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The Aging Brain:
Theories of our Inevitable Cognitive Decline

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Abstract

Cognitive decline has been found to be an inevitable part of increased age in humans. Theories as to what particular mechanism is responsible for this decline are explored, including the working memory theory, processing speed theory, inhibition theory, and sensory function theory. Neurological components of aging are also discussed. Implications for individuals who wish to preserve their cognitive functioning include pursuing higher levels of education and learning new habits to help buffer against the effects of a decline in working memory function.

Introduction

It is a well known fact that many of our cognitive abilities decline as we get older (eg: Schroeder & Salthouse, 2004). Because our various cognitive processes all seem to decay at the same rate (Lindenberger & Baltes, 1997), psychologists have speculated that there is likely a single mechanism responsible for all of these cognitive deficits. Salthouse, for instance, has proposed the processing speed theory, which asserts that the cognitive problems faced by older adults are rooted in a slowing down of the brain's processing systems (as referenced in Park, 2000). Three other theories that claim to identify the mechanism responsible for cognitive decline with age are the working memory theory, the inhibition theory, and the sensory function model. Each theory appears convincing on its own, and each share the goal of finding a specific, solitary mechanism that is the cause of all other age-related cognitive decline. Neurological findings on the aging brain show the physical effects of aging, and provide clues to the functions of various brain regions that atrophy with time (Reuter-Lorenz, 2000).

Processing Speed Theory

Timothy A. Salthouse developed the processing speed theory, explaining age-related cognitive deficits as functions of a reduced processing speed (Park, 2000). For example, when watching a play, members of the audience must be able to process the information quickly enough to keep up with the plot and understand it all. If one's speed of processing is abnormally slow, he won't be able to process the presentation at a fast enough rate, and will walk out of the play confused. As the reader can imagine, an inefficient processing speed may lead to all kinds of problems in everyday functioning.

Within the processing speed theory are two resulting mechanisms that relate directly to functional problems. The first is the limited time mechanism, which explains that, within a cognitive task, there is less time available for performing later operations because of the excess time spent on earlier operations (Salthouse, 1996). The illustration of watching a play used above is a good example of the limited time mechanism. Following a plot is a complex task, requiring the continual processing and integration of information. If a person is still processing the first thing that happened in a scene while the characters have moved on to something else, this disadvantaged audience member will not have enough time left over to process the subsequent actions of the play. Because complex cognitive operations are the ones generally affected by the limited time mechanism, Salthouse also refers to it as the "complexity effect" (1996).

The other mechanism involved in the processing speed theory is the simultaneity mechanism. When a mental operation requires simultaneous integration of one concept in working memory with another that was figured out several moments before, people with

abnormally slow processing speeds may have spent so long figuring out the second idea that they are no longer able to access the first one (Salthouse, 1996). An example might be calculating a math problem in one's head. For instance, a fairly easy trick to figure out 15% of a dinner bill (to leave as a tip) is to move the decimal one space to the left, thus getting 10%. Then, half that number so that you have 5%. Add this result to the 10% you just calculated. The resulting number is 15% of your bill. (Round this amount up to the nearest half dollar for everyone's convenience.) While most people should not have too much trouble with this operation, someone with a slow processing speed may take so long to figure out half of 10% that when he reaches that number, he is unable to remember what the value of 10% had been. Even if one has always avoided doing mental math, the ability to mentally play with different pieces of information simultaneously is necessary in a broad range of activities (Salthouse, 1996).

Working Memory Theory

Just because processing is slower, does that necessarily mean previous information is just knocked out of working memory after a period of time? Isn't working memory generally believed *not* to be limited by time, but instead by capacity of information it can hold? Craik and Byrd's (1982) theory on age-related cognitive decline addresses this issue. They proposed that cognitive decline is due to working memory decreasing in capacity over time (as referenced by Park, 2000). Working memory has been described as being made up of resources, or of energy (Baddeley, 1986, as referenced in Park, 2000), but either way it is clearly a limited mechanism, only capable of holding and manipulating a small amount of information.

