



Aging and cognition

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As we grow older, we gain knowledge and experience greater emotional balance, but we also experience memory loss and difficulties in learning new associations. Which cognitive abilities decline, remain stable or improve with age depends on the health of the brain and body as well as on what skills are practiced or challenged in everyday life. Recent research provides a growing understanding of the relationship between physical and cognitive changes across the life span and reveals ways to increase mental sharpness and avoid cognitive decline. © 2010 John Wiley & Sons, Ltd. *WIREs Cogn Sci* 2010 1 346–362

Cognition changes across the adult life span, but not in a monolithic fashion. Some cognitive abilities decline, whereas others remain stable or improve. To understand the mechanisms of these cognitive changes, it is important to know how they are related to physical changes in the body and brain. This article highlights some of the key changes in cognition that occur with age.

COGNITION AND THE BODY

The relationship of the mind to the body is a long-standing problem in philosophy and neuroscience. Although few modern-day scientists see the mind as something separate from the body as argued by dualists such as Descartes, it is also unusual for cognitive psychologists to pay much attention to physical health. However, recent studies have revealed surprisingly strong relationships between physical and cognitive functioning among older adults.^{1–5} For instance, simply asking an older adult to walk 8 ft at their normal rate and observing their gait speed can help predict how much they will decline cognitively over the next 7 years.⁶ The predictive relationship has been found going from cognition to physical ability as well; for instance, performance on cognitive tests predicts gait speed decline in the next 3 years.⁷ One potential explanation for these associations between motor performance and cognition is that they both reflect decline in some global aspect of brain function—analogue to athletes who show correlated

impairments in both cognitive performance and motor skills after a concussion.⁸

In aging, there are many possible ‘common cause’ factors that could affect both physical and cognitive functioning. For instance, diseases such as Parkinson’s affect brain regions involved in cognitive as well as motor function. Cardiovascular disease often leads to small lesions in white matter brain tissue. The extent to which older adults show white matter damage has been correlated with motor function^{5,9} as well as with cognitive function.^{10–13}

White matter consists mostly of myelinated axons that connect various gray matter areas of the brain to each other. Thus, white matter is essential for efficient communication among different brain regions. In general, cognitive processing and motor responses slow with age,¹⁴ and this age-related slowing is related to age-related declines in white matter integrity.^{15–18} Slower processing seems to contribute to many of the age-related declines seen in cognition^{14,19} and so may be one common cause factor of age-related changes in functioning.

In addition to the relationships seen between motor functioning and cognition in aging, the linkages between sensory processes and cognition also get stronger as people get older^{20,21} and changes in sensory functioning over a 6-year period are associated with changes in cognitive functioning.²² Because sensory processing is an integral component of cognition, there are several potential reasons for these associations. A lack of sensory input may lead to sensory deprivation that causes cognitive decline. Sensory impairments may force people to devote more attention to interpreting sensory input, leaving fewer cognitive resources available for other aspects of the task. Sensory impairments may simply distort incoming information, impairing the ability to use it effectively. Finally, there may be a common

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cause of both sensory and cognitive decline in the brain. Related to this issue, neuroimaging studies have revealed that older adults tend to show less activation than younger adults in posterior visual processing brain regions but more activation in anterior executive processing regions in prefrontal cortex.²³ One possibility is that such increases in prefrontal activity compensate for sensory processing deterioration. Whatever the mechanisms of these sensory, physical, and cognitive associations are, they are important to consider, as they reveal interrelationships in how aging affects basic mechanisms and more complex processes.

DIFFERENCES IN THE IMPACT OF AGING ON VARIOUS TYPES OF MEMORY

People commonly associate aging with memory loss. Indeed, the popular phrase ‘senior moment’ typically refers to a brief memory lapse.²⁴ Among adults over the age of 65, complaints about memory difficulties increase with age.^{25,26} Although it is not always clear how much subjective memory complaints reflect actual memory impairment rather than other possible factors such as depression, longitudinal studies certainly show marked decline in recall abilities.²⁷

However, not all types of memory are equally affected by aging. For instance, semantic memory, such as general knowledge or vocabulary, shows little decline with aging, with older adults often performing better than younger adults²⁸ (see Figure 1). Implicit memory also shows little age-related decline.^{29,30} Implicit memory does not involve conscious recollection and is revealed when people do a task faster or better because of previous learning.³¹ Implicit memory can contribute to skills such as riding a bike or to the simple act of how quickly one can read or identify a word, as seen in priming experiments. People also show less brain activity in response to stimuli they have encountered before. This ‘neural priming’ effect is maintained among older adults,³² consistent with the lack of age differences on other implicit memory tests.

In contrast with the well-maintained semantic and implicit memory systems, there are clear age-related deficits in episodic memory.³³ Episodic memory is the ability to remember specific past events and involves the conscious sense of remembering. Age-related episodic memory impairments are seen in autobiographical memory as well as in laboratory tasks involving recall and recognition. For instance, when asked about past events, older adults include less perceptual, temporal, and spatial information and more semantic information and feelings in their memory reports than do younger adults.^{34,35} Intriguingly,

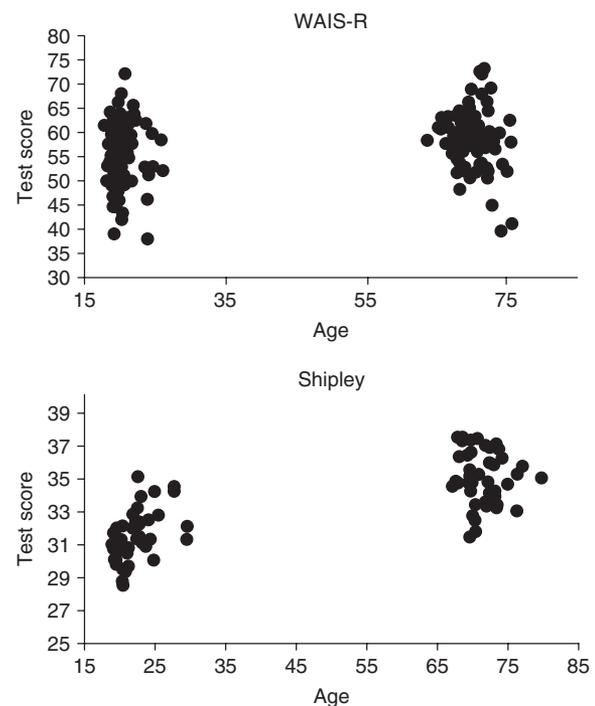


FIGURE 1 | Test scores from a meta-analysis of vocabulary scores among younger and older adults. The Wechsler Adult Intelligence Scale-Revised (WAIS-R) requires production of definitions for words and the Shipley is a multiple choice test. Reprinted with permission from Ref. 28 Copyright 2003 American Psychological Association.

older adults also produce fewer contextual details when imagining future events,³⁶ and the numbers of details older adults produce for past and future events are correlated with each other as well as with a measure of memory for associations between words. This suggests that simulating future events requires memory binding processes that recombine details from past memories into new episodes.³⁷ A later section in this article reviews age differences in memory binding and possible brain mechanisms.

