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CHANGES IN MEMORY AND METACOGNITION IN OLDER ADULTHOOD[1]

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We use our memory in a variety of settings. As people age, older adults often have difficulty remembering and retrieving names, and rely on habits, prior knowledge, strategies, and emotional processes, and these age-related changes can influence individual behavior. While there are some aspects of memory that may decline with age, older adults can utilize contextual factors (Hess, 2005) and goals-based strategies to selectively remember important information (Castel et al., 2012). In this chapter, we review how different forms of memory are influenced by the aging process, and how one's perspective and awareness of memory abilities (metamemory) can play a role in how older adults remember information.

It is well established that our ability to perform various cognitive processes may decline with advancing age (for review see Craik and Salthouse, 2008). Empirical research has shown a steady decline in working memory capacity, executive functioning, processing speed, and explicit memory ability across the adult lifespan (McCabe, Roediger, McDaniel, Balota, and Hambrick, 2010). However, some processes (such as vocabulary knowledge) appear to be impervious to, or even improve with, the aging process. Many theories have been suggested in order to explain why these selective cognitive deficits occur including a general decline in processing speed (general slowing theory), a reduction in the amount of cognitive resources available (reduced resources theory), the inability to inhibit irrelevant information (inhibition deficit theory), and the accelerated deterioration of prefrontal brain regions (prefrontal theory). In all likelihood, the confluence of these different factors contributes to age-related decline in cognitive ability.

In general, aging is accompanied by marked declines in episodic memory (Hultsch, Hertzog, Small, McDonald-Miszczak, and Dixon, 1992; Zacks, Hasher, and Li, 2000). One of the major complaints of older adults as they age is that they notice an increase in their forgetting of information and that their memory is declining (Schweich et al., 1992; Weaver Cargin, Collie, Masters, and Maruff, 2008). Indeed, our explicit memory capacity and rate of cognitive processing declines over time—from one's early 20s on, steep declines in working, short-term, and long-term memory ability are observed (Park et al., 2002). Simply put, older adults have poorer memory capacity, quality, and accuracy as compared to younger adults (Koriat and Goldsmith, 1996). However, as extensive research has shown, not all types of memory are equally impaired and older adults often use strategies to compensate for age-related memory deficits.

In this chapter, we will discuss how our memory ability changes as we age, including deficits in recollecting specific details and the source of information. We'll also review the way in which various memory abilities are preserved in old age, with older adults' reliance on schematic support and preserved ability to prioritize important information. Finally, older adults' metacognitive and in particular, metamemory, abilities will be reviewed. Importantly, the work discussed in this chapter will focus on cognitively healthy older adults who are experiencing nonpathological aging, in contrast to those with mild cognitive impairment (MCI), Alzheimer's disease, Parkinson's disease, or other neurocognitive disorders that affect cognition in older age (for reviews on various neurocognitive disorders in aging, see Caballol, Martí, and Tolosa, 2007; Carlesimo and Oscar-Berman, 1992; Petersen et al., 2001).

Memory Impairments in Healthy Aging

Recollection and Familiarity

One of the memorial consequences of growing older is a reduction in the amount and strength of recollective details (Koen and Yonelinas, 2014), as our memories may move away from the verbatim and toward more gist-based representations. Consider the following example: Imagine that you are walking down the main thoroughfare in your hometown. As you cross the street, you look up and make eye contact with someone crossing from the other side. As you walk toward him, you are overtaken by a feeling of familiarity that you have seen this man before, but are unable to remember his name or any other details about him. Still, this lingering feeling of "I've seen this man before" remains. As you pass by him, you flash a polite smile and carry on with your day. Later on, it suddenly dawns upon you: John was the coach of your son's baseball team a few years ago. You can now remember various details that you previously learned about John (e.g., his wife, Lisa, is a member of the parent-teacher association, his son was #7 on the team, etc.).

This example (similar to the classic "butcher-on-the-bus" example put forth by Mandler, 1980) demonstrates the concept of recognition memory, a type of declarative memory. In contrast to recall memory in which information is retrieved without any external stimulus cue, recognition memory involves matching an encountered stimulus or event to related information in long-term memory. Recognition memory can be further subdivided into two categories: familiarity and recollection. Events depicted in the above example provide an illustration of how this distinction might manifest in daily life. Familiarity is associated with a vague "feeling of knowing" that one has encountered a stimulus before, but with the absence of any related details. When you encounter the man crossing the street, your initial reaction (i.e., the feeling of "I've seen this man before") represents familiarity-based recognition. Recollection, however, is associated with retrieval of specific details associated with a previously learned fact or experienced event. Your ability to retrieve specific details about the man (i.e., his name, profession, where you first met him, etc.) represents a conscious, recollective experience.

