Age-Related Associative Memory Impairment and Its Influencing Factors: Postprint

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Abstract

Associative memory in older adults shows widespread impairment with age. Whether this age-related associative memory impairment is a specific deficit caused by impaired binding function or a global impairment of information representation ability resulting from overall cognitive dysfunction remains debated. The specific impairment view, represented by Naveh-Benjamin’ s (2000) Associative Deficit Hypothesis (ADH), holds that age-related associative memory impairment is related to deficits in the specific processing mechanisms that bind different items together and retrieve these bindings in older adults. By contrast, the global impairment view, represented by Benjamin’ s (2010) DRYAD model, contends that age-related associative memory impairment is associated with a global decline in memory precision due to aging in older adults. The two perspectives differ in their fundamental viewpoints, experimental support, and existing issues. Moreover, factors influencing age-related associative deficits can be broadly divided into two aspects: characteristics of stimulus information and subject-specific traits. It is also emphasized that future research should not only focus on the cognitive mechanisms and influencing factors of associative deficits in older adults, but should also pay greater attention to their practical applications and clinical guidance value.

Full Text

Age-Related Associative Memory Deficit and Its Influential Factors

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Abstract

Associative memory in older adults shows widespread impairment with age. Whether this age-related associative memory deficit represents a specific impairment caused by damaged binding functions or a global impairment of information representation capacity resulting from overall cognitive decline remains controversial. The specific deficit view, represented by Naveh-Benjamin's (2000) Associative Deficit Hypothesis (ADH), posits that age-related associative memory deficits are linked to impaired specific processing mechanisms for binding different items and retrieving these bindings. In contrast, the global deficit view, represented by Benjamin' s (2010) DRYAD (Density of Representations Yields Age-related Deficits) model, argues that age-related associative memory deficits stem from a global decline in memory fidelity. These two perspectives differ in their basic assumptions, empirical support, and limitations. Furthermore, factors influencing age-related associative deficits can be broadly categorized into stimulus information characteristics and participant subject characteristics. Future research should not only examine the cognitive mechanisms and influencing factors of age-related associative deficits but also focus more on their practical applications and clinical guidance value.

Keywords: associative memory; aging; age-related associative deficit; global deficit view; specific deficit view

Classification Number: B842

Research indicates that cognitive abilities closely related to daily activities change with age, such as memory showing age-related impairment (Zacks, Hasher, & Li, 2000). Among these, associative memory is particularly severely affected. Associative memory, a form of episodic memory, refers to memory for relationships between items (item-item) and between items and contextual information (item-context). It reflects representations of multiple items and their temporal, spatial, and situational relationships. A meta-analysis on associative memory found that older adults' associative memory abilities are significantly lower than those of younger adults, while item memory shows no significant age difference (Spencer & Raz, 1995). Clearly, aging affects these two types of episodic memory differently. Older adults can remember individual items and their sources relatively well but struggle to bind multiple features together (e.g., an item and its location or color). This difficulty in binding items with their sources is considered an age-related associative deficit (ARAD) (Chalfonte & Johnson, 1996).

1. Universality of Age-Related Associative Deficit

Perlmutter, Metzger, Nezworski, and Miller (1981) and Pezdek (1983) conducted early research on older adults' item-location associative memory, finding that older adults performed significantly worse than younger adults. Naveh-Benjamin (2000) conducted more systematic research on age-related associative deficits, revealing that older adults showed significant impairments in associative memory for word-nonword pairs, unrelated word pairs, and word-font pairs compared to item memory. Based on these findings, Naveh-Benjamin (2000) proposed the Associative Deficit Hypothesis (ADH), suggesting that while older adults' item memory remains largely intact and memory for each component of a stimulus can be maintained at a level comparable to younger adults, their associative memory for linking these components is poorer. In other words, a primary cause of age-related associative memory deficit is difficulty binding different aspects of an event into a tight association. For example, older adults might remember a person' s face but misremember their name—a "mixing up" phenomenon that reflects problems with associative memory.

