* or *peripheral representations* (Robin & Moscovitch, 2017). Craik (2002b) distinguishes between specific and general representations along a continuum of specificity.

Second, although earlier theories (e.g., van Dijk & Kintsch, 1983) viewed general representations as being *dependent* upon specific representations (i.e., general representations were thought to be

Figure 1

Depiction of Different Levels of Episodic Memory Representation and Description of Common Theoretical Assumptions of Several Leading Theories



Theoretical Assumptions of Leading Theories of Memory Representation

(1) Independence between specific and general representations
(2) Older adults retain general but not specific representations of past episodes
- Specific representations are more resource-consumptive to encode (fuzzy-trace theory) and require greater elaboration to retrieve (hierarchical representation theory)
- Aging is associated with reduced activity in posterior hippocampus regions underlying specific representations (trace-transformation theory) and losses in dendritic volume in this region that is implicated in retrieving specific but not general representations (pattern separation theory)

Note. The cloud shape for the general representation is depicted as a fuzzier cloud than the cloud shape for the specific representation to emphasize that general representations are less precise/specific in detail than specific representations. Conversely, the arrow from the general representation is depicted as a solid arrow to convey persistence in this representation across time and decreased vulnerability to interference, whereas the arrow coming from the specific representation is a broken arrow to convey sensitivity to decay and interference. Insert explains common principles of several leading theories of memory representation.

extracted from specific representations), the current theories suggest independence between these representations. This point is clearly articulated in fuzzy-trace theory (Brainerd & Reyna, 1990), which assumes that verbatim (specific) and gist (general) representations are encoded and can be retrieved independently of each other. Similarly, trace-transformation theory (Robin & Moscovitch, 2017) notes that detailed and general representations can coexist, without one necessarily depending on the other.

This point is not as clearly articulated in hierarchical representation theory (Craik, 2002b), but it appears consistent with Craik's (2002a, 2002b, 2020) position that the degree to which specific versus general details of an episode can be remembered depends on depth of elaboration at encoding or retrieval, that is, the degree to which an individual deeply reflects on their memories. For instance, at a shallow level of elaboration at retrieval, an individual may remember "I read *Moby Dick* one summer," but at a deep level of elaboration at retrieval, the individual may remember more specific details (e.g., "I read *Moby Dick* on a hot July afternoon under a pink umbrella in the Bahamas"). Remembering the more specific representation need not necessarily depend on first remembering the more general representation but rather on the degree of elaboration.

In pattern separation theories (e.g., Kirwan & Stark, 2007; Yassa et al., 2011), independence between specific and general representations is not clearly spelled out, but competing processes are theorized to be involved in distinguishing a specific learned experience (e.g., remembering seeing a red apple) from new, related content that shares general features with the learned episode (e.g., encountering a green apple) versus equating the two experiences based on their shared general features. This suggests some degree of independence between specific and general representations, at least in terms of how these representations are retrieved.

Third, and perhaps most relevant to the present review, all theories of memory representation predict that older adults' episodic memories are representationally less specific than those of younger adults. The mechanisms underlying why this is so may differ slightly from theory to theory, as reviewed in the following sections. A formal comparison of these theories is beyond the scope of the present review and would be a logistical challenge given that the extant theories are articulated as *verbal* rather than *mathematical* theories, though there have been some efforts to instantiate fuzzy-trace theory into a more mathematically explicit theory (Brainerd et al., 2009). Although we will not formally compare the different theoretical mechanisms here, we will attempt to incorporate some of them into our own theoretical framework, which will provide a basis for a more computationally explicit theory of memory representations.

Memory Representation Versus Memory Phenomenology

Before describing these theories, it is important to distinguish *memory representation* (the mental depiction of a memory) from *memory phenomenology* (our awareness of our memories; e.g., recollection vs. familiarity—Jacoby, 1991). Although there is some overlap between these concepts, there are also important differences. One of the major distinctions between representational theories and phenomenological theories is that, in the former, the context of a particular episode is at least partially accessible,[1] whereas in the latter, there can be context-free type of remembering based on familiarity. Consider the following example: While watching a new movie, you see an actor that you have seen previously. You can have a phenomenological awareness of explicitly remembering where you have seen the actor (i.e., recollection) or a phenomenological sense that you know you have seen the actor before but being unable to remember where (i.e., familiarity). Regarding remembering the context of an episode (e.g., remembering where you have seen the actor before), the *representation* of that episode can be detailed/specific or fuzzy/imprecise. Moreover, we may recollect specific details of the actor (target recollection) or of the movie (context recollection; Brainerd et al., 2014).

Although our focus is on age differences in *memory representation*, there are also age differences in *memory phenomenology*, often captured by higher rates of "know" responses tapping familiarity than "remember" responses tapping recollection (McCabe et al., 2009; Prull et al., 2006; cf. Jennings & Jacoby, 1993, 1997) among older than younger adults in the remember/know procedure (Gardiner, 1988; Tulving, 1985). We turn now to a more detailed description of extant theories of memory representation.

Fuzzy-Trace Theory

According to *fuzzy-trace theory* (Brainerd & Reyna, 1990, 2004; Reyna & Brainerd, 1995), episodic memories are represented in two independent traces—a verbatim trace tagging the specific details of an episode, and a gist trace tagging the meaning/semantic features. Fuzzy-trace theory posits that older adults have well-preserved gist but not verbatim/specific representations (Brainerd & Reyna, 2015), in part because gist representations are thought to be more immune to interference (Brainerd & Reyna, 2002) and to require less attentional resources to encode (Brainerd & Reyna, 1990). Supporting evidence for these key assumptions has come from a few studies with young adults showing that, when attention is divided during encoding, young adults are less likely to remember specific but not gist/general details of past episodes (Odegard & Lampinen, 2005; Rabinowitz et al., 1982; but see Greene & Naveh-Benjamin, 2022b, 2022c). These findings suggest that gist representations require less attentional resources to encode and that such representations are more immune to the degradative influences of interference. Older adults often fail to inhibit irrelevant information that interferes with task-relevant information (Hasher & Zacks, 1988), which could complicate their ability to rely on resource-demanding verbatim representations. For example, to maintain the specific representations of three lines arranged in order of increasing length (14 cm, 15 cm, and 16 cm), one would need to remember three numeric quantities with which other, irrelevant quantities could interfere. In contrast, to represent the lines at a gist level, one needs only to maintain a single, abstract rule (e.g., "lines are shorter to the left"). As this example further demonstrates, representing the specifics may also require holding *more* information in mind, thus implicating a greater demand on the severely constrained working memory system, which is especially limited in older adulthood (Greene et al., 2020; Light & Anderson, 1985).

[1] In Craik's theory, a memory can be represented at a level devoid of context, but this is more akin to *semantic* than *episodic* memory because the representation pertains to general knowledge (e.g., knowledge that Tom Hanks is an actor). In contrast, familiarity pertains to a sense of knowing that a specific episode had occurred (e.g., "I know I have seen this actor before") but being unable to access the details of that episode.

Gist representations may be useful for easing the burden on the limited capacity working memory system during encoding. Gist traces connect information about an episode to general knowledge, which is preserved among older adults (Nyberg et al., 1996). Older adults may be able to rely on preexisting knowledge to connect the gist of an episode to established knowledge, which can help offset capacity limitations (e.g., Cowan, 2019), though this point awaits further empirical investigation.

Hierarchical Representation Theory

In *hierarchical representation theory* (Craik, 2002a, 2002b, 2020), memories are theorized to be represented along a continuum of specificity, ranging from "context-free" memories in which information is retrieved without associated contextual details, akin to semantic memory (Tulving & Schacter, 1990), to context-rich memories, akin to episodic memory. For example, at a context-free level, one may remember that *Moby Dick* is a novel, whereas at a context-rich level, one may remember a specific time reading *Moby Dick*.