While situations like the one detailed in the introduction provide an intuitive way for us to understand the distinction between familiarity and recollection, they do not lend themselves very well to scientific inquiry. After Mandler (1980) formally described the familiarity-recollection distinction, Canadian psychologist Endel Tulving was the first to establish a procedure that could operationalize this distinction in an experimental setting. The "remember-know" paradigm (herein referred to as R/K paradigm; Tulving, 1985) was designed to allow for researchers to probe recognition memory in a controlled, methodical manner. In a typical R/K paradigm, participants are asked to study a list of sequentially presented stimuli (usually semantically unrelated words). Then, after a certain delay, participants' memory for that information is tested. Importantly, unlike a free-recall test in which participants are just asked to recall as many words as possible from the previous list, the R/K paradigm tests for recognition memory by sequentially presenting participants with previously viewed stimuli (targets) and new, not previously viewed stimuli (non-targets or lures).

Participants' memory for each stimulus is evaluated using a two-step process during testing. First, participants are required to make an objective old/new judgment about the stimulus, with "old" indicating that the stimulus was previously presented during the study period and "new" indicating that the stimulus was not previously presented. Then, if participants indicate that a stimulus was old, they are to make a subjective remember/know judgment about the quality of their memory for that stimulus. "Remember" indicates that there is a conscious, recollective experience associated with that stimulus, whereas "know" indicates that the participants have a sense of familiarity for the stimulus, but the absence of any explicit detail associated with its presentation. For example, during study, participants may have been presented with a list of words containing the following string: CRATE-DECOY-FRONT. When tested, if prompted with "DECOY," participants should provide an old response, then determine whether they consciously remember seeing the word (and thus provide a "remember" response) or if they simply know the word was presented due to a feeling of familiarity, but in the absence of any explicit memory of its presentation (and thus provide a "know" response). In some paradigms, participants are given a third option "guess" to indicate that their old response was the result of a random guess, which has been shown to increase participants' ability to correctly discriminate between old and new information (Eldridge, Sarfatti, and Knowlton, 2002). Further, if prompted with the word "SPEAR" during the test, participants should provide a new response to indicate that the word was not presented during the study period.

Much research has examined how recollection and familiarity change across the adult life span. In a large meta-analysis, Koen and Yonelinas (2014) investigated 25 empirical studies that sought to clarify the role of recollective and familiarity-based memory in cognitively healthy aging. Across all of the examined studies, moderate to large deficits in the ability to recollect information were observed. The effects of aging on familiarity-based memory was more mixed: Some studies found no impairment in familiarity (e.g., Cohn, Emrich, and Moscovitch, 2008; Parkin and Walter, 1992; Yonelinas, 2002), while others observed declines in the accuracy of familiarity-based episodic memory (Friedman, de Chastelaine, Nessler, and Malcolm, 2010; Prull, Dawes, Martin, Rosenberg, and Light, 2006; Wang, de Chastelaine, Minton, and Rugg, 2012). This apparent discrepancy in findings was attributed to the type of paradigm utilized, with deficits observed in those using the previously described R/K paradigm, but not those using other methods (Koen and Yonelinas, 2014). Regardless, these results suggest that aging is associated with a large decline in the amount of recollective details remembered, with smaller (or perhaps no) deficits in familiarity-based memory.

From a neurocognitive perspective, this dissociation between declines in recollection and familiarity can be partly explained by differences in the structural and functional deterioration of various brain regions. It is well established that within the medial temporal lobe (MTL), the hippocampus is integral in recollection, while surrounding areas like the perirhinal cortex are responsible for familiarity (Diana, Yonelinas, and Ranganath, 2007; Eichenbaum, Yonelinas, and Ranganath, 2007; Yonelinas, Aly, Wang, and Koen, 2010). While aging is associated with widespread and complex changes in neural functioning, there is generally a decrease in hippocampal volume (Driscoll et al., 2003; Raz et al., 2005) accompanied by hippocampally-dependent memory processes, like recollection (Westerberg et al., 2013; Wolk, Dunfee, Dickerson, Aizenstein, and DeKosky, 2011). However, other MTL areas like the perirhinal cortex exhibit relatively less volumetric decline (Raz, Rodrigue, Head, Kennedy, and Acker, 2004; Yonelinas et al., 2007) and may correlate with relatively intact familiarity (Wolk et al., 2011; Yonelinas et al., 2007). As such, these differences in recollection and familiarity appear to map onto structural changes in relevant brain areas that occur with age. This impaired ability to recollect specific details associated with an event can have a pervasive impact on older adults' daily lives. For example, as will be discussed in the following section, older adults may experience source memory deficits in which they are unable to correctly remember the context in which information was learned.

