Aging and Attention

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Definition

In everyday life, people often refer to attention as if it were a single, unitary thing, such as a vat of energy that can be spread across stimuli or tasks. Research suggests otherwise (**1**). There appear to be many different limited mental resources associated with different brain networks and pertaining to different levels of processing (e.g., spatial vs. central) that can be utilized in multiple ways (e.g., activation, inhibition, control). For example, one can apply extra mental effort to an important task, as in the oft-heard command "pay attention," as opposed to performing it automatically. Attention can also refer to selective processing of one thing over another (selective attention), which could be a spatial location, object, feature, thought, or entire task. Attention can also be spread amongst tasks (divided attention), often degrading performance on one or all of them. Relatedly, one can shift attention from one task to another. What all of these varieties have in common is control over how limited mental resources are utilized in the service of thought and action.

Introduction

Attention is critical for everyday performance. Yet it is usually taken for granted until it fails, as in everyday action slips (e.g., forgetting to turn off the stove) and accidents (e.g., driving accidents while talking on a cell phone), and in disorders such as ADHD and visual neglect. Furthermore, attention is a necessary precursor for many other cognitive functions to work properly. For instance, the most important aspect of *working memory* – best predicting performance in reading, reasoning, as well as academic and occupational pursuits – is not storage

capacity per se but rather how well one controls the contents of that store (i.e., attention). Likewise, attention is also critical for encoding information, so poor attention could ultimately lead to poor long-term memory as well.

The central questions motivating research on aging and attention are as follows. Do attentional abilities decline with normal aging (absent any pathologies)? Is the decline uniform across varieties of attention, or is there a mixture of preservation and decline? Can a unified theory explain all, or most, of these attentional problems that occur with old age?

The first possibility to consider is that there are no specific age-related declines in attentional functioning, per se, just a general age-related slowing of all cognitive processes, or at least all non-peripheral processes (**2,3**). Regardless of the precise cause of this generalized cognitive slowing – slower synaptic transmission, increased information loss, longer cycle time per calculation, greater neural noise, etc. – the end result is that every task that measures attention by how fast people can respond should show at least some age-related slowing. The exact amount of slowing depends on the age ranges of the older adult sample and other factors (e.g., whether the task is lexical or non-lexical), but the typical response time (RT) increase is about 50%. Performance in an attention-demanding condition should be even worse than this before researchers argue for a specific attentional deficit. To rule out general-slowing explanations, researchers often transform the data (proportional, log, or z-score) or replot the data as Brinley plots or state traces (**4,5**). Below, references to an "age effect" imply that the researchers found age effects that persisted even after correcting for generalized cognitive slowing. None of the research areas discussed below are entirely without controversy, in part due to disagreement about how to appropriately account for generalized slowing.

Empirical Review

This review summarizes research on the impact of normal cognitive aging on three broad categories of attentional function that have been widely studied: selective attention, divided attention, and switching attention. Each has been investigated using a variety of dependent measures (RT, accuracy, neuroimaging) and tasks. However, a prototypical task will include at least one condition that taxes the targeted aspect of attention, to be compared against a control condition that does not.

Selective Attention. Selective attention is the ability to focus on one thing while ignoring other things, excluding to-be-ignored information from deeper processing and control over action. Selectivity can be applied to many different things, such as locations, features, objects, sensory modalities, moments in time, or entire tasks. The selection is often a voluntary choice, although it can also be involuntary, as when we orient to a blaring police siren that we were not expecting.

Perhaps the most basic form of selectivity is allocating attention to regions of space. A real-world example is watching a stop-light for a color change. A common approach to studying space-based selective attention is the Posner cuing paradigm, in which participants use an advance location cue, either peripheral or central, to find the target. When a cue reliably predicts the target's location, the question is how well people can utilize that cue. When a cue is unreliable/irrelevant yet particularly salient (e.g., flashing or moving), the question is whether people can successfully ignore it. Many studies have shown preserved abilities with age in both cases - using location cues and resisting capture (**6,7,8**). Interestingly, whereas behavioral data usually show preserved spatial selective attention, neuroimaging data suggest that older adults rely more on top-down processes, perhaps to (successfully) compensate for underlying deficits in other processes (**9**).