Craik (2002a) suggested that older adults are less capable than younger adults of remembering specific, contextual details associated with past experiences but can remember more general details (e.g., remembering in general that they have read *Moby Dick* but not remembering specific details about when they read *Moby Dick*). This may be attributable to age-related differences in the depth of elaboration during encoding (Craik, 2002a) or retrieval (Jacoby et al., 2005; Luo & Craik, 2009), which could be due to a decline in attentional resources (Craik, 1983; Craik & Byrd, 1982). Craik proposes that, to remember a specific representation, one needs to deeply probe the contents of their memory to reintegrate the specific instantiating features of the episode. This type of elaboration is likely more effortful and attentionally demanding than elaborating on a more general type of representation. Supporting evidence for this claim comes from a study of divided attention at retrieval in young adults (Luo & Craik, 2009) showing that divided attention disrupted young adults' ability to remember the specific but not the general context in which they had studied words, simulating the same pattern of results obtained with older adults.

Neuroscientific Theories of Levels of Representation

Here, we focus on two neuroscientific theories that are complementary but provide slightly different insights into the neural bases of memory representations. The first—trace-transformation theory (Moscovitch et al., 2016; Robin & Moscovitch, 2017; Winocur & Moscovitch, 2011)—describes the neural correlates of different types of memory representations. The second—pattern separation theory (Kirwan & Stark, 2007; Yassa et al., 2011)—details the neural processes that are involved in discriminating activity patterns corresponding to episodes that share common general but not specific features.

According to trace-transformation theory (Moscovitch et al., 2016; Winocur et al., 2007, 2010; Winocur & Moscovitch, 2011), the neural bases for episodic memories change across time, initially being hippocampal-dependent but relying on connections between the hippocampus and prefrontal cortex after consolidation. Robin and Moscovitch (2017) expanded on this theory by elaborating on how different types of memory representations depend on neural activity in unique regions of the hippocampus or prefrontal cortex. When an individual remembers specific perceptual features of an episode (termed "peripheral" features because they are not usually relevant to the central elements of an episode, such as its meaning; Sekeres et al., 2016), activity in the posterior hippocampus increases, including increased blood-oxygen-level-dependent (BOLD) signaling. BOLD activity increases in the anterior hippocampus when an individual remembers the core meaning or gist (termed the "central" features) of an episode. Knowledge that is extracted over multiple similar episodes (referred to as "schemas") is represented by neural patterns of activity in the ventromedial prefrontal cortex. An important aspect of this theory is that specific (peripheral), general (central), and schematic representations can all coexist, but given particular task demands, one level of representation may be retrieved in preference to the others.

According to pattern separation theories (e.g., Kirwan & Stark, 2007; Yassa et al., 2011), when an individual encodes a new experience (e.g., studying an image of a red apple), that episode is theorized to be represented by a unique pattern of neuronal activity in the hippocampus. This pattern of activity can be reintegrated at retrieval from cues that share either complete overlap (e.g., the same red apple presented during a recognition test) or partial overlap (e.g., an image of a green apple) with the original engram. In the latter case, the original neuronal pattern is not fully reintegrated from the retrieval cue because it is not an exact match, but *pattern completion* may still occur if the amount of reintegration of the original pattern surpasses a threshold set by the individual. Then, the individual would equate the new pattern with the older pattern, believing the new episode to be one that had been experienced previously. An opposing process—*pattern separation*—occurs when, due to the incomplete match between the new and established patterns of neuronal activity, the two episodes are orthogonalized. When this occurs, the individual detects that the new episode (e.g., the green apple) is not a match with an older episode (e.g., the red apple).

Hippocampal pattern separation and pattern completion processes are theorized to occur within posterior regions of the hippocampus, the same region associated with detailed/specific representations (Robin & Moscovitch, 2017). Adult aging is associated with reduced BOLD signal activity in the posterior hippocampus and heightened activity in the anterior hippocampus and ventromedial prefrontal cortex (Rosenbaum et al., 2012; Viard et al., 2012), those regions implicated in general and schema-based representations. Also, adult aging is associated with a more liberal pattern completion rather than pattern separation process, which is related to decreased dendritic volume of the dentate gyrus and Cornu Ammonis subfields in older adults (Yassa et al., 2011). Thus, the consensus from both trace-transformation and pattern separation theories is that older adults' hippocampi are less sensitive to remembering specific representations of past episodes.

Summary of Theories of Representation

A common theme emerges across several leading theories of memory representation: They all posit that older adults' episodic memories are representationally less specific/detailed and more general in nature than those of younger adults. This is an impressive consensus, given the varied scope of these theories. However, it is important to note that none of these theories originated as theories of cognitive aging, per se. Rather, each originated at a more general level to explain the nature of episodic memory representations, and some of their theoretical principles lead naturally to their views on aging. For example, fuzzy-trace theory's principle that verbatim traces are more resource-consumptive than gist traces couples nicely with cognitive aging theories of diminished attentional resources (e.g., Craik & Byrd, 1982) to arrive at the assumption that older adults have intact gist but not verbatim representations. What is lacking in the field is a more mechanistic model that can explain the ways in which older adults differ from younger adults in how they encode, maintain, and retrieve specific versus general memory representations. We will soon describe a model suited to this endeavor. First, however, we must consider the empirical evidence that bears on the basic assumption held across these numerous theories of memory representation that older adults' episodic memories are representationally lacking in specific detail.

Empirical Evidence on Age Differences in Memory Representation

Having described several general theories, each predicting that older adults' memory representations are less specific than those of younger adults, we now turn to empirical evidence bearing on these predictions (see Table 1).

Early Studies From the Levels of Processing Framework

Some of the earliest work attempting to understand age differences in the quality of episodic memory came from the levels of processing framework of Craik and Lockhart (1972). Craik (1977) and Eysenck (1974) argued that older adults only engage in a shallow level of processing during encoding but fail to engage in the deeper elaboration that younger adults do. Older adults were thought to process items at a sensory or perceptual level (e.g., focusing on how a word sounds) rather than at a more conceptual level, which would result in better memory for the items due to deeper encoding. The idea that focusing on the conceptual aspects during encoding engenders *deeper* encoding than focusing on the perceptual aspects may seem to run counter to the ideas of hierarchical representation theory (Craik, 2002b) that deeper elaboration is required for remembering specific than general representations. However, the type of elaboration considered in these levels of processing studies pertains to a strategic process during encoding of using either shallow (sensory/perceptual) or deep (meaningful/conceptual) elaboration to enrich the encoding of a new episode. In contrast, the elaboration process described in hierarchical representation theory pertains to the degree to which an individual must effortfully reintegrate a past episode (i.e., a retrieval process), with general representations of past episodes being more automatically accessible than specific representations (e.g., Luo & Craik, 2009).[2]

The idea that older adults only focus on the perceptual features of a stimulus during encoding was challenged by empirical evidence (Smith, 1975) showing that older adults, more than younger adults, exhibited greater false recognitions of synonyms, which are *semantically/conceptually* related to studied words (e.g., "ship" is semantically/conceptually similar to "boat"). This result was incompatible with the hypothesis that older adults focused during encoding on the sensory/perceptual, but not the semantic/conceptual details of items. Rankin and Kausler (1979) replicated Smith's findings, but they also found that older adults were more prone to false recognitions of rhyming words, which are perceptually but not semantically related to studied items (e.g., "coat" rhymes with "boat"). Based on these findings, Rankin and Kausler (1979) argued that older adults attempt to process both sensory/perceptual and semantic/meaning features of items, but they do so to a less elaborate degree than younger adults do.

Shortly thereafter, Rabinowitz et al. (1982) proposed that the semantic/meaning features of words are encoded automatically, but attentional resources are required to encode contextual/verbatim aspects of words. They argued that older adults have reduced attentional resource capacities, limiting their ability to encode and retrieve specific details. In their experiments, young and older adults were tasked with generating associates to studied words. At test, participants were provided either specific retrieval cues (i.e., the associates generated at encoding) or general retrieval cues (i.e., category labels) to aid with recall. Older adults recalled fewer words than younger adults when provided specific cues but performed similarly to younger adults when given general cues. A similar pattern of results was obtained with young adults under divided attention conditions at either encoding or retrieval, which suggested that attentional resources were necessary for encoding and retrieving specific but not general/gist details. Some more recent studies challenge this assumption or at least suggest that some (perhaps smaller) commitment of attention is also required to encode gist representations (Greene & Naveh-Benjamin, 2022b, 2022c).