Source Memory

Consider the previously-mentioned example of John, the baseball coach. The inability to place the familiar face with its source is an example of a deficit in source memory. When recalling information, it is often important to remember the source of that information, as this can provide clues about credibility and help us decide how to act on that information. While item memory refers to memory for content (e.g., a word, image, or fact), source memory is memory for the context (e.g., who, what, where) in which an item was encountered (see Johnson, Hashtroudi, and Lindsay, 1993 for a review). Contextual information can be perceptual in nature, such as an item's visual location, or more conceptually tied to the item, like the truth of a statement. We encounter source information in many everyday situations. For example, when running into someone you've met before, you might want to not only remember that you've seen that person, but also who introduced you, where you met, or other contextual information so you know how to interact.

In studies of source memory, participants are typically presented with an item, such as a word, image, or phrase, that is paired with a source (e.g., a word spoken by a specific voice, an image that appears in a certain location on a computer screen). When their memory is tested, participants must not only recall seeing the item before, but also the source it was paired with. This task is more difficult than remembering the item alone, but is particularly difficult for older adults, who show specific impairments in source memory (Burke and Light, 1981; Park and Puglisi, 1985; Rabinowitz, 1989). In one study of source memory, older and younger adults studied a list of fictional, non-famous names, like "Sebastion Weisdorf." A week later, participants were tested on the names they had studied (as well as new names) and asked to identify the source of the names. Both younger and older adults made source mistakes, such that they attributed names they had seen in the experiment to those of actual famous people, but older adults were significantly more likely than younger adults to make this mistake. Older adults seemed to recognize the non-famous names as familiar, but they couldn't correctly recall the source of these names, which led to falsely believing the names were famous (Dywan and Jacoby, 1990). In another study, McIntyre and Craik (1987) showed that older adults were more likely than younger adults to falsely attribute the source of trivia questions they had learned in an experiment to a source outside the experiment (e.g., TV, book, magazine, friend, etc.). These findings not only highlight the difficulty of remembering source information for older adults, but also demonstrate how familiarity can sometimes negatively impact the ability to accurately remember source information.

One proposed hypothesis for source memory deficits in older age is that source memory largely depends on previously discussed recollection processes (Yonelinas, 1999; cf. Addante, Ranganath, and Yonelinas, 2012; Mollison and Curran, 2012). When recalling seeing a word on a computer screen, for example, recollection would involve distinctly remembering what the word looked like (e.g., font, color, size), what you were feeling and doing at the time, and maybe even what was presented beforehand or afterward. In other words, recollection often involves context-rich memories. Familiarity, on the other hand, usually includes a vague "feeling of knowing" but without knowledge of the contextual details or a very strong memory of the event itself. While remembering sources and contextual details tends to rely more heavily on recollection processes, older adults typically experience familiarity more often when remembering (see Koen and Yonelinas, 2014 for a meta-analysis), which may partially explain age differences in source memory.

Some evidence suggests that declines in executive functioning and associative memory may also contribute to source memory deficits (Shing et al., 2013). Executive functioning largely relies on an area of the brain called the prefrontal cortex (PFC) and includes tasks like focusing attention when distractors are present, holding information in memory to manipulate or use later, and adapting cognitive processes to different situations or perspectives (see Diamond, 2013 for a review). The ability to successfully integrate information with one or more sources for successful source retrieval is thought to depend on executive functioning abilities and the PFC (Mitchell and Johnson, 2009). With increasing age, the volume of and connectivity in the PFC tends to decrease, and older adults show less activity in this area compared to younger adults during source memory tasks (Dennis et al., 2008; Dulas and Duarte, 2011).