Another widely-studied example of space-based selection is the Eriksen flanker task, in which participants respond to a central target character while ignoring flanking distractor characters. Critically, these flankers can have the same or different identity as the target. As an example, a participant might see S H S and be asked to report whether the central character is an S or an H. Although it is relatively easy to find the target, whose location is fixed, people nevertheless usually respond more slowly when the flanker identity is incompatible rather than compatible with the target. Here, again, selectivity appears to be generally well-preserved with age (**10**). An electrophysiological study corroborated that conclusion from behavioral data, showing similar early visual components of the event-related potential (P1 and N1) across age groups (**11**). If anything, older adults showed enhanced target processing relative to younger adults, perhaps by applying greater top-down control over spatial attention.

The negative priming task also involves interference between targets and distractors, except that the key question is not how the distractor influences the <u>current trial</u>, but rather how it influences the <u>next trial</u>. If the distractor is inhibited to facilitate processing of the current target, then this inhibition might slow responses if that inhibited distractor becomes the next target. Researchers have examined both inhibition of distractor identity and distractor location. For younger adults, both dimensions have revealed negative priming effects. Several studies have reported that older adults showed smaller negative priming effects than younger adults, taken as a sign of reduced inhibition in older adults. However, a recent meta-analysis (**13**) reported that, overall, negative priming effects are quite similar for young (21 ms) and old (18 ms). Negative priming studies typically show little overall age-related slowing in the baseline condition so, from a generalized slowing perspective, one would also not necessarily expect older adults' negative priming effects to be much larger.

The Stroop task resembles the Eriksen flanker task, except that the competing information is (in most variants) located within the same object. In the classic version, a person must indicate the ink color of a word (typically by saying it out loud) that happens to spell out a potentially-conflicting color word. Here, selection must be accomplished by choosing one object feature (ink color) over another (color word name). Ink color-naming is slower when word meanings and ink color mismatch (incongruent) than when they match (congruent) or when the word is neutral (e.g., a row of Xs). In younger adults, this Stroop effect is famously robust, suggesting that word reading is an automatic process that cannot easily be stopped, even when doing so would benefit performance. A majority of studies have reported increases in the Stroop effect with age **(6)**. Although one meta-analysis with Brinley plots argued for a general slowing interpretation (**13**), Stroop effects were, on average, almost twice as large in older adults (480 ms) than younger adults (254 ms). Another study failed to find age effects in a few alternative Stroop-like tasks, such as with color words not in the response set (e.g., the word "NAVY" printed in green) or color-associated words ("SKY" or "BLOOD"), but did report age effects with the classic Stroop color word task that produces the strongest interference (**14**). One popular interpretation of exaggerated Stroop effects is that older adults have reduced executive attentional control (i.e., impaired inhibition). The age effect might also reflect, in part, that older adults read more automatically due to a lifetime of reading (a point discussed in more detail below).

In the flanker and Stroop paradigms, there are typically just a few stimuli (e.g., one or three) and the target location is known and fixed. In visual search tasks, however, people search for a pre-specified target in unknown location amongst a variable number (possible quite large) of distractors. In younger adults, if the target has a simple visual feature not shared by any

distractors, then visual search is usually very efficient. Meanwhile search for conjunctions of features (e.g., red and horizontal) and search for the absence of a feature tend to be very inefficient. This means that RT increases relatively steeply as the number of items in the visual display increases (i.e., the search slope is steep). Many studies of simple feature search have reported only modest effects of age on visual search performance, roughly in line with what one would expect from a general slowing of all cognitive processes. Researchers have, however, reported age effects with especially difficult visual searches with high target-distractor similarity, conjunction searches, and also on target-absent trials.

Overall, the general trend in studies of selective attention is that age effects are small or non-existent for many relatively easy tasks (e.g., selection by location), but can become relatively large when the task becomes sufficiently difficult (e.g., classic Stroop and particularly challenging visual searches).

Divided Attention. The selective attention tasks discussed above might present multiple objects per trial but there is really only one task: find the target and report some attribute. In daily life, however, we often attempt to do more than one thing at a time, such as texting while walking. For younger adults, regulating multiple processes simultaneously often results in substantial dual-task costs, possibly because one must spread limited mental resources across multiple tasks. In fact, one popular account (the *central bottleneck model*) asserts that we cannot perform any central operations – those that fall in-between perception and action, such as response selection – on more than one task at a time (**12**). Even highly-practiced tasks such as driving and talking can interfere to a degree, resulting in accidents.

Although dual-tasking is already difficult enough for younger adults, it apparently is even more difficult for older adults. Dual-task costs have often been cited as being particularly

sensitive to age effects (**13,15**) and many authors have argued for a specific deficit in multi-tasking. One review reported an average dual-task cost of 215 ms for older adults but only 106 ms for younger adults (**13**). These age effects have been attributed to mere slowing of component central processes, reduced processing resources, or more cautious task-coordination strategies by the elderly.