Studies of Situation Model Processing in Reading Comprehension

Research on older adults' reading comprehension provides additional insights into the representational nature of their memories. Inspired by theories of discourse and reading comprehension (e.g., Johnson-Laird, 1983; Kintsch & van Dijk, 1978; van Dijk & Kintsch, 1983), studies in this domain have focused on age differences in memory for the surface form of a passage of text (e.g., the specific syntax used) versus situation models of the text (i.e., a representation of what the text is about). The surface representation is important for initial reading comprehension but rapidly disintegrates (Sachs, 1967). The situation model represents the core meaning of an event, such as a passage of text, and is necessary for successful comprehension (Radvansky & Dijkstra, 2007).

As an illustration of this literature, Radvansky et al. (2001) presented young and older adults with historical or fictional narratives, followed by recognition tests featuring four unique types of memory probes. Verbatim probes were actual sentences from the text. Paraphrase probes featured sentences that were reworded but retained the proposition content of original sentences. Inference probes were novel sentences containing information that could be inferred from the meaning of the original text, but these sentences did not appear in the text. Incorrect probes were novel sentences presenting information unrelated to the meaning of the original text. Retention of the surface form is indicated by the ability to discriminate verbatim probes from paraphrase probes. Retention of the text content (i.e., the details for what was said, which is often referred to as the "textbase" model level

[2] Both the degree to which an individual strategically encodes information and effortfully retrieves that information is likely to influence whether they remember specific or general details (Craik, 2002a, 2002b).

of representation) is indicated by the ability to discriminate paraphrase probes from correct inference probes. Retention of the situation model is indicated by the ability to discriminate correct inference probes from incorrect inference probes. Radvansky et al. (2001) found that younger adults had superior memory for the surface form and textbase levels of representation than older adults, whereas older adults had superior memory for the situation model. Several other studies have produced similar findings (Morrow et al., 1992, 1997; Radvansky, 1999; Radvansky, Copeland, Berish, & Dijkstra, 2003; Radvansky, Copeland, & Zwaan, 2003; Reder et al., 1986; Stine & Wingfield, 1988; Stine-Morrow et al., 2002, 2004), which supports the idea that older adults characteristically process and retain the *gist* of information but fail to retain specific information.

False Memory Studies

In the classic Deese–Roediger–McDermott (DRM) paradigm, participants study a list of items related to an unpresented lure (e.g., for the lure "sleep," studied words may include "bed," "dream," and "pillow"). Deese (1959) and Roediger and McDermott (1995) reported high rates of false recall and recognition of the unpresented lure in young adults. Variants of the paradigm were tested with older adult participants in many studies, which consistently found that older adults were even more prone to false recall or recognition of the lures (Balota et al., 1999; Dennis et al., 2007; Gallo & Roediger, 2003; Kensinger & Schacter, 1999; Koutstaal & Schacter, 1997; Koutstaal, Schacter, Galluccio, & Stofer, 1999; Norman & Schacter, 1997; Tun et al., 1998; for reviews, see Devitt & Schacter, 2016; Gallo, 2006; Schacter et al., 1997). These studies popularized the notion that older adults preferentially process the gist of information (i.e., a "gist-based processing preference"; Tun et al., 1998). The assumption is that older adults preferentially focus on the gist/meaning that connects the items in a list (e.g., "bed," "dream," and "pillow" are all related to the concept of sleep), enhancing their susceptibility to endorsing the lure as having been studied. Although this view suggests that older adults' reliance on gist representations is a *preference*, it is also likely that their ability to access specific representations is more limited, given potential poorer encoding, maintenance, or retrieval of these representations.[3]

Visual Mnemonic Discrimination Recognition Studies

Most of the studies reviewed so far have primarily relied on verbal stimuli, with some exceptions (e.g., Koutstaal & Schacter, 1997). However, recognition procedures with visual stimuli, similar to those used in some of the earlier word recognition studies in the levels of processing framework (e.g., Rankin & Kausler, 1979) involving the discrimination of old items from similar lures and novel distractors, have provided evidence that older adults possess more gist-like rather than specific representations for visual stimuli as well (Kirwan & Stark, 2007; Koutstaal, 2003; Pidgeon & Morcom, 2014). These recognition tasks are visual mnemonic discrimination tasks but have sometimes been called behavioral pattern separation studies when these procedures are coupled with neuroimaging techniques, as evidence for the involvement of the dentate gyrus and Cornu Ammonis hippocampal subfields in discriminating old items from similar lures has primarily come from these types of tasks (Kirwan & Stark, 2007; Stark et al., 2013; Yassa et al., 2011).

An early study using a visual mnemonic discrimination task in the context of aging was conducted by Koutstaal (2003), in which participants encoded pictures of everyday items (e.g., an apple). The test featured old items (e.g., the same apple), new items (e.g., a balloon), and similar lures (e.g., a different apple). Koutstaal (2003) found that older adults were about twice as likely as younger adults to endorse similar lures as having been studied, a finding showing that older adults are less able to discriminate visual targets from similar distractors, much like in earlier studies with word stimuli (Rankin & Kausler, 1979).

An important difference between this task and the DRM paradigm is that the study list did not consist of semantically associated items, so a common gist across the items of the study list would not have been primed. Thus, the finding of higher rates of false recognitions of visual lures among older adults in the study by Koutstaal (2003) and others using similar tasks (e.g., Paige et al., 2016; Pidgeon & Morcom, 2014; Trelle et al., 2017) provides additional strong support that older adults' memories are less specific than those of younger adults, even in situations in which items are not semantically related during encoding.

In visual mnemonic discrimination tasks, similar lures are both perceptually and conceptually related to studied items. Thus, older adults' heightened false alarms to lures could be driven either by *semantic gist* (i.e., shared meaning between the lure and the original item) or *perceptual gist* (i.e., shared perceptual similarities between the lure and the original item). Much as semantic gist representations are strengthened by exposure to lists containing items that are related in meaning (e.g., DRM lists; see Koutstaal & Schacter, 1997), perceptual gist representations can also be strengthened via exposure to multiple visual items with similar perceptual features like shape or color (e.g., Koutstaal, Schacter, Verfaelli, et al., 1999). However, a few studies have suggested that older adults' heightened false alarms to visual lures are attributable to shared conceptual/semantic gist and not to shared perceptual gist. Koutstaal et al. (2003) presented participants with unfamiliar abstract shapes that were grouped into categories based on visual similarity. In one condition, the categories lacked any verbal labels, whereas in a second condition, abstract shapes belonging to the same category were assigned a common verbal category label, thus adding a semantic label to those shapes. Older adults were more prone than younger adults to false recognitions of perceptually similar lures *only* in the condition in which category labels had been provided but not in the condition without category labels. These findings are consistent with a semantic categorization account, suggesting that older adults' false recognitions are influenced by semantic but not perceptual gist. Pidgeon and Morcom (2014) produced similar results in a replication of this work, even when the number of exemplars in a category was reduced, which should lessen both semantic and perceptual gist. Collectively, findings from studies employing visual mnemonic discrimination recognition procedures converge on those with verbal stimuli showing that older adults' memories are less specific in nature.

[3] Although not the focus of the present review, it is worth mentioning that DRM procedures have shown that older adults with dementia are also susceptible to gist-based false memory illusions (Budson et al., 2000), whereas more standard recall procedures suggest that a major distinguishing factor between healthy older adults and those with dementia is in the ability to reintegrate episodes from gist representations (Brainerd et al., 2009; Brainerd & Reyna, 2015).