In general, the more that a memory process requires self-directed strategies such as organizing lists by category, keeping certain items in mind, keeping goal-irrelevant information out of mind, or creating new associations that can be used later as retrieval cues, the more likely it is to be affected by aging.³⁸ Thus, free recall is affected more than recognition²⁷ and tests requiring conscious retrieval reveal more impairment than tests measuring increased efficiency of processing due to previous exposure to the information.

Perhaps the most important self-directed process in memory is control over which mental representations are currently the focus of attention. Keeping certain things in mind while avoiding distraction from irrelevant information is necessary in order

to complete goals and work through problems. As reviewed below, older adults show deficits both in keeping task-relevant information in mind and in keeping task-irrelevant information out of mind.

In terms of keeping desired information in mind, many studies have revealed that the ability to keep information active via rehearsal processes declines with age.³⁹ Behavioral studies indicate that age-related impairments are more pronounced when working memory tasks require both maintenance of information and simultaneous processing of the information,⁴⁰ suggesting that executive processing components of working memory are affected more in aging than storage or maintenance components. However, recent functional magnetic resonance imaging studies reveal that older adults show more prefrontal activation than younger adults do during tasks that emphasize maintenance, suggesting that older adults engage executive or strategic processes to compensate for declines in maintenance processes (for a review see Ref 41).

Complex working memory tasks involve several component processes. Recent work has revealed an age deficit in a basic self-directed process of reflection, known as refreshing.^{42,43} This refers to briefly thinking of a just-activated representation, foregrounding that representation relative to other active representations. A task used to measure refreshing⁴² involves reading one word at a time as it appears on the screen. Some of the words are followed by a new word (single condition), some by the same word (repeat condition), and some by a dot that cues participants to say the preceding word again (refresh condition). In general, people are slower to name words on refresh trials than on the other trials; however, older adults take disproportionately longer to refresh words^{42–44} and benefit less from refreshing in how well they remember the words later^{42,44} (Figure 2(a)). Compared with younger adults, older adults show reduced refresh-related activity in left dorso-lateral prefrontal cortex,^{43,44} (Figure 2(b)), an area involved in refreshing,^{45,46} suggesting that a frontal component of the refresh circuit is disrupted in aging.

Older adults also perform more poorly than younger adults on tasks that require inhibiting the first response that comes to mind or avoiding being distracted by goal-irrelevant information.^{47–49} One study used the fact that different brain regions process faces and scenes to examine how well younger and older adults were able to ignore certain stimuli when instructed to do so.⁵⁰ In the study, participants were either instructed to remember faces and ignore scenes or to remember scenes and ignore faces from a short sequence of alternating faces and scenes (Figure 3).

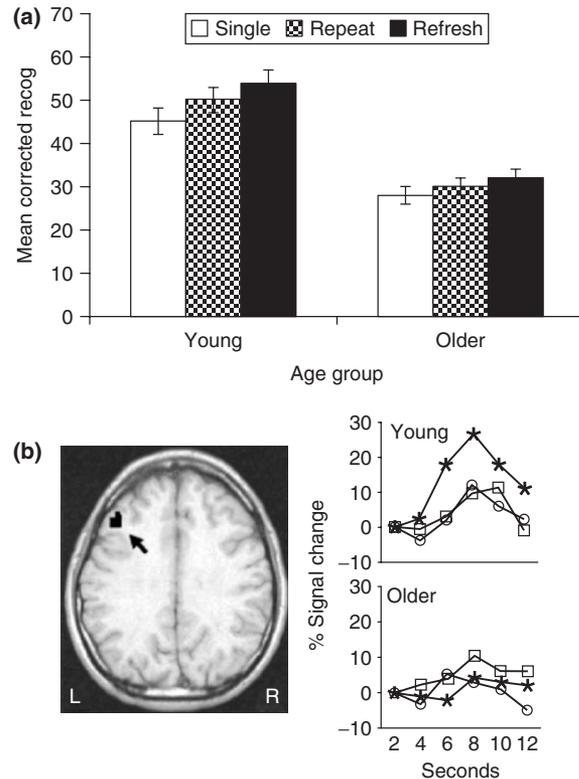


FIGURE 2 | (a) Mean corrected recognition (Recog) scores for single presentation, repeat, and refresh trials. Bars indicate standard error of the mean. Figure reprinted with permission from Ref 42 Copyright 2002 Wiley-Blackwell. (b) Left prefrontal region in which older adults showed less refresh-related activation and the corresponding average time courses within a trial for younger and older adults. Asterisks show results for refresh trials, circles show results for repeat trials, and squares show results for read trials. Figure reprinted with permission from Ref 142 Copyright 2004 Wiley-Blackwell.

There also was a control ‘passive-view’ condition to measure baseline activation levels. After the sequence, there was a blank screen for 9 s and then participants in the remember conditions were tested on the faces or the scenes. Younger participants showed greater activation during the stimuli presentation period of the trial in a region of the brain specialized for processing scenes in the remember-scenes condition than in the passive-view condition, and less scene-specific brain activity in the ignore-scenes condition than in the passive-view condition. Older adults showed the same degree of scene-specific enhancement in the remember-scenes condition, but did not show any difference in scene-specific activation between the passive-view condition and the ignore-scene condition. Thus, the older adults seemed to have a deficit in suppressing neural processing of task-irrelevant information, consistent with behavioral findings indicating reduced ability to ignore or suppress goal-irrelevant information among older adults.