Subsequently, numerous researchers have investigated age-related associative memory deficits using various materials, demonstrating that such deficits are widespread and represent a key factor in older adults' episodic memory decline. Studies using picture pairs (Naveh-Benjamin, Hussain, Guez, & Baron, 2003), word pairs (Naveh-Benjamin, 2000), word-nonword pairs (Naveh-Benjamin, 2000), figure-color pairs (Chalfonte & Johnson, 1996), figure-location pairs (Mitchell, Johnson, Raye, Mather, & D' Esposito, 2000), and word-font pairs (Naveh-Benjamin, 2000) have all found age-related deficits in associative memory. Additionally, researchers have used stimuli with higher ecological validity to examine associative memory in younger and older adults. Naveh-Benjamin et al. (2009) studied older adults' memory for face-name associations, finding that older adults' associative recognition performance was significantly lower than that of younger adults, indicating a clear age-related associative deficit. Similar results have been found in other face-name association studies (Mcgillivray & Castel, 2010). Kersten, Earles, Curtayne, and Lane (2008) found similar patterns for person-action pair associative memory.

Old and Naveh-Benjamin (2008) conducted a meta-analysis of data from 90 studies, finding that older adults' associative recognition performance was significantly lower than younger adults' across various experimental conditions, demonstrating universal age-related associative deficits. Guez and Lev (2016) used picture pairs and word pairs to investigate the effects of verbal and pictorial presentation on age-related associative deficits. They found that regardless of presentation format, older adults' associative memory performance was significantly lower than younger adults', indicating that age-related associative deficits are related to age but not learning content. That is, the binding mechanism in associative recognition is content-independent and represents an age-related phenomenon (Ratcliff & McKoon, 2015).

2. Specific Deficit View and Global Deficit View of Age-Related Associative Deficit

Although Naveh-Benjamin' s (2000) ADH is the primary theoretical explanation for this widespread age-related associative memory deficit, debates persist (Naveh-Benjamin & Smyth, 2016). The main controversy lies between the global deficit view, represented by Benjamin' s (2010) DRYAD model, and the specific deficit view, represented by Naveh-Benjamin' s (2000) ADH. The debate centers on whether age-related associative deficits represent a specific impairment due to damaged binding functions or a global impairment of information representation capacity due to overall cognitive decline.

2.1. Global Deficit View and Experimental Support

Proponents of the global deficit view argue that associative deficits result from overall cognitive ability impairment caused by aging, which makes processing more difficult for older adults and leads to a series of weakened cognitive processes. Benjamin' s (2010) DRYAD model best exemplifies this view, with three basic assumptions: (1) a global deficit assumption—that aging effects on memory result from overall impairment in memory fidelity; (2) a non-specific representation assumption—that no cognitive mechanism or process independently controls the encoding and storage of "items" and "context" in memory; and (3) a sparse representation assumption—that stimuli, contexts, and events unrelated to task goals, perceptual preferences, and attentional preferences tend to be represented sparsely in memory. In other words, this perspective suggests that age differences in memory performance essentially reflect overall differences in memory fidelity, and that age-related associative deficits result from older adults' global memory deficit—an overall impairment in representing all information in memory (Benjamin, 2016; Benjamin, Diaz, Matzen, & Johnson, 2012). This global memory deficit manifests not only as reduced effective representation of all events and items in memory but also as greater impact on weakly encoded, sparsely represented stimuli.