Studies of Autobiographical Memory

Autobiographical memory pertains to memories of the events of one's life (e.g., Tulving, 2002). Autobiographical memories can vividly capture the specifics of a particular episode or can be more categorical/overgeneral, capturing details shared across many experiences (Williams, 1996). For example, an individual may have overgeneral autobiographical memories in which they remember summer camping trips. A specific autobiographical memory would pertain to a particular camping trip, in which they encountered a bear.

The tendency to remember specific but not overgeneral autobiographical memories declines in older adulthood (Beaman et al., 2007; Cohen, 1998; Levine et al., 2002; Piolino et al., 2002). These declines may depend partially on the specificity of the prompt that an older adult is given when asked to recall a personal memory (Cohen, 1998), as older adults can produce more vivid recall of a specific episode when given focused prompts (e.g., "Tell me about the *last time* you visited your family") versus less focused prompts (e.g., "Tell me about an experience where you visited your family"). However, these benefits may be time-limited, as Levine et al. (2002) found that probing questions only improved older adults' specific autobiographical recall for recent, but not distant, memories. The picture may be somewhat more nuanced, though, given that, even among younger adults, the ability to recall specific autobiographical memories worsens with time (Piolino et al., 2002; Rubin & Schulkind, 1997). In addition, older adults can often remember more specific autobiographical memories occurring in certain times of their lives, especially in adolescence and young adulthood (Rubin & Schulkind, 1997), so the age of the memory is not the only factor that determines whether older adults can remember a specific autobiographical memory.

Nevertheless, the picture from studies of autobiographical memory is convergent with more standard laboratory tests of episodic memory in showing that older adults' memories tend to be less specific. It is important to keep in mind that studies of autobiographical memory recall often have less experimental control than the other paradigms reviewed here (e.g., in terms of ensuring that all participants are tasked with remembering the same set of stimuli). This may confound whether older adults' tendencies to report overgeneral but not specific autobiographical memories are attributable to a failure to retain specific memories or to a preference to describe their memories in a more general fashion.

Representational Precision in Working and Long-Term Memory

Age differences in the *precision* of memory—a topic more common in working memory than long-term memory (e.g., Bays et al., 2009; Zhang & Luck, 2008; but see Brady et al., 2013)—mirror those on the specificity of memory, though these two literatures are not often discussed together. Precision pertains to how accurately individuals can recall/reproduce details of a studied event, such as reproducing the precise color of an object using a color wheel. The extant, albeit limited, research on older adults' memory precision is informative to our discussion of the representational nature of older adults' memories.

Only a few studies, mostly conducted in the working memory literature, have examined older adults' memory precision. In a study by Peich et al. (2013), participants viewed simple line stimuli that were presented in a circular array with either one (low load) or three (high load) stimuli per array. Each line stimulus was oriented in a unique direction and had a unique color (e.g., a red line pointing at a 45° angle). At test, a line appeared on screen, and participants used response dials to rotate the line to its correct angular orientation and/or to select its correct color from a color wheel. Older participants, compared to younger participants, produced more recall error distributed around the correct response, in reproducing both the orientation and the color of the lines, especially in the high load condition. These findings were the first to show that the representations of items held in visual working memory were less *precise* in older adults than younger adults. This finding was replicated by Souza (2016) and was also shown by Pertzov et al. (2015) to apply to reproduction of the location of object stimuli in visual working memory. More recently, Korkki et al. (2020) and Rhodes et al. (2020) adapted these tasks to examine age differences in the precision of memory in both working memory and long-term memory. Like the previous studies, those by Korkki et al. (2020) and Rhodes et al. (2020) showed that older adults' episodic memories were less precise, especially in long-term memory.

Studies of Associative Memory

Many theories of episodic memory describe the importance of binding of components of an episode (e.g., a person and a location, or a face and a name) into a cohesive representation (Treisman, 2006; Tulving, 1983; Underwood, 1969; Zimmer & Ecker, 2010; Zimmer et al., 2006). Numerous studies have demonstrated that older adults exhibit an *associative deficit*, whereby they are impaired in their ability to bind together different components of an episode (*associative deficit hypothesis*, Naveh-Benjamin, 2000; Naveh-Benjamin et al., 2003, 2004; see also, Boywitt et al., 2012; Chalfonte & Johnson, 1996; for meta-analyses, see Old & Naveh-Benjamin, 2008; Spencer & Raz, 1995).

Castel (2005) showed that older adults' associative memory deficits can be reduced when existing schematic knowledge can aid in remembering novel associations (cf. Castel et al., 2007, 2013). In his study, young and older adults studied grocery items and associated prices, which were either realistic (e.g., a gallon of milked priced at $3.25) or unrealistic (e.g., a loaf of bread priced at $15.45). In the realistic scenario, the presented item-price association is consistent with preexisting knowledge about the price of this item in the real-world, whereas in the unrealistic scenario, the association does not fit with preexisting knowledge (either an over- or an underestimation of the price of the object in the real world). Castel (2005) showed that older adults could rely on this preexisting knowledge to effectively eliminate their associative deficit for item-price associations in the realistic price scenario. Even in the unrealistic price scenarios, older adults could effectively remember the *general* price range associated with an item (e.g., remembering the loaf of bread was overpriced). These findings showed that older adults could remember some episodic associations at less specific levels of representation, and other studies have shown similar effects when preexisting schematic support can be leveraged to older adults' advantage (e.g., for face–age or face–name pairs, in which generation-normed names are associated with age-matched faces; McGillivray & Castel, 2010; Peterson et al., 2017). Similar patterns of results were reported when other relevant information based on semantic memory may be used to reduce the load on episodic binding, for example, when semantically related rather than unrelated words are paired together (e.g., Naveh-Benjamin et al., 2003).

Can older adults also remember the gist of associations when preexisting schematic support is likely to be less helpful? This question was addressed recently by Greene and Naveh-Benjamin (2020, 2022a; cf. Greene et al., 2022). In their task, participants studied face–scene pairs, such as an old man paired with a park scene, for which preexisting schematic support (e.g., knowledge of encountering old men in parks) would be of little use, because an equally plausible preexisting schema may exist for alternative pairings (e.g., a young woman paired with the park, based on experiences of encountering young women in parks). In the test phase, participants discriminated intact pairings (e.g., the old man with the same park) from foils that were either highly similar distractors (e.g., the old man paired with a different park), less similar distractors (e.g., the old man paired with a forest), or dissimilar distractors (e.g., the old man paired with a kitchen). In order to reject each type of foil, an individual would need to access increasingly more specific information about the originally studied association as the foils became increasingly similar (i.e., from dissimilar distractors to highly similar distractors). Compared with younger adults, older adults were more likely to endorse highly similar distractors as having been studied before, but the age differences were smaller for less similar distractors and were absent for completely dissimilar distractors. These results suggest that, even for some episodic associations for which preexisting schematic support would provide little or no assistance, older adults can remember these associations at less specific levels of representation but fail to remember highly specific representations like young adults can.

However, this may not be true of all associations. Simons et al. (2004) found that older adults were prone to forgetting not only specific source information (i.e., which of two males spoke a given sentence) but also partial source information (i.e., whether a sentence had been spoken by a male or female voice). There are important differences between the paradigms from Greene and Naveh-Benjamin (2020) and Simons et al. (2004), including differences in the modality with which information is presented (visual vs. auditory) and potential differences in interference (e.g., in Simons et al., 2004, there were only four voices, each of whom spoke many different sentences, leading to potentially greater interference). Nevertheless, more research on this topic is needed to see whether the results from Greene and Naveh-Benjamin (2020) would replicate with other types of complex episodic associations.

Summary of Empirical Evidence

The last five decades of research has produced an impressive set of empirical findings across a number of domains (see Table 1) that are in line with predictions of several leading theories of memory representation reviewed earlier, converging on an apparent universal principle of cognitive aging: Older adults' episodic memories are representationally less specific/detailed than those of younger adults. A major objective for the future of the field is to determine *why* this is so. To this end, we consider a more mechanistic model that will allow us to test predictions about different encoding, maintenance, and retrieval processes that may underlie older adults' deficiencies in specific but not general representations. We turn now to describing such a modeling approach.