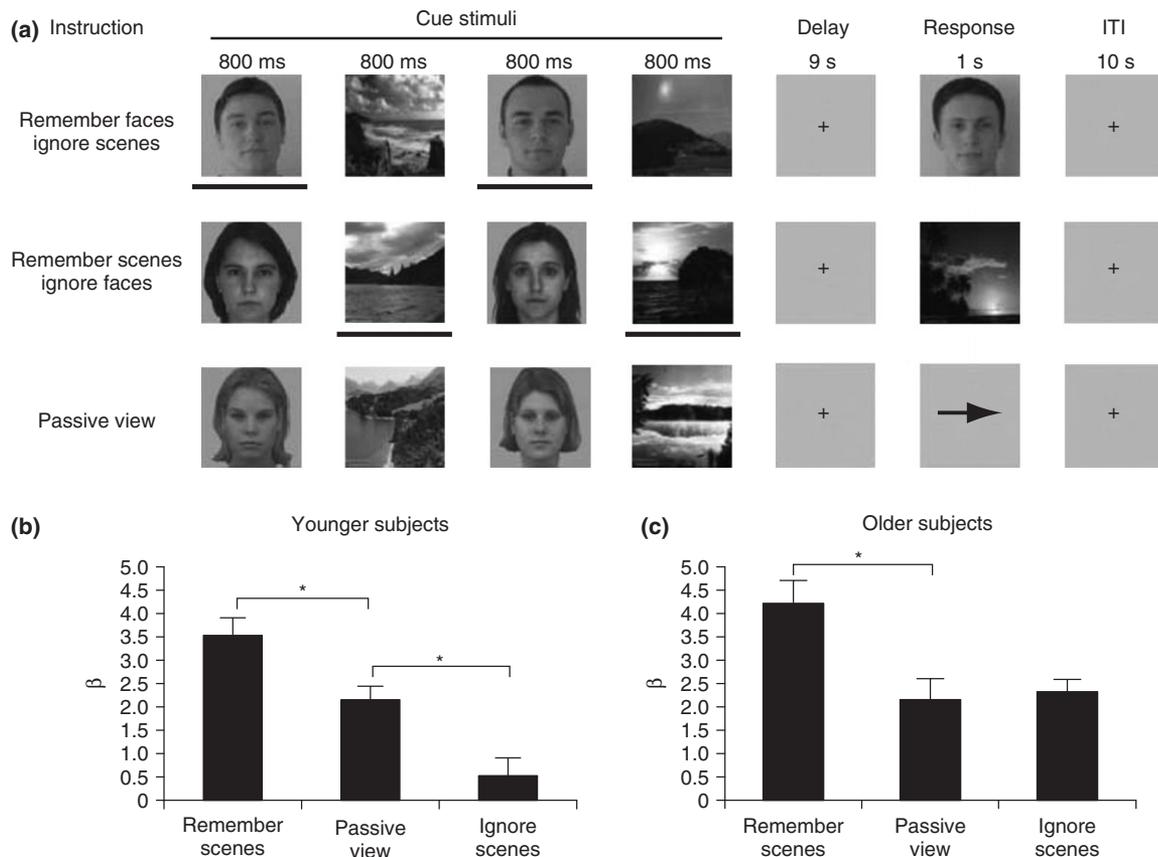


FIGURE 3 | (a) Participants completed working memory trials that differed in the instructions given at the beginning of the run about whether to remember the faces, the scenes or just observe the images. (b) For younger participants, signal magnitude within a scene-processing region of the brain was greater when they were trying to remember the scenes than when they were passively viewing them—but more interesting, signal magnitude within this same region was lower when they were trying to ignore the scenes and remember the faces than when they had just passively viewed all the images. (c) Older adults showed greater signal magnitude in a scene-selective brain region when trying to remember scenes than when passively viewing, but they did not show the same suppression of activity as younger adults in the ignore-scenes condition. Figures reprinted with permission from Ref 50 Copyright 2005 Nature Publishing Group.

STRATEGIC PROCESSING IN MEMORY

What might be the cause of older adults' deficits in strategic memory processes? Possible candidates are functional or structural changes in prefrontal brain regions. Patients with prefrontal brain lesions show impairments in memory that are due to deficits in effortful memory processes, such as the use of organizational strategies or control of interference. For instance, whereas normal participants do much better at remembering the word sequence when asked to learn the order of words on a list than when not asked to learn the order, patients with dorsolateral prefrontal lesions show little improvement when informed about the test in advance.⁵¹ Prefrontal brain regions decline more in volume in normal aging than many other brain regions (Figure 4),⁵² and older adults show impairments on many of the tasks that reveal deficits in patients with prefrontal lesions.⁵³

Furthermore, older adults' deficits on memory tasks involving strategic processes, such as memory for the source of information, tend to be correlated with their performance on measures tapping prefrontal function.^{54–57}

Despite the linkages between older adults' patterns of memory decline and the type of memory tasks that have been found to rely on prefrontal brain regions, there is little evidence directly linking prefrontal volume and strategic memory task performance in older adults. In fact, in some studies, the relationship is the opposite of what would be expected, with older adults with smaller prefrontal gray matter volumes doing better on certain memory tasks (for a review, see Ref 58).

However, several studies have revealed correlations between age-related decline in prefrontal dopamine activity and episodic memory tasks as well as executive tasks more broadly (for reviews, see

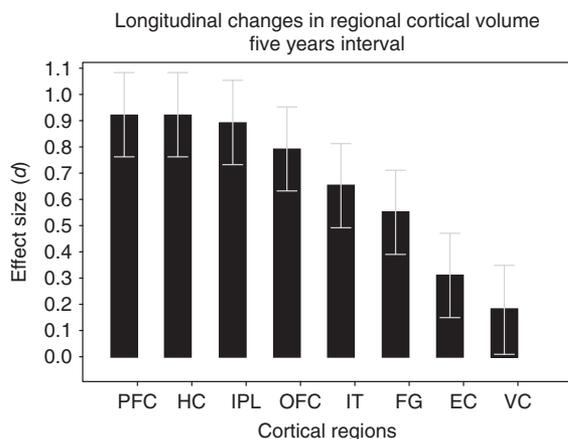


FIGURE 4 | Summary of 5-year changes in cortical regions. The effect size (Cohen's d) is the difference between the baseline and 5-year follow-up measures in standard deviation units. PFC, lateral prefrontal cortex; HC, hippocampus; IPL, inferior parietal lobule; OFC, orbitofrontal cortex; IT, inferior temporal cortex; FG, fusiform gyrus; EC, entorhinal cortex; VC, primary visual cortex. The bars indicate 95% confidence limits of d . Reprinted with permission from Ref 52 Copyright 2007 The New York Academy of Sciences.