The aforementioned dual-task studies typically present participants with two novel tasks and provide a minimal amount of practice during a single session lasting about an hour. In contrast, many real-world tasks of interest involve extensive practice, possibly over many years. This observation raises the question of whether younger and older adults can combat dual-task interference by automatizing some or all of the component processes. Automaticity of a mental process can entail many different things, such as being fast, obligatory, or uncontrollable. In a dual-task context, though, the main question is whether a mental process can operate capacity-free (i.e., not requiring any limited mental resources). There are two distinct issues: can older adults acquire new automaticity, and can they maintain previously acquired new automaticity?

With regard to acquisition of new automaticity, the picture is somewhat bleak. Although older adults can improve performance on novel tasks with practice (**16**), they often do so more slowly than younger adults. More importantly, they are in many cases less likely to eventually achieve capacity-free automaticity. Studies of visual search with consistent stimulus-response mappings, for example, have shown that practice reduces search slopes (the RT increase per item to be searched) to nearly zero for younger adults, consistent with parallel display processing, but not for older adults (**17**).

In dual-task practice studies with novel tasks, younger adults can – under favorable conditions (simple tasks, distinct input modalities, distinct output modalities, etc.) – eventually

learn to perform the two tasks in parallel, bypassing the central bottleneck. It has been reported, however, that older adults typically continue to perform central processes serially despite considerable practice levels. One study reported that older adults fail to achieve dual-task automaticity despite receiving extra practice on even easier tasks, to the point that they responded just as fast as younger adults on each task in isolation (**12**). This dual-task finding is very difficult to explain in terms of mere generalized slowing, so it appears to indicate a genuine age-related deficit in the acquisition of new task automaticity.

Nevertheless, it is not simply the case that old adults avoid all automaticity across the board. It has been argued, in fact, that they actually rely even more heavily on previously automatized routines, while avoiding novel tasks. Studies of expertise have consistently shown that older adults maintain automaticity acquired earlier in life. Expert typists, for example, appear to maintain their skill well into old age. They can sometimes even maintain their high typing rate, compensating for general cognitive slowing with greater chunking (**18**). Language skills and vocabulary are also generally well-preserved into old age. Some studies have even found that older adults can access the mental lexical <u>more</u> automatically than young adults (**19**). A possible exception to the general rule is that certain motor skills that are automatic in young and middle age (such as walking or writing) are sometimes found to require more attention in old age to compensate for motoric deficits.

In summary, older adults have extra difficulty performing multiple novel tasks at the same time, and this difficulty cannot generally be overcome simply by providing more practice. Although older adults typically maintain automaticity acquired earlier in life, they have difficulty acquiring new automaticity of novel tasks. This might explain the anecdotal observation that

younger adults frequently attempt multiple tasks at the same time (texting while driving, walking

or almost anything else) but older adults do not.

A lingering question is whether older adults are merely slow to acquire new automaticity

(and eventually would if researchers were to invest in much more lengthy training regimens).

Relatedly, do the findings reflect a deficit in forming new associations (reduced plasticity), a

decrease in processing resources, or increased cautiousness? Interestingly, one study

successfully induced more automatic memory retrieval in older adults by providing monetary

rewards for fast responding (**20**), though it is as yet unclear how widely this finding will apply.

Switching Attention. People have a remarkable ability to control their minds and

reconfigure themselves to carry out any arbitrary new task, rather than reflexively repeating the

last task or performing the task most strongly associated with the current environment. This

control, however, comes with a cost. It takes extra time and effort to instantiate the new task set

and, once instantiated, performance of a new task tends to be slower than performance of an old

task. In the terminology used in task-switching experiments, task-switch trials are slower than

task-repetition trials. Critically, this is typically true even given ample time to prepare for a new

task. This *residual switch cost* might be due to carryover of the previous task set or to an

inability to completely reconfigure a new task set via mental preparation alone, without actually

performing the task.