Working memory, which “[plays] a central role in discourse comprehension” (Hasher & Zacks 1988, p. 196), is a necessary component of everyday functioning. Also called short-term memory, it allows us to continually relate one experience to the next as we navigate through time. Many times, the information we are grappling with is presented in front of us so that we do not have to strain our working memory so hard. For instance, when taking a multiple choice test, students are able to look at each of the choices many times before finally deciding on an answer. Some students may even cross out the incorrect choices to help them narrow down the right answer. Think how much more difficult it would be if the question had been presented orally, and the student had to remember all the answers in his head while he figured out the correct choice. Having the options in front of you on paper is an example of environmental support.

Environmental support is defined as anything in the environment that helps cue one’s memory (Park & Shaw, 1992). It takes over some of the workload that would otherwise have been performed by one’s working memory. Craik and Byrd (1982) suggested that environmental supports would be especially beneficial for older people who have less efficient working memories (Park, 2000).

Park and colleagues did a study in which surveys were presented to older and younger adults, both orally and visually. Older and younger adults answered the survey similarly when it was presented visually, but quite differently in the oral test. When presented orally, older adults were much more inclined to choose the last answer choice for multiple choice questions (Park, 2000). Presumably, this happened because older adults were unable or had difficulty retaining the information from the earlier answer

choices due to a limited capacity working memory. The written surveys, on the other hand, provided visual environmental support.

Hasher and Zacks write that “when the demands on storage are high, older adults are particularly disadvantaged compared to younger adults” (1988, p. 197). They hypothesized that inference formation would be hindered as a result of decreased capacity working memory (1988). Through a series of studies, they presented two groups of participants (one of older adults and one of younger adults) with twelve short stories, followed by questions about those stories. Each story had three different versions—explicit, expected, and unexpected—which were scrambled so that each participant had four stories in each of those formats. An explicit version of a story presented the facts directly, while the two implicit (expected and unexpected) versions required participants to make an inference about a central event in the story. The expected version of the story was very much like the explicit version, differing only in that it deleted the explicit detail that was to be inferred. The unexpected version of the story involved a swift and unexpected change in thought, requiring the reader to use later information to make inferences about earlier statements in the story (Hasher & Zacks, 1988).

An element of environmental support was also tested in these experiments. The experiment described above was carried out three separate times, under three different conditions with different participants each time. In one condition, the oral presentation, each story was read aloud to the participants at a slow but steady pace. Participants then had to remember the story in order to answer the target question. Aside from the oral condition, there were two written conditions: non-cumulative and cumulative. In the non-cumulative condition, the participant sat and read a sentence from the story on computer

screen. The participant controlled when to move on to the next sentence by pressing a button. However, with each successive sentence, the participant was unable to go back and reread earlier sentences. The cumulative condition was similar to the non-cumulative condition, except that each time the button for a new sentence was pressed, the new sentence was simply added to the preceding sentences. Thus, the reader could continually scan over earlier parts of the story and reread crucial information (Hasher and Zacks, 1988).

In the oral presentation (which involved the least environmental support), older participants did significantly worse than younger participants in both of the implicit conditions. Older people matched the younger group in the ability to answer correctly only when the target information was stated clearly in the story and no inferences needed to be made. In the non-cumulative condition, in which participants could read each story at their own pace, older adults were able to infer the target information just as well as younger adults in the expected versions of stories, as well as in the explicit versions. (In other words, they were able to make inferences when those inferences naturally flowed with the order of the story.) They did significantly worse, however, in making inferences in the unexpected version of the story. In the cumulative condition (where participants could reread earlier sentences of the story) older adults did just as well as younger adults in making inferences for all three versions of the stories (Hasher and Zacks, 1988). These findings show that older adults are just as capable as younger adults at making even subtle inferences, as long as they have the information provided before them. Older adults are worse at making inferences when they need to hold information in working

memory because of their “relative inability to retrieve needed information” (Hasher and Zacks, 1988, p. 204).