Refs 59, 60). Dopamine receptors and transporters both decline in normal aging^{61,62} and the dopaminergic system plays a role in many cognitive processes requiring prefrontal cortex involvement, such as working memory, planning and episodic memory. Thus, some of older adults' difficulties with cognitive control may be due to the decreased effectiveness of dopamine to modulate processing.⁶³

Recent neuroimaging studies also reveal altered patterns of brain activity in prefrontal regions during strategic memory processing. Older adults show a more bilateral pattern of frontal recruitment than do younger adults⁶⁴ and also show an increase in frontal activity associated with a reduction in posterior brain activity.²³ Increased recruitment of frontal regions may reflect the need to engage more cognitive resources to compensate for the diminished effectiveness of certain neural processes.⁶⁵

MEMORY BINDING

Memory binding, the ability to remember associations between different items or components of an event, is another memory function that is particularly affected by aging^{66–72} (Figure 5). Theories about the neural underpinnings of memory generally agree that the hippocampal formation (the cornu ammonis fields of the hippocampus, dentate gyrus, and subiculum) and the adjacent regions of the medial temporal lobes (including the perirhinal, entorhinal, and parahippocampal cortices) are necessary to link

together different traces in memory.^{68,73,74} Thus, patients with medial temporal lobe lesions are able to maintain several objects or locations in working memory but not able to maintain object–location conjunctions.⁷⁵

Given the patient literature on the role of the hippocampus in memory binding, one possibility is that older adults' memory binding deficits are related to age-related hippocampal atrophy. However, along the same lines as the prefrontal cortex findings reviewed earlier, research studies reveal no clear relationship between hippocampal volume and memory abilities among people in general⁷⁶ (Figure 6). The lack of an overall relationship between hippocampal volume and memory function may be the result of two opposing factors. The first is that in early development, the loss of cortical gray matter is associated with improvement in cognitive abilities, consistent with findings that smaller hippocampal volume predicts better memory among children, adolescents, and young adults.⁷⁶ The second is that declines in hippocampal volume among older adults are a signal of Alzheimer's disease and associated with memory decline.⁷⁷

It is also important to keep in mind that changes in volume and neuron counts in a brain region provide only partial clues about how it may be changing with aging. Recent studies have revealed that, unlike in most of the rest of the brain, new neurons are created in the dentate gyrus of the hippocampus throughout adulthood, with evidence of neurogenesis seen even in people in their late 60s and early 70s.⁷⁸ These new neurons only survive for a short time and it is unknown what role they might play in memory,⁷⁹ although one hint is that survival of new neurons in the dentate gyrus is often enhanced when animals learn new information.⁸⁰ The number of newly generated neurons in the primate hippocampus declines linearly with age,⁸¹ which may compromise the ability to form new associative memories.

Furthermore, studies with animals reveal age-related impairments in synaptic plasticity in the hippocampus,⁸² including deficits in long-term potentiation.⁸³ Long-lasting memories are generally believed to depend on late-phase long-term potentiation that depends on gene transcription and protein synthesis. Both age-related declines in neurogenesis and synaptic plasticity may contribute to age-related declines on memory tasks that rely on the hippocampus.

EMOTION AND COGNITION

Emotion can have a powerful impact on cognition, influencing what people pay attention to and what