In addition, successful source memory depends on the ability to bind two or more pieces of information together in memory (i.e., an item and its contextual details), known as associative binding or associative memory. Associative memory also declines in older age (Chalfonte and Johnson, 1996; Naveh-Benjamin, 2000; Siegel and Castel, 2018) and is reliant on many brain areas but especially the hippocampus. Older adults show reduced hippocampal activity in source memory tasks compared to younger adults (Dennis et al., 2008), which may also account for some of the difficulty in performing these tasks. While both associative binding and executive functioning are important for successful memory performance in general, they seem to be required to a greater degree in the successful integration of items with their sources.

Although there is ample evidence supporting a source memory deficit in older adults, there seem to be some instances in which age differences in source memory are reduced. In one study, for example, older and younger adults studied statements that were read by either a male or female voice. One of the voices (e.g., the female voice) always indicated that the statement was true, whereas the other voice always indicated the statement was false. When tested after a delay on which voice was paired with each statement, older adults were less accurate than younger adults, which was in line with prior work showing age-related deficits in source memory. However, when tested on the truth of the statements, there were no age differences in performance, indicating that older adults were able to remember more conceptual or meaningful contextual information (Rahhal, May, and Hasher, 2002). Another study extended these findings by examining memory for source information about various food items. As expected, older adults were worse at remembering the perceptual details of the foods than younger adults. Interestingly, older adults also showed lower performance than younger adults in remembering a conceptual detail that was neutral in nature (serving temperature), but were just as good as younger adults at remembering an emotional conceptual detail (whether the food would make people sick or not; May, Rahhal, Berry, and Leighton, 2005). These findings suggest that memory for conceptual, meaningful context, particularly information that is emotional or socially important in nature, is more likely to be preserved in older age.

In these cases, remembering the truth of statements or safety of food items may have also been more in line with older adults' goals than remembering the perceptual details. Other work has supported the role of goals or motivation in improving age-related deficits in source memory. For example, age differences are reduced or even eliminated when participants relate the items to themselves (Hamami, Serbun, and Gutchess, 2011; Leshikar and Duarte, 2012) or when source information is central to task goals and affects gains or losses (Bell, Giang, Mund, and Buchner, 2013). These findings are in line with theories of aging that suggest motivational shifts occur in older age (e.g., Carstensen, 2006), and older adults may become more selective with their limited resources and focus on meaningful or valuable information to optimize outcomes (e.g., Hess, 2014). As will be discussed below, these ideas have been further supported by work showing that older adults are able to selectively allocate their attention and cognitive resources to information that is important, valuable, or meaningful, both subjectively and objectively, and are able to successfully remember this information (e.g., Castel, 2008; Castel, McGillivray, and Friedman, 2012; Siegel and Castel, 2018). Overall, it seems that while older adults may experience deficits in memory for source information, they retain the ability to focus on contextual details that are in line with emotional or meaningful goals.

Preserved Memory Abilities in Old Age

Value-Directed Remembering

Often the information that we are attempting to remember varies in importance. For example, it is usually more important to remember your doctor's office phone number as compared to your neighbor's, or the location of your wallet as compared to your pen. The value or importance of this information, then, can influence what we pay attention to and remember. In particular, as we age, we tend to become more selective in the information that we attempt to (and later do) remember. This can be viewed as an adaptive strategy in order to offset an age-related impairment in memory capacity—that is, older adults may think to themselves: "Well, I cannot remember all of the information present, so I may as well remember what is most important." Younger adults, on the other hand, may not routinely utilize such selective strategies and attempt to remember as much information as possible.

As previously discussed, older adults often experience marked declines in various types of memory. However, in some cases, older adults are able to use strategies to compensate for age-related memory deficits. The selection, optimization, and compensation model (SOC; Baltes and Baltes, 1990) posits that older adults, aware of their overall memory deficits, are able to selectively focus on specific information in an effort to alleviate those memory deficits. The model predicts that older adults *select* important information to which they can focus cognitive resources toward in order to *optimize* potential gains and *compensate* for potential losses. The SOC model predicts that older adults may be able to selectively focus on and later remember information that they deem important. Given clear memory deficits, this strategy represents an efficient use of cognitive resources by older adults.