Benjamin et al. (2012) asked younger and older adults to prioritize memory for different components of sentences (subject or object) and then tested them. They found that older adults' associative memory performance was significantly lower than younger adults' . Specifically, when participants were asked to prioritize memory for sentence subjects, objects showed memory impairment, and when asked to prioritize objects, subjects showed impairment. These results suggest that stimuli unrelated to task goals are represented more sparsely in memory, leading to memory impairment for those components, which supports the global deficit view. Rahhal, May, and Hasher (2002) found that when older adults were asked to remember whether a specific statement was spoken by a male or female voice, they showed associative deficits. However, when asked to evaluate whether the speaker was a good or bad person, no age-related associative deficit appeared even though gender information was present. This also supports the DRYAD model' s view that for older adults, important information sources or contextual information may receive deeper encoding and produce dense representations, thus preventing age-related associative deficits. In contrast, weakly encoded, sparsely represented information is more affected by aging, producing age-related associative deficits. Similarly, compared to younger adults, older adults experience declines in perceptual processing, such as reduced visual acuity and increased auditory thresholds. These sensory declines may require older adults to allocate more attentional resources to processing stimuli, resulting in weaker encoding and poorer representation of other information related to the stimuli, thereby causing age-related associative deficits. Naveh-Benjamin and Kilb (2014) simulated age-related sensory changes in younger adults by presenting them with degraded visual and auditory information, finding that degrading younger adults' sensory abilities significantly reduced their associative memory performance, producing age-related associative memory deficits. This suggests that sensory decline is an important factor in age-related associative deficits and supports the global deficit view—that when older adults see presented learning items, they first focus attention on identifying what the item is, relatively reducing attention to surrounding information. Consequently, the representation precision of surrounding information is more affected by aging, weakening associations between items and reducing older adults' associative memory performance.

However, many studies have found that the DRYAD model cannot explain the role of attention in age-related memory changes. According to DRYAD' s assumptions, when attentional resources are reduced, representations of associations between items become sparser, leading to associative deficits. Thus, under divided attention conditions, younger adults should show similar associative deficits, and older adults' deficits should be exacerbated. However, Kilb and Naveh-Benjamin (2007) had younger and older adults learn word pairs under divided and full attention conditions, then tested item and associative memory. Although they found age-related associative deficits, they also discovered that when participants were asked to learn either items or associations, younger adults did not show associative deficits under divided attention, and older adults did not show greater associative deficits under divided attention. Additionally, Smyth and Naveh-Benjamin (2015) required younger participants to learn words in different fonts under full and divided attention conditions, asking them to focus on either the word, the font, or the word-font association during the learning phase, then testing all three types of memory. According to the DRYAD model, divided attention conditions reflect global memory impairment caused by aging, so compared to full attention conditions, representations of content unrelated to the experimental task should be sparser, and memory impairment should be greater. However, results showed that when tested on content not required to be learned (i.e., task-irrelevant), memory performance did not differ significantly between full and divided attention conditions. In contrast, when tested on content that participants were instructed to learn, the difference between full and divided attention conditions was largest. This result contradicts and cannot be explained by the DRYAD model' s predictions.

2.2. Specific Deficit View and Experimental Support

Naveh-Benjamin (2000) proposed the Associative Deficit Hypothesis (ADH), suggesting that a primary cause of age-related associative memory deficit is older adults' difficulty in binding different aspects of an event into a tight association

—a selective, specific impairment. That is, compared to younger adults, older adults' item memory remains largely intact, and memory for each component of a stimulus can be maintained at a level comparable to younger adults, but older adults show impairments in the specific processing mechanisms for binding and retrieving different components of memory. This is currently the most widely accepted view and has received substantial empirical support.

Badham and Maylor (2011) investigated the effects of item meaningfulness on age-related deficits in item and associative memory, finding that item meaningfulness (item support) could improve item memory but did not benefit age-related associative deficits. Other studies have found that inter-item relatedness (i.e., semantic relatedness between word pairs, or associative support) could improve older adults' memory for word pair associations and reduce associative deficits (Badham, Estes, & Maylor, 2012; Naveh-Benjamin et al., 2003). This suggests to some extent that age-related associative deficits result from impairment of a specific processing mechanism. Mohanty, Naveh-Benjamin, and Ratneshwar (2016) further examined how these two types of semantic memory support affect age-related deficits in item and associative memory from the perspective of consistency between support type and memory type. They found that although both types of semantic memory support improved memory performance in older and younger adults, age-related deficits could be effectively eliminated when the provided support type matched the tested memory type. Specifically, inter-item relatedness (associative support) could reduce age-related associative memory deficits, while item meaningfulness (item support) only improved item memory in older adults.