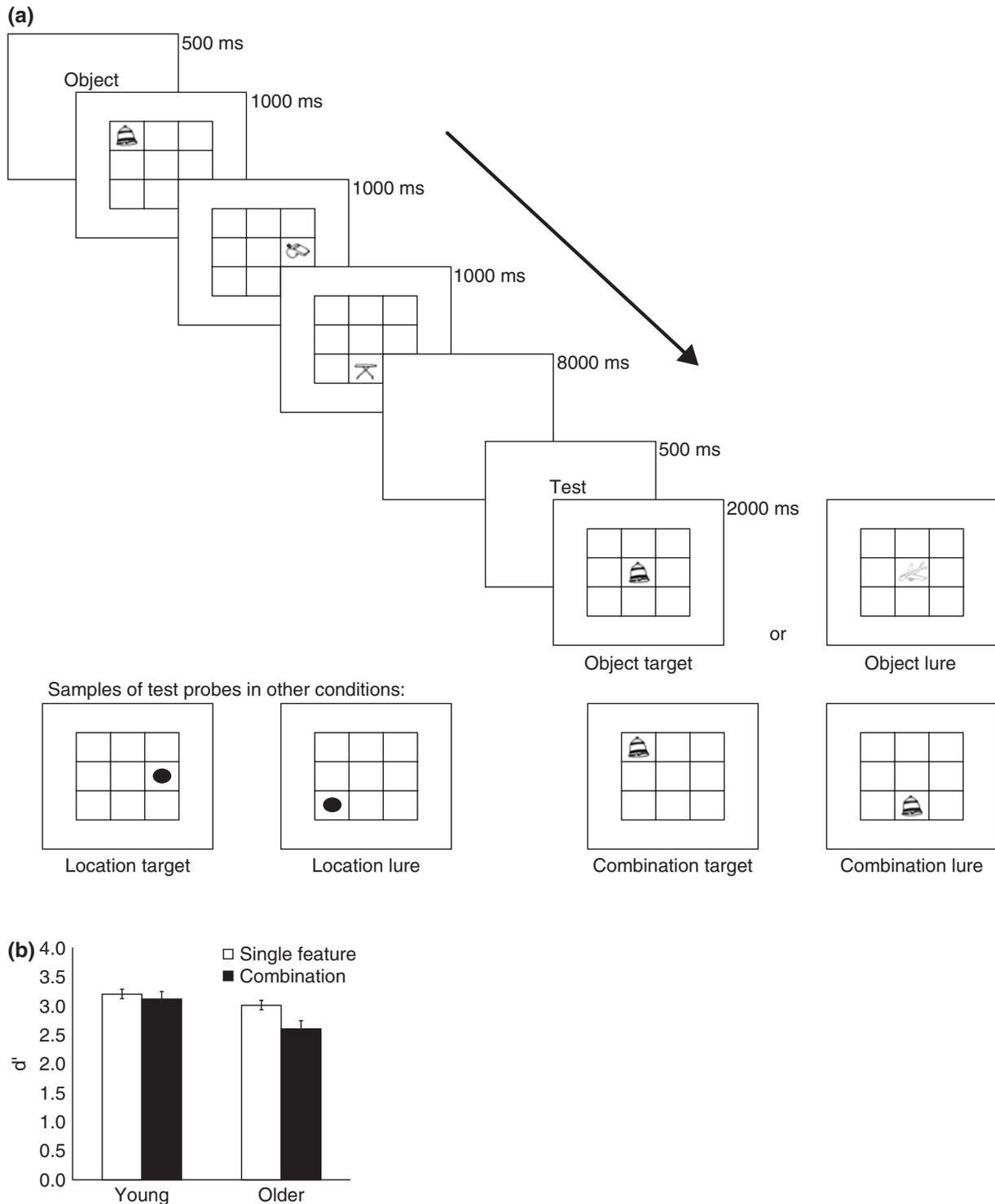


FIGURE 5 | Participants completed a working memory task (a) in which they were shown a series of three objects in specific locations and then had to keep the information in mind during an 8-s delay before responding to a test probe. On object trials, they were prompted to remember the objects, on location trials they were prompted to remember the locations and on combination trials they were prompted to remember the object–location pairings. Older adults were more accurate (measured using d') for the single-feature object and location trials than for the combination trials, and this difference between feature and associative memory was greater for older adults than younger adults (b). Figure adapted with permission from Ref 69 Copyright 2000 American Psychological Association.

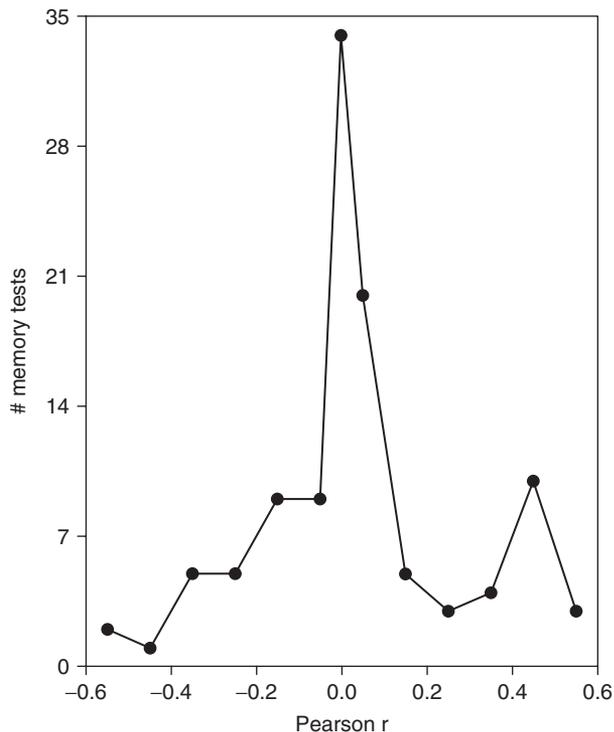


FIGURE 6 | Frequency distribution of reported correlations between hippocampal volume and 107 memory tests used across the 33 studies in a meta-analysis. Correlations between 0.60 and 0.50 were collapsed and plotted as 0.55, correlations between 0.50 and 0.40 collapsed and plotted as 0.45, and so on. The distribution reveals no consistent relationship between hippocampal volume and memory performance. Reprinted with permission from Ref 76 Copyright 2004 Elsevier.

they remember. Emotion's sway remains strong throughout the life span and may even increase its influence.⁸⁴ One possibility is that emotional brain systems, which show relatively little decline with age, compensate for other decline.⁸⁵ Emotion's influence over cognition can be separated into two broad categories: those resulting from arousal and those resulting from valence.^{86,87} Many studies reveal that, for younger adults, emotionally intense or arousing stimuli attract attention and are remembered better (for a review, see Ref 88). This advantage for emotionally arousing stimuli seems well maintained among older adults. Like younger adults, when presented with a neutral and emotional picture, their eyes tend to fixate first on the emotional picture⁸⁹ (Figure 7(a)), revealing that information gathered before any eye fixations have occurred direct attention to the emotionally arousing picture. Older adults are also faster at detecting threatening faces in an array of neutral faces than at detecting other types of faces^{90,91} and faster at detecting that one of nine objects is not from the same category as the others if that object is

arousing than if it is neutral.⁹² In these studies, the advantages in detecting arousing items were as large for older adults as for younger adults.

Thus, automatic processes that preferentially process emotionally arousing stimuli are well maintained among older adults. However, despite these similarities in automatic emotional processing, age differences emerge when people are able to process emotional information in more strategic or goal-directed ways, with older adults showing more of a positivity (or anti-negativity) effect than younger adults. For instance, compared with younger adults, less of what older adults recall from a picture slide show consists of the negative pictures,^{43,93} and autobiographical memories are more likely to be distorted in a positive direction.⁹⁴