Empirical research in the domain of memory selectivity has shown that older adults are in fact able to focus on high-value information at the expense of competing low-value information, a process termed value-directed remembering (VDR; Castel, Benjamin, Craik, and Watkins, 2002; Castel, 2008). In this experimental paradigm, older and younger adults were shown a list of 12 unrelated words, each paired with a point value 1–12. Participants were told that they would receive the point value associated with a word if they correctly remembered it and that their goal was to maximize their score (the summation of all the points associated with correctly remembered words). The results showed that although older adults remembered a lower proportion of the lower value words (values 1–9), they remembered the same proportion of high-value words (values 10–12) as the younger adults. The author suggests that the older adults, aware of their limited memory capacity, were able to selectively focus on the high-value words in order to maximize their score. So, while older adults remembered a lower proportion of words overall, they were able to compensate for age-related memory deficits by focusing on the important information to boost their point scores.

While the VDR paradigm defines value using a point-based system, what makes information valuable in the real world can vary from the likelihood of using that information in the future (e.g., your new doctor's phone number) to the consequences of not remembering that information (e.g., severe symptoms resulting from a failure to take your medication). Other research has also shown that older adults can employ VDR strategies in more applied contexts. Hargis and Castel (2017) presented younger and older participants with photos of people that they met at a fictional party and were designated as less important (i.e., they would not be seen or interacted with again), broadly important (i.e., they would be seen, but not interacted with, again), or personally important (i.e., they would be seen and interacted with again). In addition, each person was paired with a name and occupation. While younger adults recalled more relevant information for less important people, there was no difference in memory between younger and older adults for broadly and personally important people, extending previous VDR findings to an applied social context. Further research has demonstrated older adults' memory selectivity for important medication side effects (Friedman, McGillivray, Murayama, and Castel, 2015; Hargis and Castel, 2018), memory for people who owe them money (Castel, Friedman, et al., 2016), and memory for important items in varying spatial locations (Siegel and Castel, 2018). Thus, when presented with more information than they can remember, older adults may focus on the most important information in a variety of different contexts to offset their limited memory capacity.

While both younger and older adults can selectively prioritize information in memory, the mechanism underlying this selectivity may be different, as evidenced by neuroscientific studies. Advancing age is linked to a decline in dopaminergic modulation (Bäckman, Nyberg, Lindenberger, Li, and Farde, 2006; Kaasinen et al., 2000) and many of the cognitive impairments associated with age have been associated with a degradation of dopaminergic systems (Volkow et al., 1998). Importantly, the activation of dopaminergic reward systems has been proposed as a possible explanation for VDR effects, at least in younger adults. Cohen, Rissman, Suthana, Castel, and Knowlton (2014) examined the neural correlates of VDR, using pairs of words and point values that were tested via free recall. Younger adults were given a standard VDR paradigm while undergoing fMRI which revealed greater activation in dopaminergic reward regions (i.e., the ventral tegmental area and nucleus accumbens) on high-value relative to low-value trials. These results indicate that, for younger adults, episodic memory benefited from reward anticipation. In addition, there was greater activation in the left ventrolateral prefrontal cortex (left VLPFC; an area associated with deep semantic processing) when encoding high-value words and a significant correlation of activity in this area with a measure of memory selectivity, suggesting that explicit usage of deep semantic processing strategies may also contribute to the selective encoding of high-value information in the context of this task.

When examining older adults, it was found that similar semantic processing regions were associated with memory selectivity, but that the pattern of activation in such areas differed from younger adults (Cohen, Rissman, Suthana, Castel, and Knowlton, 2016). Specifically, older adults were *less* likely to engage areas associated with semantic processing (e.g., the left VLPFC) during the presentation of low-value information, whereas younger adults were *more* likely to engage these areas during the presentation of high-value information. Interestingly, activation in dopaminergic reward regions was not modulated by the value of information in older adults. These findings highlight the importance of semantic processing areas but call into question the role of dopaminergic reward systems, at least for older adults, in VDR tasks. Given that older adults often show equivalent (or in some cases, enhanced) selectivity on VDR tasks (Castel, 2008; Castel et al., 2002), future research should investigate the extent to which activation in dopaminergic reward systems and engagement of fronto-temporal regions during explicit strategy use contribute to older adults' selectivity on these reward-based tasks.