Additionally, numerous studies have found that a significant reason for age-related associative deficits may be that age-related deficits in recollection are severe, and older adults cannot effectively use recall-to-reject processes. This also supports the specific deficit hypothesis. Peterson, Schmidt, and Naveh-Benjamin (2017) found that changes in schematic support enabled older adults to use recall-to-reject processes during retrieval, reducing their false alarm rate for associations and thereby mitigating age-related associative deficits. That is, older adults can utilize changes in schematic support between learning and testing phases to improve their impaired recollection ability. Fine, Shing, and Naveh-Benjamin (2018) investigated how matching versus mismatching schematic relationships between learning and testing phases (e.g., young faces-young names at learning, but young faces-old names at testing for mismatching conditions) affected age-related associative deficits in product-price and face-name associations. They found that age-related associative deficits appeared only in matching conditions, not in mismatching conditions, suggesting that changes in schematic support help reduce age-related associative deficits. This indicates that in associative memory, older adults can better utilize changes in schematic support and employ recall-to-reject processes to reduce false alarm rates in associative recognition, thereby improving associative memory performance and weakening age-related associative deficits.

The specific deficit view has also received support from electrophysiological studies of older adults' associative memory. Kamp and Zimmer (2015) used an associative recognition task to examine aging effects on associative memory encoding, finding that younger adults showed clear Dm effects while older adults' Dm effects did not reach significance. Clearly, older adults showed smaller or later Dm effects during associative memory encoding, indicating that their associative memory is impaired during the binding phase at encoding (Zheng, Xiao, Lang, Li, & Li, 2017). Older adults show impairment not only during the binding phase at encoding (Craik & Rose, 2012; Addis, Giovanello, Vu, & Schacter, 2014) but also during retrieval when extracting these bindings. ERP studies on age differences in source memory during retrieval have consistently found that older adults show smaller left parietal old/new effects compared to younger adults, who show typical left parietal old/new effects (Kamp & Zimmer, 2015). The absent or smaller left parietal old/new effect in older adults indicates that their recollection process is severely affected by aging, which may be the main reason for their decreased associative memory performance.

Of course, although some studies have demonstrated that encoding and representation of items and associations are independent (Aue, Criss, & Fischetti, 2012), and Li, Naveh-Benjamin, and Lindenberger (2005) found that simulated neuromodulatory deficits (which occur in older adults) lead to fewer internal representations and specific deficits in associative binding compared to younger networks, some researchers have questioned the specific deficit view. The questions are: (1) Does aging selectively impair only "context," causing age-related associative deficits? (2) Is the ADH' s distinction between "items" and "context" largely related to how precisely individuals define the boundaries of things? Despite these questions, the Associative Deficit Hypothesis remains the most influential theory.

3. Influential Factors of Age-Related Associative Deficit

Age-related associative deficits are widespread across various memory materials, but what factors influence these deficits? Researchers have begun to investigate many aspects to identify factors that could reduce age-related associative deficits and improve older adults' associative memory abilities.

3.1.1. Value or Importance of Information

Although free recall and recognition performance decline with age, numerous studies show that older adults often perform as well as younger adults when memorizing valuable materials (Ariel, Price, & Hertzog, 2015; Castel, Benjamin, Craik, & Watkins, 2002; Cohen, Rissman, Suthana, Castel, & Knowlton, 2016; Spaniol, Schain, & Bowen, 2014). Research also indicates that older adults can focus on high-value items at the expense of competing low-value items (Castel et al., 2002). Based on this, Castel (2007) proposed value-directed memory (VDR), which refers to individuals selectively allocating attention and cognitive resources to high-value information and prioritizing the processing and memorization of important information.

Studies have found that value also affects older adults' associative memory performance. Castel and colleagues (2002) assigned values to each word pair using numbers (higher numbers indicating higher value) and asked younger and older adults to remember as many word pairs as possible to maximize their scores, with final scores calculated as the sum of values for all correctly remembered word pairs. Although younger adults had better overall memory performance, there was no significant age difference for high-value word pairs, suggesting that high information value can mitigate age-related associative deficits. Hargis, Mcgillivray, and Castel (2017) used face-name-occupation materials to investigate whether information importance affects age-related associative memory deficits. They found that younger and older adults performed equally well when recalling important information, indicating that information importance can reduce age-related associative deficits. Similarly, Siegel and Castel (2018) asked participants to remember associations between item pictures and their locations, finding that age-related associative deficits were reduced for high-value pictures, whether presented simultaneously or sequentially.