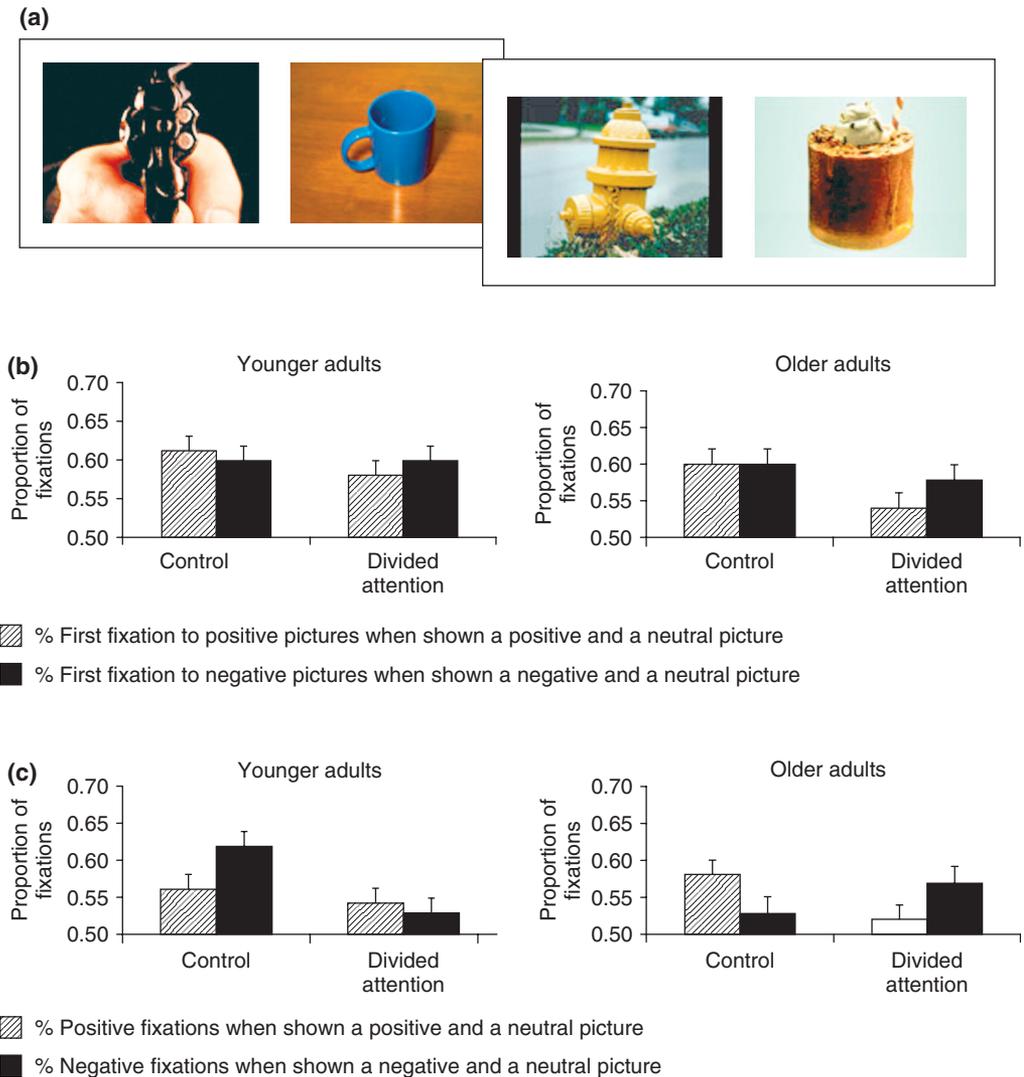
Older adults' positivity effect may be the result of a greater focus on emotion regulation goals among older adults than among younger adults, leading older adults to prioritize positive over negative information in their information processing.⁹⁵ Consistent with this goal-directed account, older adults have response biases favoring remembering positive items over negative items.^{97–99} Older adults who do well on tests measuring cognitive control show greater positivity effects than those doing poorly,^{43,100} consistent with the notion that older adults engage cognitive resources to help direct attention and memory in ways that support emotional goals. Furthermore, when distracted and thus unable to engage cognitive resources in the service of emotional goals, older adults no longer show a positivity effect in attention or memory, but instead show a negativity bias^{43,89} (Figure 7(b)).

These findings suggest that well-maintained cognitive processes may help older adults maintain a high level of well-being. In turn, being in a good mood may have benefits for cognition by increasing engagement in activities and social interactions and decreasing stress. Indeed, in a large representative sample, older adults with higher cognitive function had higher levels of well-being.¹⁰¹

LANGUAGE

Language—and especially verbal knowledge—is an aspect of cognition that appears to be mostly resistant to age-related decline. However, speaking, reading, and comprehending a language are complex processes that involve some of the cognitive processes already reviewed, such as attention, semantic memory, working memory, and memory binding. Thus, it is not surprising to find subtle deficits in language processing

FIGURE 7 | Younger and older adults' eye movements were measured while they looked at pairs of pictures for 6 s each. An example negative–neutral pair and an example neutral–positive pair are shown (a). Divided attention participants were distracted by a concurrent listening task while they looked at the pictures, whereas control participants just looked at the pictures. As indicated by the above-50% scores, participants' first fixation was more likely to be on an emotional picture than on a neutral picture, regardless of age (b). However, age differences emerged in the remaining time the pictures were shown, with older adults showing a positivity effect in the control condition but a negativity effect in the divided attention condition. Figures adapted with permission from Ref 89 Copyright 2007 American Psychological Association.



reflecting these processes, such as reductions in the use of context in language comprehension.¹⁰²

In contrast with language functions that are well-maintained or show only subtle changes with age, word finding shows more dramatic age effects. Indeed, older adults report forgetting people's names as their most irritating and embarrassing memory problem.¹⁰³ Speaking requires rapid retrieval of appropriate words to convey one's meaning. Despite the fact that retrieval of the meaning of words and other semantic processes show little change with aging, older adults show a decline in the phonological aspects of word retrieval.¹⁰⁴ This decline is correlated with gray matter density in the insula, a region involved in phonological processing.¹⁰⁵ Age-related weakening of connections among linguistic representations may impair phonological retrieval more than semantic retrieval because semantic networks have more redundancy in their interconnections.¹⁰⁴

DECISION MAKING AND PROBLEM SOLVING

Making decisions can take many different forms and involve many different processes, from quick decisions such as which television channel to watch or which cereal to buy, to difficult and complex decisions about which job offer to accept or which medical treatment plan to select. Furthermore, decisions sometimes are embedded in a problem solving process in which the decision maker needs to generate alternative solutions or strategies and then decide on a strategy. Given the complex and multifactorial nature of decision making, it is challenging to discern consistent patterns in age differences in decision making.