Inhibition Theory

The working memory theory makes sense, but it still leaves us with the question of what causes working memory to become smaller in capacity. Hasher and Zacks explored this question, and came to the conclusion of the inhibition theory. Hasher and Zacks (1988) propose that working memory does not actually get smaller. Instead, people lose the ability to stop unnecessary and irrelevant information from entering into it, thus replacing the relevant information that was being stored there. As described in the above experiment, older adults have a decreased ability to make inferences that require one to reexamine earlier information in light of newer information. This, they explain, is due to a tendency to stick with a developed inference, and to be unable to move on and incorporate new data as it becomes available (Hasher and Zacks, 1988).

Comprehension, including inference making, requires the listener to focus specifically on information that is related to the idea being developed. Hasher and Zacks refer to this as “following the goal path” (1988). We are constantly being bombarded with off-goal-path information, such as minor details within a story, as well as other stimuli in the environment, like conversations of other people standing nearby, or even one’s own daydreams or passing thoughts. Many people experience temporary intrusions of such distractions into their working memories, but are able to quickly dismiss these irrelevant details. “Inefficient inhibition will enable the initial entrance into working memory of information that is off the goal path. It will also result in the prolonged

maintenance of such information in working memory” (Hasher & Zacks, 1988, p. 213). This irrelevant information will stay in working memory and compete with the truly relevant data for space, as working memory is limited. Hedden and Park recently have found evidence that this irrelevant information stays in working memory because of problems with deletion operations (2001). Hasher and Zacks conclude that “a person with reduced inhibitory functioning can be expected to show more distractibility, to make more inappropriate responses and/or to take longer to make competing appropriate responses, and, finally, to be more forgetful than others” (1988, p. 215). According to the findings of Hasher and Zacks, older people are able to perform as well as younger people on a number of cognitive tasks, if and only if interfering stimuli are reduced, and environmental supports are readily available.

Sensory Function Theory

One of the largest scientific experiments conducted to assess changes on old and very old adults was the Berlin Aging Study (Lindenberger & Baltes, 1997). A stratified sample of 516 participants, ranging in age from 70 to 103, were assessed for a number of cognitive, sensory, and medical-biological variables. Cognitive variables including perceptual speed, reasoning, memory, knowledge, and fluency all decreased continually from ages 70 to 103, even when participants diagnosed with dementia (as 21% were) were not counted. Lindenberger and Baltes point out that this cross-sectional decrease may, in fact, be an underestimate, due to the fact that the adults who lived to 103 were exceptional for having lived so long. Most of the participants in their 70s will not live to see their 90's. Those who do are likely those who function cognitively on a higher level

than their peers. Lindenberger and Baltes recommend follow-up longitudinal studies to help eliminate this possible bias of their cross-sectional sample (1997).

The most unique finding of the Berlin Aging Study was that sensory and sensorimotor abilities are highly predictive of cognitive ability (Lindenberger & Baltes, 1997). The fourth proposed mechanism for cognitive decline is the sensory function theory, which asserts that cognitive decline is due to sensory decline, particularly auditory and visual impairments (Park, 2000). Frieske and Park tested younger and older adults' memories for news reports (including television, radio, and print media) and found that sensory function and processing speed accounted for age-related problems with recall (1999). The Berlin Aging Study also found that socio-biographical factors are correlated with knowledge (Lindenberger & Baltes, 1997), but they do not affect the amount or likelihood of cognitive decline an individual will undergo over her lifespan (Park, 2000).

Neurological Findings

When brains of people over the age of 60 were compared with those of adults under 35, clear differences emerged (Reuter-Lorenz, 2000) that were not contradictory to what behavioral studies have suggested. For instance, one of the areas of the brain that suffers the most atrophy is the hippocampus (Reuter-Lorenz, 2000), a region that is known for its memory storage and retrieval functions. Its decay correlates with the findings that memory functions become less efficient with age.

Reduced branching of dendrites was also found in the older brains, which shows that there is less communication between individual neurons (Reuter-Lorenz, 2000). This

lack of connection between neurons may account for a slower processing speed, because as neural links break, the direct routes of processing are lost, and new “detour” links must be formed in order to process the same information (Cerella, 1990).