However, some studies have found different results regarding value effects on associative memory. Ariel et al. (2015) found that although both younger and older adults could selectively learn and remember high-value information, age-related associative deficits appeared across all value levels. Other studies using concrete word pairs (Hennessee, Knowlton, & Castel, 2018) or visuospatial arrays (Siegel & Castel, 2018) support this view, suggesting that while older adults may use strategic control to select more high-value items, they cannot completely eliminate age-related associative deficits.

Researchers suggest that inconsistent results may relate to differences in how researchers or participants define information value or importance. Previous value-directed memory studies typically used selective task paradigms (Castel et al., 2002; Castel, 2007), where items were artificially assigned numerical values representing their worth, and participants only needed to remember the value assignment rule (e.g., higher numbers = higher value). However, information also has inherent value influenced by participants' subjective experiences (prior knowledge and experience can determine what is high-value) and dependent on the individual's situation (the need to remember certain high-value information) (Castel, 2007). In Hennessee et al.'s (2018) experiment, participants were asked to imagine being in a state of physiological need deprivation (e.g., thirst), where items that could satisfy this need were clearly high-value. This demonstrates that information value can be objectively defined by assigning different values to items or subjectively evaluated by participants based on personal preferences. Therefore, distinguishing between objective and subjective value of items in research will better enable investigation of how item value affects age-related associative deficits.

3.1.2. Emotional Nature of Information

In daily life, people often remember shocking events, and compared to neutral stimuli, emotional stimuli are more easily remembered (Canli, Desmond, Zhao, & Gabrieli, 2002). Some studies have found that memory for the color or location of emotional items is better than for neutral items (Mather, Gorlick, & Nesmith, 2009), while others have found that memory for the background of emotional pictures is worse than for neutral pictures (Bisby & Burgess, 2014). To explain this, Mather (2007) proposed object-based memory binding theory, suggesting that whether emotion enhances or impairs associative memory depends on whether the association is intra-item (e.g., item and its color or location) or inter-item (e.g., item and its background). Emotion enhances intra-item associative memory but impairs inter-item associative memory (Zhao, Bai, Yang, & Mao, 2016).

Numerous studies have found that emotion enhances younger adults' intra-item associative memory while impairing their inter-item associative memory (Guillet & Arndt, 2009; Pierce & Kensinger, 2011; Schmidt, Patnaik, & Kensinger, 2011; Mao, Shu, & Yang, 2017). However, research on how emotion affects older adults' associative memory remains scarce. Nashiro and Mather (2011a) first investigated emotion's impact on older adults'associative memory using composite pictures of emotional background images and abstract figures, testing older adults'memory for figure locations. Results showed that younger adults were better at remembering abstract figure locations in emotional background conditions, while emotion had no effect on older adults' figure-location associative memory. Earles, Kersten, Vernon, and Starkings (2016) also found no effect of emotion on older adults' associative memory. They used videos of people performing positive, neutral, and negative actions, asking younger and older adults to remember person-action associations. Although emotion improved action recognition rates for both age groups, older adults made more binding errors and could not correctly remember person-action associations, showing age-related associative deficits in both neutral and negative action conditions. In other words, although emotion improved older adults' item recognition for actions, it did not improve their person-action associative memory. However, Nashiro and Mather (2011b) found that when task difficulty was reduced, emotional arousal promoted older adults' picture-location associative memory. Murray and Kensinger (2013) also found that when older adults were asked to integrate two words into a unitized representation, memory for emotional word pairs was significantly better than for neutral word pairs. These results indicate that emotion' s effect on age-related associative deficits is not singular but interacts with other factors to produce combined effects.