A Theoretical Framework for Future Research

We now introduce a theoretical framework that can inspire future empirical and computational research to elucidate the mechanisms underlying why older adults' episodic memory representations are less specific in nature. The framework is not intended to supplant existing theories of memory representation. Rather, it will build on themes discussed in current theories, along with computational theories of human memory (e.g., Shiffrin & Steyvers, 1997), to propose a more explicit, mechanistic model of age differences in memory representations.

In keeping with Salthouse (1988), we propose a sketch of a model that can be fitted to data from young adults with a few critical assumptions (captured by parameters in a computational model) to simulate what mechanism underlie specific and gist memory representations in young adults. We can then adjust parameters of the model to see whether freeing a single parameter, or some combination of parameters, can enable the model to fit data from older adults whose memory representations are less specific (see Healey & Kahana, 2016 for a similar approach). For example, we may allow a parameter governing the rate at which specific representations are encoded to differ for young and older adults, modeling slower formation in older adults in keeping with processing speed theories of aging (Salthouse, 1996), but hold constant parameters governing forgetting across time, if we assume no age differences in forgetting. The framework has not yet been formalized in a computational model, but this represents an important direction for future research.

Background and Basic Components of the Framework

Core to the framework is the assumption that a given episodic memory can be represented as a sum of constituent components, in keeping with descriptions from verbal theories that view episodic memory as a bound representation of event units (Tulving, 1983; Underwood, 1969). For example, an episode may consist of components like *location, time*, and *person*, which are integrated, such that this episodic memory represents a person in a particular location at a specific time.

In describing the framework, we will work with a simpler example involving studying words for a later free recall or item recognition test. Each learning trial (e.g., each word presented during the study phase) can be represented as a set of associated features stored in a vector (e.g., Cox & Criss, 2020; Cox & Shiffrin, 2017; Gillund & Shiffrin, 1984; Raaijmakers & Shiffrin, 1981; Shiffrin & Steyvers, 1997). The vector consists of all the attributes of the learning trial that can be encoded (e.g., the font in which a word appears, its position on a screen, the meaning of the word, the preexisting familiarity of the word). For the present demonstrative purpose, we have not committed to the specific nature of the vectors, such as how many units make up the vector or whether these units are represented on a binary scale (with 0's and 1's denoting the absence and presence of a feature, respectively) or as a set of associative weights (i.e., probabilities ranging from 0 to 1 that denote the degree to which a feature of the learning trial is encoded into memory). These specifics remain to be fleshed out in a more formal mathematical instantiation of the theory, but at present, this schematic representation enables us to lay out a basic architecture (i.e., vectorized representations of learning trials) to test predictions about age-related differences in the encoding, maintenance, and/or retrieval of specific and more general representations.

The theoretical model makes the following key assumptions. First, the encoding of specific and general/gist features of an episode (e.g., the specific perceptual features of a word and its semantic meaning) occurs independently. To represent this in our vectorized architecture, we will depict two separate encoded vectors for specific and general features of a learning trial. Second, the maintenance of specific features across time is independent of how many general features can be maintained. Consequently, different forgetting rates can occur for the specific compared to the general feature vector in our model. Third, the retrieval of specific versus general features of an episode can occur independently. The nature of the memory test itself (e.g., recall vs. recognition, and within recognition, the degree of similarity of the test probe to the studied item) can also independently influence the retrieval of specific versus gist features of an episode. These points are summarized in Figure 2, which depicts a schematic illustration of the basic architecture of the theoretical framework.

Modeling Age Differences in Specific Representations

In the following, we consider separate encoding, maintenance, and retrieval mechanisms that may account for why older adults' episodic memory representations are less specific.

Encoding Mechanisms

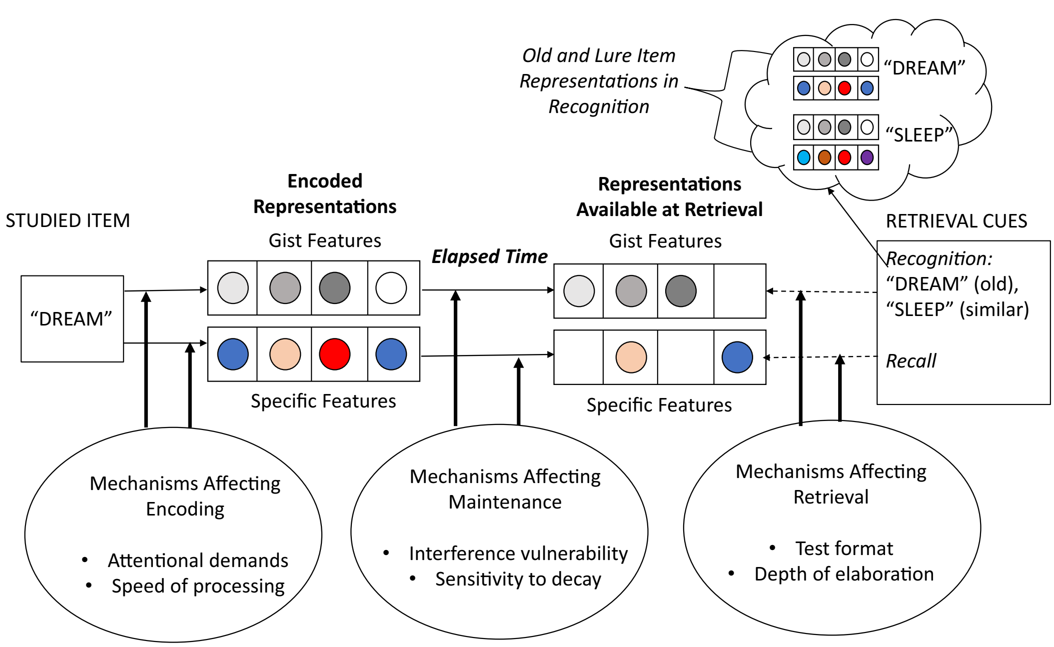
We consider two possible encoding mechanisms—the resource-consumptive nature of specific and gist representations, and the speed at which each type of representation can be formed—that may underscore differences between young and older adults in initially establishing specific memory representations.

Resource Costs of Encoding Specific and Gist Representations. Recent empirical work in young adults has shown that, when attention is divided between encoding face–scene pairs and simultaneously completing an auditory choice reaction time task, there are deficits in both specific and gist memory representations for the face–scene pairs (Greene et al., 2022; Greene & Naveh-Benjamin, 2022b, 2022c). This evidence suggests that some attentional resources are necessary to encode not only specific but also gist representations, at least for associations between components of an episode, refuting an earlier held view that gist representations are established automatically (Rabinowitz et al., 1982). Nevertheless, it remains an open question as to whether differential attentional resources are needed to encode gist versus specific representations, and future empirical work will be needed to determine this, for example, by manipulating the difficulty of the divided attention task.

Given older adults' reduced working memory/attentional resource capacity (Craik & Byrd, 1982; Greene et al., 2020; Light & Anderson,

Figure 2

Schematic of Theoretical Model for Assessing Age Differences in the Encoding, Maintenance, and Retrieval of Specific and Gist Episodic Memory Representations



Note. Specific features (e.g., perceptual characteristics of an item) and gist features (e.g., semantic meaning of an item) are encoded in independent vectors. Gist features are depicted as grayscale circles; specific features are depicted as colored circles (see online article for color version). Different mechanisms at encoding, maintenance, and retrieval can have unique effects on gist versus specific representations. For example, the figure depicts a greater forgetting of specific than gist features by the time of retrieval (fewer retained colored circles in the specific feature vector than grayscale circles in the gist feature vector). The cloud insert at retrieval depicts feature vectors for recognition probes that are an exact match at both specific and gist levels (old item—"DREAM") versus recognition probes that are a match at gist but not specific levels (similar lure—"SLEEP"). See the online article for the color version of this figure.