However, given what we know about age differences in cognition more generally, researchers have made several predictions about how decision making and problem solving should differ with

(a)

	Safety	Fuel economy	Cost	Handling	Comfort
Luxor					
Anima		very good			
Venture					
Accentra					
Atlas					

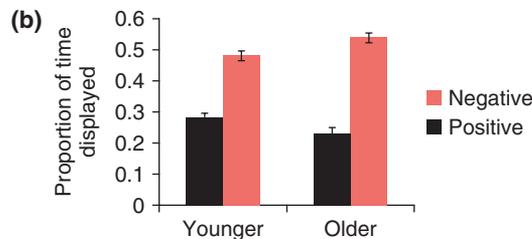


FIGURE 8 | Participants were asked which of five hypothetical car models they would purchase and were given information about each car's safety, fuel economy, cost, handling, and comfort that could be displayed by clicking on the corresponding box (a). Compared with younger adults, older participants spent a larger proportion of their time examining positive attributes of the cars and a smaller proportion of their time examining negative attributes (b). Figure adapted with permission from Ref 109 Copyright 2005 American Psychological Association.

age. One prediction is that because older adults are more focused on emotion (as reviewed above), they will show more influence of emotional goals (such as avoiding negative affect) in their decision processes.^{106,107} Supporting this possibility are findings that older adults spent relatively less time searching out and considering negative features of choice options and spent relatively more time on the positive features than younger adults^{108,109} (Figure 8). A greater focus on protecting emotional experience may also help explain older adults' greater tendency to distort memory for past choices in a choice-supportive fashion.¹¹⁰ In particular, when asked to explicitly evaluate chosen options, older adults end up listing more positive and fewer negative attributes and end up more satisfied with their decisions than do younger adults.¹¹¹ Older adults also select their favorite options more frequently than younger adults do when planning future consumption episodes rather than prioritizing variety,¹¹² a decision strategy that should help protect future well-being.¹¹³

In the problem solving literature, findings are mixed regarding age differences in problem solving effectiveness, with some evidence that it declines with age (for a review, see Ref 114) and some that it improves with age (for a review, see Ref 115). However, one consistent finding is that older adults are especially effective at solving interpersonal problems¹¹⁶ and that when younger adults outperform older adults, the age differences are larger for instrumental than for interpersonal problems.¹¹⁴ Thus, older adults' decision-making style may be well suited to handling the emotional nature of interpersonal problems.

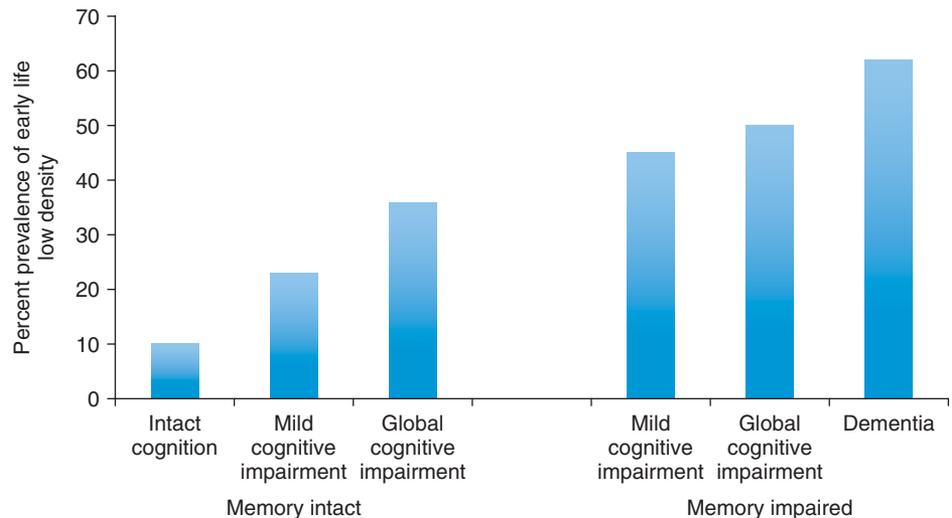
Another prediction researchers have made about older adults' decision making is that age differences

should increase as the complexity and cognitive demands associated with a decision increase. Indeed, when presented with information about health plans, dietary options, mutual funds, or banks, older adults made more comprehension errors when asked questions about the information.¹¹⁷ Furthermore, older adults tend to seek less information when making decisions (for a review, see Ref 107). These reductions in the quality and amount of information considered are likely to affect decisions, although seeking out less information may in some cases be an indication of expertise or more efficient decision making.

HOW CAN WE AVOID COGNITIVE DECLINE IN AGING?

People with more cognitively challenging careers or activities tend to show less cognitive decline,¹¹⁸ and one obvious conclusion is that cognitive engagement helps to maintain cognitive function. However, another possibility is that factors in early development may predict both how much people chose to challenge themselves mentally in their daily activities and careers and how susceptible they are to develop dementia related pathology later in life. A study of nuns who wrote autobiographies when entering their convent around their early 20s found that the idea density expressed in the essays predicted which of them showed memory impairment in late life (Figure 9), as well as their brain weight and degree of Alzheimer's disease neuropathology at the time of death.¹¹⁹ Likewise, intelligence test scores from age 11 predicted change in cognitive test scores in later life.¹²⁰ Those with higher childhood intelligence scores tended to improve their cognitive test performance from the test

FIGURE 9 | The percent prevalence of low idea density in early life autobiographies by late life cognitive state for 180 participants in the Nun Study. Data from Riley et al.¹¹⁹



to retest session in late adulthood, whereas those with lower childhood intelligence scores showed decline in their cognitive test scores from the initial test to the retest in late adulthood.

Findings that people with higher intelligence, education, occupational attainment, or engagement in stimulating leisure activities show less age-related cognitive decline have been interpreted as revealing cognitive reserve in which brain networks that are more effective to start with may be less susceptible to disruption and the existence of alternate networks may compensate for decline.¹²¹ However, thinking about protection against loss may not tell the full story of why those with higher initial intelligence or education show less decline, as indicated by the finding that those with high intelligence at age 11 showed improvement between ages 77 and 80 when tested twice with the same cognitive test. People with higher initial cognitive test scores may be more likely to learn new skills and information. When presented with a cognitive test, they may be more likely to think analytically about it in ways that would improve their future performance on the test. Likewise, in their everyday lives, they may be more likely to learn new information and skills. Thus, rather than a bank of accumulated cognitive reserve buffering them against loss, it may be their learning of new strategies and information that helps avoid decline.