Another major finding from brain scans was that frontal lobe regions decline significantly with age (Reuter-Lorenz, 2000). The frontal lobes are responsible for goal-directed behaviors, planning, and inhibition of irrelevant details. Frontal lobe decline is congruent with the behavioral findings of Hasher and Zacks, as it gives rise to a decreased ability to stay focused, difficulty inhibiting irrelevant data, and problems with following complex plots or ideas.

The right frontal lobe has been found to be highly active when younger adults encode and retrieve information (Reuter-Lorenz, 2000). However, in older adults, there is a significant decline in activation of this region. The left prefrontal lobe becomes more active in these instances. This phenomenon occurs due to mixed signals that stop the brain from knowing which side to activate, or it could reflect a compensating mechanism in which the left prefrontal lobe takes over as a response to the weakened state of the right prefrontal region (Reuter-Lorenz, 2000).

Implications

Cognitive decline appears at this point to be an inevitable reality for all human beings fortunate enough to live past the age of 25 (see Schroeder & Salthouse, 2004). While some cognitive decline is unavoidable, there is evidence of a correlation between higher levels of education and a lesser degree of deficits in brain functioning. Hasher and Zacks state that “adults with high verbal ability and/or levels of education seem to be

buffered from the considerable aging declines often found in discourse comprehension tasks” (1988, p. 197; referenced from Hultsch & Dixon, 1984). Correlations have been found between working memory span and vocabulary proficiency ($r = .35$; Hasher and Zacks, 1988). It is likely the increased “exercising” of neural connections serves to buffer the brain from future decay. Individuals who want to function optimally for decades to come would likely do well to immerse themselves in intellectually stimulating activities, such as continued education, reading from a wide variety of media (novels, newspapers, magazines, historical narratives, etc.), attending lectures, and actively engaging in mind-stretching debates and conversations.

The Berlin Aging Study also suggests the existence of a causal relationship between sensory functioning and cognitive ability. While some hearing and vision loss may be unavoidable, taking precautions to protect these senses is generally considered to be effective in preserving them. Wearing sunglasses on sunny days and keeping headphones at a lower volume may be the first step in preventing the chain reaction of sensory deficiency and subsequent cognitive debility.

A recurrent theme in cognitive aging research is the role of environmental support on our processing ability. Environmental supports (usually involving some of the to-be-processed information available visually) are clearly more helpful as we age and our working memory becomes less efficient (see Hasher & Zacks, 1988). Being aware of the usefulness of environmental supports can be helpful for individuals who want to continue functioning well as they age.

A social implication, related to the use of environmental supports, is the finding that aging does not impede upon one’s abilities in the workplace. At least until the age of

50, world knowledge is found to increase, and these increases are sufficient to make up for any slowing of the processing mechanisms. According to Schroeder and Salthouse (2004), older employees are often more efficient than their younger counterparts because they are more familiar with the details of their job, and more experienced in a variety of situations their company faces. It is not wise for companies to drop older employees in order to bring in younger ones.

The neurological findings offer increased support for what has already been speculated about the functions of the frontal lobes and the hippocampus. The hippocampus clearly plays a role in the storage and retrieval of memories, and the frontal lobes atrophy in concordance with a decreased ability to inhibit irrelevant thoughts and follow complex ideas.

Discussion

None of the theories presented above are necessarily wrong. They all contain true elements of the cognitive aging process. It seems most likely physical factors involved in the process of aging are the root mechanism for cognitive decline. The sensory function theory explains this in its suggestion that cognitive ability is somehow related to sensory ability. The neurological findings show that brain areas physically weaken with age. Human beings, like all living things, decaying with age. Our skin wrinkles, our bones become brittle, and our arteries become stiffer. It would be a biological anomaly if the brain were exempt from this gradual decay process that the rest of our body experiences. A decaying brain will, intuitively, lead to decreased efficiency in cognitive functioning.

Physical decline of the body and brain appears to be the initial mechanism behind the cognitive decline that occurs with age.

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