1985; Wingfield et al., 1988), it is conceivable that they may be unable to allocate enough attention to encode specific representations but can allocate enough attention to encode gist representations. To model this possibility, we can include attentional filter parameters that account for how many units of each type of representation can be encoded into memory, as depicted in Figure 3. Figure 3A shows the encoding of specific and gist representations in young adults, and Figure 3B, C show the encoding of these representations in older adults under the assumption that there are absolute age differences in the number of specific features encoded (Figure 3B) or in the precision of the specific features that are encoded (Figure 3C). These two possibilities reflect differences inherent in discrete-slot models of working memory (Cowan, 1988, 2001, 2019) and in resource models (Bays & Husain, 2008; Ma et al., 2014). The lambda parameter governing the number of gist features that is encoded is held constant across the two age groups, while the parameter governing the number or precision of specific features that is encoded is smaller in older than in younger adults.

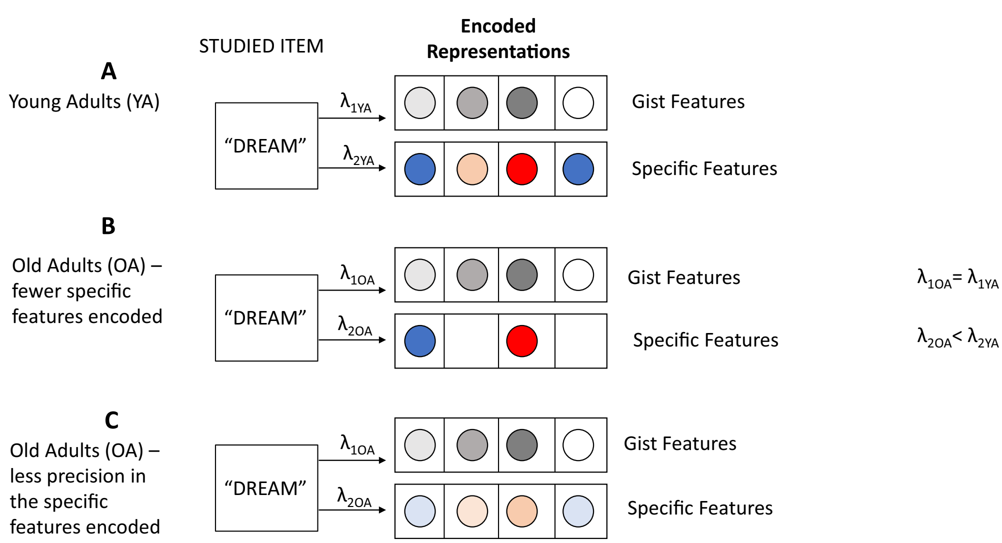
Speed of Formation of Specific and Gist Representations at Encoding. In young adults, several studies have shown that gist representations are encoded independently of, and sometimes more rapidly than, verbatim representations. Draine and Greenwald (1998) showed that participants were more accurate at identifying target names as either prototypically male or female (e.g., Sarah as a female name) when the target was preceded by a prime that was semantically congruent with the target (e.g., Jane) versus incongruent with the target (e.g., Adam), even as participants were unable to perceptually detect the primes. That is, semantic/gist representations of a prime could be formed within 30–50 ms of presentation time even as specific/verbatim representations of the primes were not yet established (cf., Wallace et al., 1998). More recent support for this independence assumption has come from studies of visual long-term memory for scenes (Ahmad et al., 2017) and for face–scene associative memory (Greene & Naveh-Benjamin, 2022d), in which gist representations are established as rapidly, or in some cases more rapidly, than corresponding specific representations of these complex visual stimuli.

However, there is not yet a clear picture as to whether gist representations form more rapidly than specific representations among older adults. Future empirical work will be needed to determine whether this is so, but tentatively, we can conjecture why this may be the case. Processing speed theories of aging suggest that older adults are slower at carrying out cognitive processes, such as the encoding of information into memory (Salthouse, 1996). We have a clear picture from studies like those of Greene and Naveh-Benjamin (2020) that older adults' gist representations are on par with those of younger adults when given the *same* amount of time to encode memoranda. It is conceivable that with more time to encode memoranda, older adults' specific representations could be more on par with those that younger adults possess under shorter presentation times. For example, if older adults had 6 s to encode a face–scene pair in the procedure by Greene and Naveh-Benjamin (2020), compared with 4 s for younger adults, it is possible that there would be no age differences in specific representations. While future empirical work will be necessary to test this hypothesis, we can visualize how this may look in the vector model.

Figure 4 depicts the encoding phase of the theoretical model in which different theta parameters govern the *rate* at which gist and specific features are encoded. For visual purposes, the two theta

Figure 3

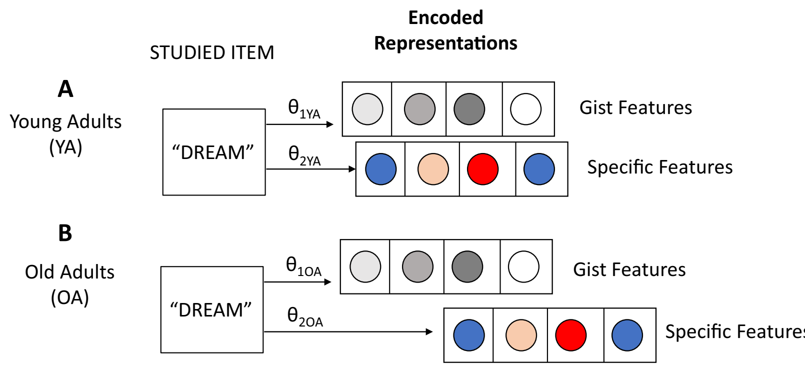
Schematic of Age Differences in the Number or Precision of Specific Features That Are Encoded



Note. Depiction of the encoding phase of the theoretical model for young adults (A), and older adults, assuming differences in number of specific features encoded (B), or in the precision of specific but not gist features encoded (C). Circles represent attributes of the studied item encoded as units in a vectorized representation. The parameter lambda governs the strength of encoding or the number of features that can be encoded into the vector. Specific/verbatim features are colored, gist/semantic features are shaded. In (C), the colors for the specific features are set to a lighter shade from those in (A) to emphasize less precision in the encoding of these features for older than younger adults. See the online article for the color version of this figure.

Figure 4

Schematic of Age Differences in the Rate of Formation of Specific and Gist Features at Encoding



Note. Depiction of the encoding phase of the theoretical model for young adults (A) and older adults (B) in which there are age differences in the rate at which specific but not gist features are encoded. Model depicts an ideal situation in which older adults eventually encode the same number of specific features as younger adults but require more time to do so. Circles represent attributes of the studied item encoded as units in a vectorized representation. The parameter theta governs the rate at which specific or gist features are encoded. Specific/verbatim features are colored, gist/semantic features are shaded. See the online article for the color version of this figure.

parameters for young adults (Figure 4A) are set at similar rates, with gist representations slightly preceding specific representations. For older adults (Figure 4B), we depict a situation in which θ_2, governing the rate at which specific features are encoded, is much larger than θ_1, governing the rate at which gist features are encoded, such that the extraction of specific features of an episode is more protracted. It is conceivable that there could be no age differences in θ_1, whereas values of θ_2 would be larger (indicating slower formation of specific features) for older than younger adults.

As a final point regarding the encoding mechanisms, it is likely that both mechanisms reviewed here may be critical for accounting for why older adults' memory representations are less specific in nature. Thus, a more accurate theoretical model would need to include separate parameters governing the attentional demands and rates of encoding for specific and gist features. It is also important to note that how these parameters would operate on the vectors (e.g., multiplicatively) awaits further determination.