Given that dual-task costs are exaggerated with age, one might naturally expect that task-

switching costs would as well. Indeed, note that dual-task studies almost always involve task-

switching as well. However, the picture is not quite this simple. When calculating switch costs

between task-repetition and task-switch trials within a block – sometimes called *local switch*

costs – many studies have found little or no effect of age beyond generalized slowing (**12,21**),

especially with pairs of relatively simple tasks that do not overburden working memory. Substantial age effects often do emerge, however, when comparing task-repetition trials within "mixed" blocks containing both tasks to task-repetition trials in "pure" blocks of only one task, called *global switch costs* (**12,22**). The cause of this pattern is not yet clear. One speculation, however, is that although task repetitions within mixed blocks could theoretically be performed with minimal executive control, older adults apply extra top-down control anyway. This conservatism by older adults would have two consequences: (a) slowing performance in mixed blocks (hence exacerbating global switch costs), and (b) undermining the usual benefit of task repetition which (perhaps counterintuitively) reduces measured local switch "costs" (**21**).

 Summary. The findings reviewed above reveal age-related deterioration in some attentional functions that cannot easily be explained by mere generalized cognitive slowing. Yet age effects in attention tasks are far from universal. The strongest evidence of age effects have been obtained when holding multiple tasks active (divided attention and global task switching), suppressing competing semantic representations (Stroop), and when attempting to acquire new automaticity. Meanwhile, the functions that are relatively well-preserved with age tend to be those involving shifts of spatial attention (e.g., using spatial cues, resisting capture, filtering out flankers), local task-switching, and the retention of automaticity acquired earlier in life.

 A common trend, however, is that even where age effects are generally spared, deficits begin to emerge when the component tasks become more complex (9). A potentially related recurring finding is that even when older adults show equivalent behavioral performance, neuroimaging data often show greater activation in older adults, especially in prefrontal cortex. This finding inspired the CRUNCH (Compensation-Related Utilization of Neural Circuits) hypothesis, which states that older adults compensate for emerging cognitive deficits by utilizing

more top-down resources (**23**). This compensation might be successful for relatively easy tasks, allowing older adults' performance to mimic that of younger adults, yet be insufficient when overwhelmed by sufficiently difficult tasks. Over-utilization of top-down control might also explain why older adults sometimes have great difficulty acquiring new automaticity, which requires performance of a task with fewer resources rather than more.

Theories of Age-Related Attentional Deficits:

It is conceivable that the age-related changes in attention noted above reflect a large set of unique underlying deficits. Alternatively, there might be just a very small set of global attentional deficits, or perhaps just one, that causes all the attentional problems observed in old age. Several such accounts have been proposed.

One influential account is the inhibitory deficit view, which attributes a wide variety of age-related cognitive declines to a decline in inhibition (**24**). This view could explain the oft-reported age effects in the Stroop task. It could also conceivably explain difficulties juggling multiple tasks (e.g., multi-tasking and task switching) in terms of a reduced inability to suppress the irrelevant task. Although this inhibitory deficit view has been highly influential, and it is plausible that older adults do sometimes show reduced inhibition, several lines of evidence now argue against a strong version of the account. Several tasks that would seem to be particularly sensitive to inhibition – such as inhibition of return and negative priming – actually tend to show little or no age effect (**13**). Meanwhile, other paradigms (e.g., acquisition of new automaticity) do show age effects despite not obviously relating to inhibition.

The frontal lobes decline in volume and integrity more rapidly with advancing age than the other lobes. This has led many to argue that frontal lobe attentional functions such as inhibition and switching, should decline more rapidly with age than parietal lobe attentional

functions such as shifting spatial attention (**6**). This prediction loosely fits the findings noted above that spatial attention tends to show the least age effects, whereas certain aspects of executive control (global task switching, dual-task costs, working memory span) tend to show relatively large effects. It is also supported by the observation that cognitive deficits in old age are quite similar to (though milder than) those caused by frontal lobe damage. A potentially inconsistent finding, however, is the lack of an age effect on local task switching, although this exception could perhaps be explained by compensation.

Other single-cause theories of cognitive aging have focused on the dopamine system, or more specifically on dopamine projections to prefrontal cortex (**25**). Note that the above single-cause theories overlap to some degree and are not mutually exclusive. For example, inhibition is a frontal lobe function, and the frontal lobes are a main target of dopaminergic pathways. Further research combining behavioral and neuroscientific approaches is needed to achieve greater resolution regarding the primary causes of declines in attention with age.

Cross-References

Automaticity and Skill

Aging and Inhibition

Inhibitory Decline Theories of Behavior and Cognition

Executive function

Working memory in old age

General Slowing

Cognitive Plasticity

Expertise

Cognitive Compensation

Common-Cause Theory in Aging

Cognitive control and self-regulation

Cognitive Resource Theories

Response Time

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