3.2.1. Education Level

Stern (2002) proposed the cognitive reserve hypothesis to explain how education level affects age-related associative deficits. This hypothesis suggests that individuals with high cognitive reserve (higher education) have more tightly connected brain networks, allowing other brain regions to compensate more actively when one region is damaged, thereby showing fewer cognitive dysfunctions. Cognitive changes depend to some extent on prior knowledge and experience. Compared to individuals with lower education, higher education may help maintain cognitive function, as highly educated individuals often develop age-related diseases (e.g., Alzheimer' s disease) later in life (Amieva et al., 2014; Karlamangla et al., 2009; Yaffe et al., 2009).

Previous research on education level' s effect on age-related associative deficits has yielded inconsistent results. Some studies suggest that older adults with higher education show better associative memory performance and that education may moderate age-related associative deficits, though it does not seem to completely eliminate age differences in associative memory (Shimamura, Berry, Mangels, Rusting, & Jurica, 1995). However, recent research indicates that education level does not affect age-related associative deficits. Peterson and Naveh-Benjamin (2016) found age-related associative memory deficits in associative recognition tests that were unrelated to participants' education levels. This suggests that education level is distinct from cognitive ability, and therefore, when studying age-related associative deficits, researchers should assess not only education level but also participants' cognitive abilities to ensure no significant cognitive differences between younger and older adults.

3.2.2. Stereotypes

Many studies have demonstrated that stereotypes negatively affect individual behaviors. For example, under stereotype threat, women' s math and driving performance is lower than men' s (Yeung & Von, 2008). Hess, Auman, Colcombe, and Rahhal (2003) also found that older adults' memory performance significantly decreased after receiving instructions suggesting that their memory abilities were inferior to those of younger adults.

Brubaker and Naveh-Benjamin (2018) were the first to investigate stereotypes' effects on age-related associative deficits. They provided participants with different news articles: one conveying that there were no memory differences between older and younger adults, and another stating that older adults' memory was significantly weaker than younger adults' . Subsequent associative memory tests revealed that older adults who received the explicit stereotype manipulation showed age-related associative deficits, while those who did not receive the explicit stereotype manipulation showed no significant differences from younger adults.

3.2.3. Effective Strategy Use

Some research suggests that age-related associative deficits may be related to older adults' inability to spontaneously use effective memory strategies. Pezdek (1983) compared two studies with different results, finding that Perlmutter et al. (1981) asked participants to remember building locations on a map using materials that could be encoded meaningfully (e.g., "the church is north of the school"), and found that older adults' item-location associative memory was significantly worse than younger adults' . In contrast, Mccormack (1982) asked participants to remember word locations using materials that could not be encoded meaningfully, and found no significant age differences in item-location associative memory. This suggests that older adults show age-related associative deficits under meaningful encoding conditions because they cannot spontaneously use effective memory strategies like younger adults. When younger adults also cannot use meaningful encoding, age differences in associative memory disappear. Dunlosky and Hertzog (1998) concluded that age-related associative deficits may arise from older adults' lower usage of memory strategies, as their inability or reduced use of memory strategies makes their associative memory worse than younger adults' , producing age-related associative deficits. Conversely, if older adults can be helped to use memory strategies correctly and effectively, their associative memory performance should improve, thereby reducing age-related associative deficits.

Currently, the most frequently used strategy in associative memory research is the unitization strategy. Unitization refers to the process of integrating two or more separate items into a single unified representation. The advantage of unitization is that once stimulus materials are encoded as a unified representation during the learning phase, presenting partial information during retrieval may activate the entire representation (Zheng, Li, & Xiao, 2015). In other words, unitized encoding helps individuals successfully retrieve learned materials, thereby improving age-related associative deficits. Naveh-Benjamin, Brav, and Levy (2007) used unrelated word pairs as memory materials and divided participants into three groups: the first group received no memory strategy instruction; the second group was instructed to create meaningful sentences from the two words during encoding (using the unitization strategy), for example, creating a meaningful sentence like "the rice is in the bowl" when learning the word pair "rice-bowl" ; and the third group was instructed to use the unitization strategy during both learning and testing phases. Results showed that older adults in the first group had significantly lower associative memory performance than younger adults, older adults in the second group showed significantly reduced age-related associative deficits compared to the first group, and older adults in the third group showed no age-related associative deficits. In other words, effective use of the unitization strategy can reduce age-related associative deficits.