Maintenance Mechanisms

Between encoding and retrieval, there is likely to be some forgetting of representations due to decay or interference from intervening events (Wixted, 2004). Fuzzy-trace theory assumes that gist representations are more immune to decay and interference (Brainerd & Reyna, 1990, 2002, 2004), an assumption that has been supported in studies of narrative recall (Sekeres et al., 2016; Thorndyke, 1977). Nevertheless, gist representations likely also undergo some forgetting across time, as evident in recent studies with both young and older adults by Greene and Naveh-Benjamin (2022a, 2022b, 2023) showing losses across time not only of specific representations for associative memory but also in gist representations, albeit at a more protracted rate (i.e., losses in specific representations across time unfolded more rapidly).

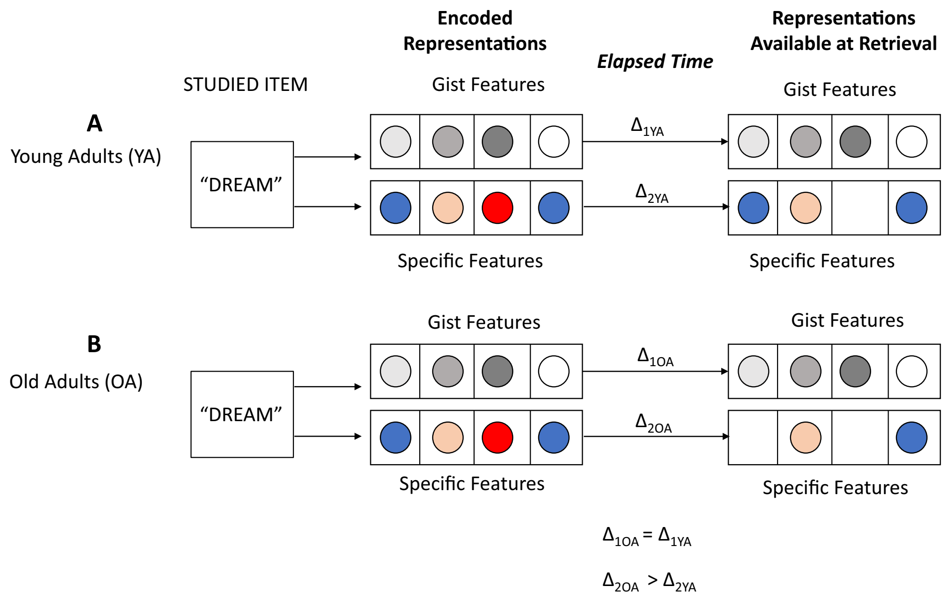
If interference or decay is exacerbated for older compared to younger adults, then this could be one reason why older adults show deficits in specific memory representations. Even if older adults initially establish specific representations to the same degree as younger adults, those representations may be more vulnerable to rapid forgetting. Indeed, Greene and Naveh-Benjamin (2022a) showed that, under some conditions, older adults could access specific representations of episodic associations as well as younger adults almost immediately after encoding face–scene pairs, but not in long-term memory, suggesting that the locus of age deficits may not be solely at encoding. Figure 5 depicts how to model a possibility where, even if older adults *initially* encode the same number of specific features as younger adults, over time, older adults forget more specific features. This is accomplished by setting the forgetting parameter on the postencoded vector for specific features (Δ_2) to a larger value for older adults (Figure 5B) than for younger adults (Figure 5A). At the same time, the model assumes no age differences in the forgetting of gist features (Δ_1). For simplicity, in Figure 5, no loss of gist features is depicted for either young or older adults. Of course, the magnitude of forgetting of specific or gist features that will occur will depend not only on the vulnerability of each type of representation to interference or decay but also on the absolute amount of interference (e.g., the number of intervening events between encoding and retrieval) and the total amount of elapsed time.

Retrieval Mechanisms

At retrieval, we must consider how different test formats (recall vs. recognition) may influence the accessibility of specific and gist representations. Older adults perform disproportionately worse on tests of recall than recognition (Danckert & Craik, 2013; Rhodes et al., 2019), which may be related to differences in environmental support (Craik, 1986). The types of cues provided

Figure 5

Schematic of Age Differences in the Forgetting of Specific but Not Gist Features in the Time Between Encoding and Retrieval



Note. Depiction of the maintenance phase between encoding and retrieval of the theoretical model for young adults (A) and older adults (B) in which there are age differences in the forgetting of specific but not gist features between encoding and retrieval even when there are no age differences in the number of specific features initially encoded. Circles represent attributes of the studied item encoded as units in a vectorized representation. The parameter Δ models forgetting. Specific/verbatim features are colored, and gist/semantic features are shaded. See the online article for the color version of this figure.

at test are likely to play an important role in determining which types of representations are more easily accessible. For example, in conjoint recognition tasks, presenting an old item as a probe is a strong elicitor of verbatim representations, whereas presenting a similar lure as a probe is a strong elicitor of gist but not verbatim representations (Brainerd et al., 1999, 2019, 2022; Stahl & Klauer, 2008).

In recognition procedures, accessing the gist of a past episode may be less effortful than accessing a verbatim representation. Luo and Craik (2009) showed that, for young adults whose attention was divided during *retrieval* rather than at encoding for an item-context memory task, there were deficits in memory for the specific but not the general context in which items had been encoded (cf. Dodson et al., 1998). These results suggest that more attentional resources are necessary for reintegrating a specific representation during retrieval, which may be related to the need to elaborate on more impoverished specific memory traces (e.g., Brainerd & Reyna, 1990). However, the picture appears to be somewhat reversed for recall procedures. In recall, directly accessing a verbatim representation of an old item is less effortful than reconstructing an episode from its gist representation (Brainerd et al., 2009). For example, Barnhardt et al. (2006) showed that false recall of semantic lures in the DRM procedure tends to occur toward the middle or end of the free recall protocol, after several true recalls have been committed. This may speak more to how effortful it is to reconstruct an episode from its gist trace than how accessible gist traces are at retrieval. For instance, during the free recall period of a DRM procedure, a participant may automatically access the gist of the encoded list (“all the items pertained to sleep”), but reconstructing an item from the list on the basis of this gist may be effortful (e.g., “I remember seeing items related to sleep, but *which* items related to sleep did I see?”).

There is some universality to older adults’ diminished ability to access specific representations regardless of whether the memory test is a recognition or recall procedure. In conjoint recognition, associative recognition, and mnemonic discrimination procedures, older adults commit more false alarms to similar lures that share a gist representation with studied items (e.g., Greene & Naveh-Benjamin, 2020; Koutstaal, 2003; Stark et al., 2013). In addition, in recall procedures, older adults’ recall of fewer items may be related to their ability to directly access verbatim representations rather than in their ability to reconstruct episodes from gist representations (Brainerd et al., 2009).