Reliance on Schematic Knowledge

The usage of schemas, cognitive heuristics based on prior experience that dictate what information is likely to be part of a given event, aids in the encoding and retrieval of memories. Take, for example, ordering a meal at a restaurant. Based on your prior experiences, you probably have some generalized knowledge about the typical sequence of events: You take a seat at the table, review the menu, place your order with the waiter, and then receive your meal. If you are unable to retrieve the exact details of a particular restaurant experience, then, you can rely on this "ordering at a restaurant" schema to infer what events most likely occurred. In this sense, schemas are particularly useful, allowing us to encode and retrieve memories of typical events with relative ease. However, much like other cognitive heuristics, the usage of schemas can lead to errors, especially for atypical events (events that are inconsistent with a schema), causing us to remember an event how it "should have" occurred rather than the actual details of an experienced event. In any case, the role of schematic knowledge in memory has been extensively researched in the aging population, suggesting that, with fewer remembered episodic details, older adults may be more reliant on schemas to aid memory (Castel, 2005; Craik and Bosman, 1992; Hess and Slaughter, 1990), even in cases of pathological aging like Alzheimer's disease (Rusted, Gaskell, Watts, and Sheppard, 2000; Zacks, Speer, Vettel, and Jacoby, 2006). This can be beneficial when newly learned information is consistent with schematic knowledge helping to reduce memory deficits, but particularly detrimental when information is inconsistent with older adults' prior knowledge and experience.

An early seminal study examined the role of schematic knowledge in remembering places in younger adults (Brewer and Treyens, 1980). In this study, participants were asked to wait in what they were told was a graduate student's office prior to their participation in an experiment. The waiting room was carefully constructed to include objects that were schema-consistent (e.g., a desk, typewriter, and coffee pot) and schema-inconsistent (e.g., a skull and toy top). Crucially, there were also schema-consistent items that were intentionally omitted from the room—that is, there were no books in the offices when most graduate student offices would certainly contain books of some variety. When later asked to recall the contents of the room, while most people correctly remembered schema-consistent information that was present like the typewriter and coffee pot, many participants falsely recalled the presence of books. Participants were also less likely to remember the presence of schema-inconsistent information within the room like the skull or toy top. These findings suggest that participants were relying on a schema to remember what objects were present within the office and that participants' expectations of what is typically present in academic offices altered their recall of the scene, leading to errors in memory in this circumstance.

Older adults' reliance on schematic knowledge has since been demonstrated in a variety of different contexts. Hess and Slaughter (1990) also explored how memory for visual scenes would be influenced by schemas in younger and older adults. In this task, younger and older adults were presented with drawings of objects varying in typicality depending on the context. Spatial configurations were also varied, such that in an organized condition, participants were shown a kitchen scene containing objects in typical locations (e.g., the refrigerator next to the stove, the window above the stove, etc.), while in an unorganized condition, objects were randomly presented within the array. The results indicated older adults' attentional allocation processes (examined via fixation duration) and subsequent memory (tested via object recognition tests) for the information within the scene were disrupted to a greater extent by a lack of organization relative to younger adults. Further, the likelihood of an object being present within the scene had a greater effect on object recognition performance for older adults, with more accurate memory for more likely objects. Other related work suggests that when older adults are able to use schema-based spatial information, age-related memory deficits may be reduced or eliminated (Dai, Thomas, and Taylor, 2018; Waddell & Rogoff, 1981) and that older adults recruit similar brain regions to younger adults (e.g., the ventromedial prefrontal cortex; vmPFC) when retrieving schema-specific visual information (Webb and Dennis, 2019). Taken together, these findings demonstrate that the use of schemas in visual scene recognition persists in old age and suggest that the removal of schema-based spatial information is particularly detrimental for older adults, highlighting their reliance on schematic knowledge in these tasks.

Outside of the visual memory literature, other work exploring the role of schematic knowledge in price evaluations has found that older adults' memory may benefit when the prices of various items are consistent with previously formed schemas about the value of those items (Castel, 2005). Younger and older adults were presented with grocery items and associated prices that were either underpriced (e.g., \$0.39 for a jar of pickles), overpriced (\$17.89 for a jug of milk), or market value (\$1.89 for a head of broccoli). On a cued recall test for the prices, younger adults outperformed older adults on underpriced and overpriced items. However, there were no differences in memory performance when examining market value items. This finding suggests that, for market price items, older adults were able to rely on their schematic knowledge of what items "should" be worth in order to aid their memory performance, while they were not able to do so for items that were underpriced or overpriced. In fact, in this task involving naturalistic materials, older adults' reliance on schematic knowledge eliminated age-related memory deficits for price information. This memorial benefit of schematic support for older adults has been demonstrated in a variety of other contexts including higher memory performance for statements made by a doctor (relative to a bank teller) after a medical schema was activated during encoding (Besken and Gülgöz, 2009), for faces that were presented with congruent ages (relative to incongruent ages; McGillivray and Castel, 2010), when statements were consistent with previously held stereotypes (Mather, Johnson, and De Leonardis, 1999), and for typical actions read in prose passages (Hess and Pullen, 1996). In each of these tasks, older adults' memory performance is significantly negatively impacted when schematic support is removed or otherwise made unavailable, suggesting that older adults may rely on schemas to remember information in a variety of contexts.