Regarding how the unitization strategy can reduce age-related associative deficits, the Binding of Items and Contexts (BIC) model proposed by Eichenbaum, Yonelinas, and Ranganath (2007) and further developed by Diana, Yonelinas, and Ranganath (2007) offers the following explanation: Under unitized encoding conditions, the perirhinal cortex, which is primarily responsible for item memory, can also participate in the encoding and retrieval processes of associative memory (with the hippocampus being the brain region responsible for associative memory). Diana, Yonelinas, and Ranganath (2008) verified this hypothesis, finding that when to-be-associated information is highly unitized, the brain region responsible for information binding shifts from the hippocampus to the perirhinal cortex. Therefore, the unitization strategy provides older adults with a method to encode and retrieve associative information, reducing dependence on brain regions that degenerate with age (e.g., the hippocampus) and thereby reducing age-related associative deficits.

4. Future Research Directions

As living standards improve, China' s aging trend is becoming increasingly severe. Many current studies focus on age-related associative deficits, which has great practical significance. Only by clarifying the fundamental causes of age-related associative deficits, identifying relevant influencing factors, and making corresponding adjustments or interventions can we find ways to mitigate these deficits and improve older adults' associative memory. Future research should also address the following areas:

(1) Future studies could combine functional magnetic resonance imaging (fMRI) and other high spatial resolution techniques to more deeply investigate the neurophysiological mechanisms of age-related associative deficits, seeking stronger evidence for their fundamental causes. Currently, most associative memory research uses behavioral experiments and ERP techniques, though some researchers have begun using fMRI. Moreover, previous studies on how emotional valence affects associative memory have mostly suggested that negative emotions capture attention more easily, reducing associative memory performance. However, Okada et al. (2011) used fMRI to find that amygdala activation induced by negative emotion during encoding might reduce associative memory performance. This demonstrates that using high spatial resolution techniques better enables us to understand the neurophysiological mechanisms of age-related associative deficits.

(2) Future research should further clarify whether age-related associative deficits result from global impairment or specific processing impairments, as this will provide targeted guidance for clinical applications and methods to mitigate these deficits. For example, should older adults receive training in overall memory ability, or should they receive guidance only on specific associative memory processing? Clear theoretical guidance is needed to find more targeted methods and avoid unnecessary waste of social and economic resources.

(3) Future research should consider differences in the era backgrounds of older and younger adults. First, individuals over 60 are generally classified as older adults, but older adults of different ages have lived through quite different era backgrounds. Is it reasonable to group older adults with large age spans into one category? For instance, the World Health Organization (WHO) has proposed new age categories: 60-74 years as "young-old" or

"pre-old age," and 75-89 years as "old age." Second, older and younger adults have different era backgrounds, such as vastly different education levels. Directly studying cognitive ability effects on age-related associative deficits may be more accurate than studying education level effects. Future research should consider these differences.

(4) Future research should consider improving stimulus materials for participants of different ages. For example, when researchers investigate how a variable affects age-related associative deficits but provide identical stimulus materials to younger and older adults, they inadvertently introduce sensory decline as a confounding variable. Few studies have addressed this issue, such as by presenting stimuli to older adults for longer durations than to younger adults to equate encoding levels (Murray & Kensinger, 2013). Future research should systematically address this problem, find corresponding solutions to standardize stimulus materials, and investigate how influencing factors affect age-related associative deficits after controlling for sensory decline.

(5) Future research on age-related associative deficits should examine not only encoding and retrieval phases but also consolidation and reconsolidation phases. Research shows that during reconsolidation, retrieving stimuli makes stored information unstable, allowing non-invasive techniques to reconstruct people' s memories (Schiller et al., 2010). How older adults' associative memory changes during consolidation and reconsolidation is a very worthwhile research question.

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Note: Figure translations are in progress. See original paper for figures.