Related to this issue is the question of whether the act of acquiring new learning might have benefits beyond just the acquisition of the specific information. Studies that have attempted to give participants a cognitively engaging intervention have found that people get better at whatever cognitive skill they are practicing, but there is not much evidence that the new learning has benefits beyond the specific skill domain

practiced. For instance, a study in which about 2800 participants between 65 and 94 years of age were assigned to one of three cognitive training groups (targeting memory, reasoning or speed of processing) or a no-training control group revealed that each intervention led to improvements in the targeted domain but no effects on everyday function.¹²²

However, there are ways to improve cognitive function without actually practicing the specific cognitive skill. This review began with a discussion of the strong relationship between cognition and the body. Thus, it should not be surprising that health-related factors play an important role in predicting cognitive abilities during aging. Studies that have randomly assigned people over the age of 55 to exercise or control groups have found that exercise enhances performance on executive processes, spatial abilities, and speed of processing, with the largest benefits seen for executive processes.¹²³ Much research with animals indicates that intermittent fasting or calorie restriction has protective effects for the brain (for reviews, see Refs 124–126). The beneficial effects of reducing food intake seem to extend to humans, as well. For instance, normal-to-overweight older adults who reduced their calorie intake by 30% for 3 months had better verbal memory at the end of the 3 months than those in a control group.¹²⁷

Related to both exercise and diet, a health factor particularly likely to affect cognitive function for older Americans is cardiovascular disease. As shown in Figure 10, over 70% of Americans between the ages of 60–79 suffer from cardiovascular disease.¹²⁸ In comparison, dementia prevalence estimates for North American adults range from 0.8% for ages 60–64 to 6.5% for ages 75–79.¹²⁹ The fact that the majority

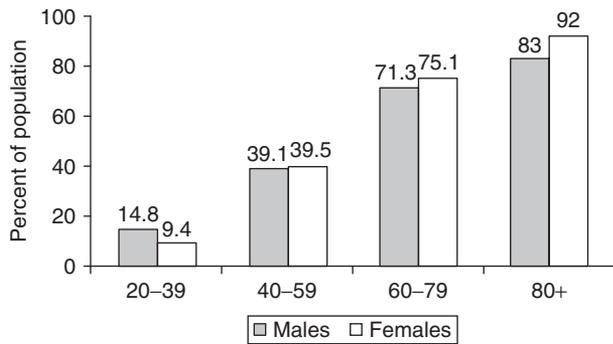


FIGURE 10 | The percent prevalence of cardiovascular disease in adults aged 20 and above by age and sex. Figure reprinted with permission from Ref ¹²⁸ Copyright 2007 American Heart Association; data from the 1999–2004 National Health and Nutrition Examination Survey.

of older Americans have cardiovascular disease is cause for concern not only for the associated health and mortality risks but also because symptoms of cardiovascular disease have been linked with cognitive decline in many studies.¹³⁰ For instance, in a large, stroke-free British cohort, men and women with vascular disease performed worse than those without vascular disease on memory, reasoning, vocabulary, and verbal fluency tests.¹³¹ In addition, hypertension predicts future cognitive decline, especially when not treated.^{132,133}

Although not fully understood yet, there appear to be many reasons why cardiovascular fitness and disease affect cognition. At the most basic level, neurons depend on blood cells to deliver oxygen and other substances and to eliminate waste products. Neurons, glia, and vascular cells coordinate in regulating cerebral blood flow during brain activity, but this neurovascular coupling is disrupted in conditions such as hypertension and stroke.¹³⁴ In addition, hypertension impairs both the structure and function of cerebral blood vessels, making them less effective for challenges such as maintaining a relatively constant cerebral blood flow even as arterial pressure changes.¹³⁴ Thus, cardiovascular disease is likely to have widespread effects on brain function and improving cardiovascular function should be a primary goal for anyone concerned about brain function. Furthermore, improving cardiovascular function by exercising does more than just stave off decline, as it stimulates new blood vessel growth in the brain and leads to an increase in new cells, especially in the dentate gyrus of the hippocampus.¹³⁵

Stress reduction may also have cognitive benefits for older adults. Older adults with high or increasing cortisol levels over the past few years had

worse delayed recall and spatial memory and smaller hippocampal volumes than those with moderate or decreasing levels.¹³⁶ Even brief intervals of acute stress can impair cognition. For instance, on days when older adults experienced more stress, they also had more memory failures.¹³⁷ Likewise, 20 min after experiencing an acute stressor, older adults' strategies in a driving game were less effective than when they were not stressed,¹³⁸ whereas stress had less of an impact on younger adults' strategies. Another suggestion that stress may have a larger impact on older individuals comes from a study showing that chronic stress decreases neurogenesis in the hippocampus more for older animals than for younger animals.¹³⁹

The damaging effects of stress seem to be somewhat reversible, even among older adults. A study in which people between the ages of 70 and 79 completed a story recall test once and then again 3 years later found that 76% of those whose cortisol levels declined over that period (indicating decreased stress) had improved story recall, whereas 70% of those whose cortisol levels increased had worse story recall 3 years later.¹⁴⁰ One's reaction to stress in the environment may play a key role. For instance, one population-based study found that the degree of stress in one's work environment did not predict later susceptibility to dementia, but that people who were more reactive to stress were more likely to be assessed as having dementia about 30 years later.¹⁴¹

CONCLUSIONS

During aging, many functions decline in effectiveness while others remain stable or improve. General knowledge, vocabulary, and unconscious learning (known as implicit memory) either decline little in normal aging or show improvements. Older adults also retain the ability to quickly detect emotional information in the environment. Furthermore, supporting effective emotion regulation, older adults are more likely than younger adults to show positivity effects in attention and memory. In contrast, the abilities that decline most in aging reveal impairments in self-directed cognition and the ability to integrate new information. Older adults are less effective than younger adults at focusing on targeted information while ignoring irrelevant information. The ability to create links among new information in memory also declines more than just learning individual pieces of information.

The interrelationships reviewed in this article suggest common factors that may affect multiple functions. For instance, age-related declines in cognitive abilities such as memory and reasoning can be predicted to an impressive degree by physical

abilities such as walking and balance. Cardiovascular disease and fitness affects brain function in ways that impact a wide array of cognitive abilities. In contrast, the surprisingly weak evidence for links between brain

volume and cognitive function among healthy older adults suggests that we need to reexamine the common assumption that bigger is better in terms of gray matter volume in the aging brain.

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