It is important to note, however, that there is also work suggesting that older adults' usage of schematic knowledge may not reduce observed memory deficits (Arbuckle, Cooney, Milne, and Melchior, 1994; Morrow, Menard, Stine-Morrow, Teller, and Bryant, 2001) and may even hinder it in some instances by increasing errors (Balota et al., 1999; Mather et al., 1999; Norman and Schacter, 1997; Tun, Wingfield, Rosen, and Blanchard, 1998). For example, a sample of airline pilots, ranging in age from 20 to 75 years old, were asked to listen to simulated air traffic control messages describing a route (e.g., "Climb and maintain 7000 feet," "Increase speed to 220 knots") while referring to a visual chart of the airspace (Morrow et al., 2001). Later, they were asked to recall the specific routes described by the messages by reciting the messages and drawing the routes on a map. Younger pilots recalled flight-related information more accurately than the older pilots, indicating that age-related memory deficits were not reduced for pilots, even though they could rely on their schematic knowledge. This was the case even though the older pilots had more experience than their younger pilot counterparts. Another study found that although older adults were more negatively affected by the violation of a typical house layout schema, age-related memory deficits were still present when tested on their memory for typical house layouts (Arbuckle et al., 1994).

This over-reliance on schemas has also been shown to produce more memory errors in older adults. Take, for example, the Deese-Roediger-McDermott (DRM; Deese, 1959; Roediger and McDermott, 1995) task, in which participants study semantically associated words (e.g., *sill*, *curtain*, *view*, *pane*, *glass*). In this task, participants are likely to recall a semantically associated, but non-presented target word (e.g., *window*). Prior work has shown that older adults are more likely to remember this non-presented target word, as well as other non-presented, but semantically related words (Balota, et al., 1999; Norman and Schacter, 1997; Tun et al., 1998). These results suggest that the activation of a particular schema (in this case, information related to the word "window") caused older adults to falsely remember information that was unpresented at a higher rate than younger adults. Further, in investigating memory for stereotypical information (a form of a social-based schema), older adults were more likely than younger adults to falsely attribute an unpresented statement (e.g., "The federal government must do more to protect our environment") to a stereotype-consistent individual (e.g., a Democrat) as compared to a stereotype-inconsistent individual (e.g., a Republican; Mather et al., 1999).

In sum, older adults' ability to apply schematic knowledge and rely on schematic support remains intact across the lifespan and this reliance can aid memory in certain circumstances like remembering market price grocery items or typical spatial layouts. However, in atypical or unusual cases, this dependence on schemas can lead to memory errors for older adults who may experience fewer episodic details and rely more on schematic support as they age.

Metacognitive Changes in Older Adulthood

Metacognition, the ability to monitor and control our cognitive processes, is a crucial aspect of daily functioning. Metamemory, the metacognitive processes associated with memory, allows us to assess memory quality or strength and adjust our behavior to regulate our memories. For example, when learning information for an upcoming exam, it is imperative for a successful student to accurately evaluate their knowledge of the material (e.g., "How well do I know this piece of information?") and adjust their behavior to account for this evaluation (e.g., "I do not know it that well, so I need to study this information in more depth"). Metacognitive functioning is also critical in old age when memory errors may be more frequent. For example, older adults must remember which medications they have taken in a given day and must be able to adjust their behavior in order to account for this assessment (e.g., "I forgot to take my blood pressure medication earlier, so I must do so now"). As such, it is important for younger and older adults to accurately monitor their memory performance and subsequently control their behaviors to maximize this performance.