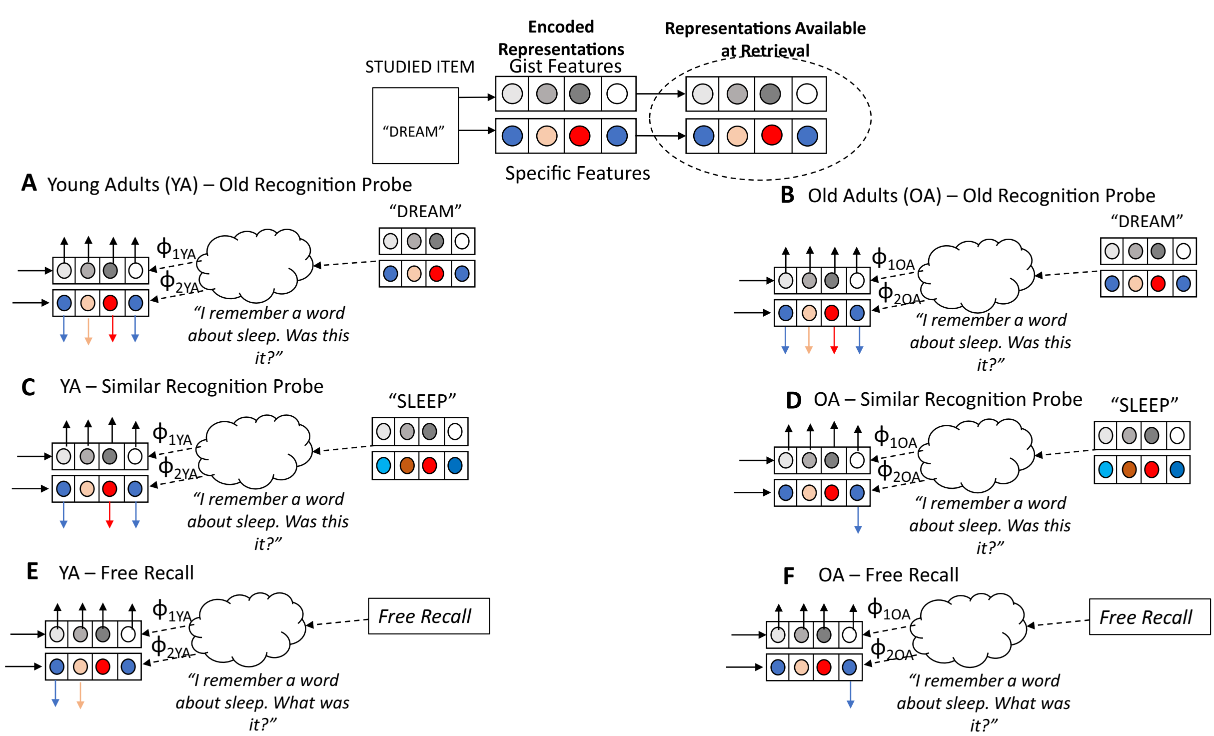
In constructing a theoretical model, it is important to consider that problems during earlier stages of processing may compound older adults’ difficulties with retrieving specific representations. As described in the preceding sections, deficits at encoding and during maintenance may lead to a situation in which, by the time of retrieval, older adults are left with a highly impoverished specific memory representation (e.g., one in a vectorized model in which there are very few accessible units corresponding to specific features of the encoded event).

Nevertheless, there may be certain retrieval mechanisms that additionally underscore age differences in specific memory representations. One possibility is related to age differences in elaboration at retrieval (Jacoby et al., 2005), with older adults being less likely to deeply elaborate on the contents of their memories (i.e., thinking deeply on the details of an episode to reintegrate specific features of that episode). Age differences in elaboration may manifest differently depending on the nature of the task (recall vs. recognition), which may in part reflect how much environmental support is provided in the form of a retrieval cue.

In Figure 6, we depict an ideal situation in which older adults initially encode and retain as many specific and gist features of an episode as younger adults, yet differences in elaboration at retrieval based on the type of memory cue provided can still lead to older adults retrieving *fewer* specific but not gist features. However, the extent to which this occurs is influenced by the amount of environmental support provided in the retrieval cue (i.e., memory probe). When the retrieval cue is an exact reproduction of the originally studied item, the degree to which an individual must deeply elaborate on the contents of their memory is minimized. In this situation, older adults are depicted as retrieving the same number of specific features of the original episode as younger adults can, as old items are excellent retrieval cues for specific representations, even among older adults (Brainerd et al., 1999, 2019; Greene & Naveh-Benjamin, 2020, 2022a; Stahl & Klauer, 2008). However, when a similar lure is presented in a recognition experiment, the lure provides a good match to the gist representation of the original item but is a poor match for the original item's specific representation (Brainerd et al., 1999, 2019). In this situation, an individual must attempt to reintegrate the specific representation of the original item to reject the similar lure, but older adults are less likely to engage in this type of effortful reflection (Greene & Naveh-Benjamin, 2020), which appears to be an attentionally demanding process (Greene & Naveh-Benjamin, 2022c; Odegard & Lampinen, 2005). Thus, when a similar lure is presented, older adults are less likely than younger adults to remember the specific representation of the original item. Finally, when no retrieval cue is provided in the form of a recognition probe (i.e., when the test

Figure 6

Schematic of Age Differences in the Extent of Elaboration and Search of Memory During Retrieval for Specific and Gist Features in a Dual-Trace Model



Note. Depiction of the retrieval phase of the theoretical model in an ideal setting in which young and older adults initially encode and retain the same number of specific and gist features (top). Retrieval of specific and gist features is affected by environmental support provided by retrieval cues for both young adults (A, C, and E) and older adults (B, D, and F). Young and older adults must reflect/elaborate on their memories, and the degree to which this elaboration is successful depends in part on how much environmental support is provided in the retrieval cue. The number of specific and gist features of the originally encoded item that can be retrieved is indicated by arrows being output from the colored circles (specific features) and the grayscale circles (gist features) in the retrieval vectors. Three types of retrieval cues are depicted, an old recognition probe (A and B), a similar lure (C and D), and a free recall prompt (E and F). Each type of retrieval cue influences separate phi parameters that result in the output of gist (Φ_1) and specific (Φ_2) features. For demonstrative purposes, the same number of gist features is output for young and older adults and for each type of retrieval cue. The number of specific features of the original episode that is retrieved is greatest for the exact match probe ("Dream"), with no age differences depicted for this type of memory probe. However, for similar lures ("Sleep"), older adults retrieve fewer specific features of the original item than younger adults do, and the same is shown under "Free Recall" instructions. Specific features are colored, and gist features are shaded. See the online article for the color version of this figure.

is a free recall procedure), older adults' limited depth of elaboration at retrieval (Jacoby et al., 2005) contributes to their diminished ability to retrieve specific representations of original episodes.

Conclusion

Age deficits in episodic memory are well-documented (Light, 1991; Naveh-Benjamin & Old, 2008; Salthouse, 1991; Zacks et al., 2000). However, it appears that these deficits are characterized by a diminished quality of specific representations in older adulthood, as older adults can remember episodic memories at less specific levels of representation. This seems to be true in both short-term and long-term memory, and for numerous aspects of episodic memory, including items or components and the complex associations between components that lie at the core of episodic memory. Thus, it could be said that one general principle of aging is that the *quality* of episodic memory representations is less specific in nature in older adulthood.

An important consequence of this principle is that researchers must consider whether theoretical mechanisms—like an associative binding deficit (Naveh-Benjamin, 2000), or slower processing speed (Salthouse, 1996)—are always present in accounting for age deficits in episodic memory, or if these mechanisms are constrained to different levels of representation. For instance, do older adults exhibit associative deficits only at highly specific or also gist levels of representation? Findings like those from Greene and Naveh-Benjamin (2020) suggest that, at least for some types of complex associations, age-related associative memory deficits do interact with the qualitative level of representation; that is, they are only present at specific but not gist levels of representation. In other words, theories attributing age deficits in episodic memory to a single factor must consider the interaction of that factor with the qualitative representation of the underlying memory. Doing so can help clarify the conditions under which age deficits in a mechanism like impaired associative binding are present or absent. Such an approach is in accord with recent computational modeling efforts, like those of Healey and Kahana (2016), showing that assuming a single factor is responsible for age deficits cannot sufficiently account for age-related effects on recall and recognition. In a similar vein, the present review of the literature suggests that an important factor to consider when evaluating age deficits in episodic memory is the qualitative level of representation itself.

We have reviewed decades of empirical work that converge on this general principle, and we detailed a theoretical framework, inspired by computational models of memory, that can serve as a model for future research to better elucidate the mechanisms underpinning age differences in the specificity of memory representations. Formalizing the theory into a computational model will be an important direction for future research. There are many other exciting directions for future research, including tests of some of the framework's mechanistic assumptions, such as those pertaining to age differences in the rate of formation of specific representation. In addition, we have concentrated primarily on what mechanisms may underpin why older adults' episodic memories are representationally less specific than those of younger adults. However, it is important to consider that there may also be advantages to representing information at gist levels of representation, especially for older adults (see Greene & Naveh-Benjamin, in press). Gist representations may be especially suitable for assisting older adults in carrying out goals for which memory for specific details is not necessary, as in understanding the meaning of a conversation, and retaining gist representations when more specific representations are lacking may help older adults avoid making errors like searching for their car on the wrong floor of a parking garage.

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