Metamemory is generally subdivided into two separate, but closely related processes: monitoring and control (Nelson, 1996). Monitoring involves checking in on or assessing the strength or accuracy of one's own knowledge and is measured by feelings of knowing (FOK), judgments of learning (JOL), and confidence judgments (for a review of these different measures, see Schwartz, 1994). Accurate monitoring is particularly crucial as it informs us of what we know and how well we know it and allows us to adjust future behaviors to improve memory performance. Control, on the other hand, involves the manipulation and regulation of memory processes including changes in study decisions. It is evident that these two processes are intrinsically linked with monitoring affecting the subsequent control of memory. Much like memory itself, metamemory is also prone to errors—for example, when learning a new acquaintance's phone number, we may *think* we know the information well and adjust our behavior to account for this knowledge (no longer trying to memorize the digits), but ultimately misremember the number representing both memory (i.e., misrecalling the number) and metamemory (i.e., inaccurately assessing your knowledge) errors.

Importantly, while aging is accompanied by declines in memory performance, this does not necessarily definitively imply metamemory deficits. That is, despite committing more memory errors, one could be equally as accurate in assessing their knowledge. Effective metacognitive functioning may become more important as we age due to an increase in the frequency of episodic memory errors (Hertzog and Dixon, 1994). Thus, the ability to monitor when information will be later remembered or forgotten may be a particularly important skill for older adults. In contrast to well-documented episodic memory deficits that occur with advancing age (for a review, see Hess, 2005; Zacks and Hasher, 2006), metacognitive processes associated with memory may experience little to no age-related decline in some circumstances (Castel, Middlebrooks, and McGillivray, 2016; Hertzog and Dunlosky, 2011; Siegel and Castel, 2019). Various metamemory studies utilizing judgments of learning to examine how well participants can assess whether information will be later recalled have found negligible differences in JOL accuracy between younger and older adults (Hertzog, Sinclair, and Dunlosky, 2010; Hines, Touron, and Hertzog, 2009). Additional work has shown that older adults are equally as accurate as younger adults in determining when and how much information they may have forgotten between initial encoding and retrieval (Halamish, McGillivray, and Castel, 2011).

Importantly, this lack of age-related differences in JOL accuracy may only be the case when judgments are made on a local, item-by-item basis. Other work has demonstrated that, when asked to make global predictions about recall performance on an entire set of to-be-remembered materials, age-related differences are observed, as older adults may be overconfident in their memory performance (Bruce, Coyne, and Botwinick, 1982; Connor, Dunlosky, and Hertzog, 1997; Hertzog, Saylor, Fleece, and Dixon, 1994; cf. Kavé and Halamish, 2015). In one study examining predictions of performance on a VDR task, older adults were overconfident in the number of words they would remember on an upcoming list, displaying inferior metacognitive accuracy relative to younger adults (Siegel and Castel, 2019). However, when predicting how many points they would earn in a separate experiment, older adults were equally as accurate suggesting that the type of information being monitored may affect metacognitive accuracy. Older adults may also be overconfident in predicting how much information will be accompanied by recollective experience (as compared to feelings of familiarity or knowing), suggesting that there are also age-related declines in the monitoring of recollection (Soderstrom, McCabe, and Rhodes, 2012). Thus, while older adults' item-by-item metacognitive processing may be relatively unimpaired, the application of the information gained from this monitoring to make a global assessment may be difficult for older adults.

Conclusion

In general, our ability to remember information as we age tends to decline. Older adults notice an increase in forgetting and often complain that their memory is declining (Schweich et al., 1992; Weaver, Cargin, Collie, Masters, and Maruff, 2008). In particular, aging is accompanied by deficits in remembering details associated with particular events and a shift to more gist-based representations, as demonstrated by studies comparing recollection and familiarity-based memory (Koen and Yonelinas, 2014). Older adults also have difficulties in binding the source of information, like the context in which it was experienced (Johnson, Hashtroudi, and Lindsay, 1993). Despite these overall declines, in some circumstances older adults can engage in strategies to mitigate these effects by relying on schematic knowledge or knowing what "should have" occurred during a particular event (Hess and Slaughter, 1990). Thus, these age-related declines can also be conceptualized in terms of age-related changes, and some of these changes can be predictable and based on interference or use of prior knowledge. Further, the ability to prioritize information in memory appears to remain relatively constant or even improve with age, allowing older adults to selectively remember important information (Castel, 2008; Castel et al., 2012). This maintained prioritization reflects older adults' effective metacognitive monitoring and control which, in some cases, is comparable to younger adults' (Hertzog and Dunlosky, 2011). As such, while there are certainly declines in memory ability in aging, these declines may be partially offset by changes in strategy use and metacognitive awareness of one's capabilities as we age.

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