Attention

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At any moment in time, our senses are flooded with a diverse array of sights, sounds, smells, tastes, and textures. We cannot deeply process all of these stimuli, nor would we want to (most are irrelevant to current goals). Therefore, it is imperative that we be selective in which stimuli we process and which we ultimately respond to. It is also imperative that we be selective in which tasks we perform on these stimuli. When hurriedly leaving the house, one needs to find the keys without being distracted by other potential tasks (e.g., reading the paper, cleaning the floor).

Control over cognitive processing, which is often loosely called ‘attention,’ becomes even more critical as we age. Sensory and motor processes can slow dramatically, further increasing the need for selectivity in which stimuli we perceive and respond to. Fortunately, many forms of attention are preserved with age. Other forms of attention, however, decline with age, resulting in severe performance problems.

The purpose of this article is to review this important area of research, highlighting reliable generalities as well as unresolved issues.

Varieties of Attention

The study of attention is complicated by the fact that it is not a unitary construct. There are many different varieties of attention that are used in different situations and that are sensitive to different variables. In the present article, we concentrate on three impor-
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Adult Age Differences in Capacity

The term ‘attentional capacity’ has been used in many different ways by many different researchers. Typically, it refers to the ability to process information quickly and/or the ability to process multiple stimuli or multiple tasks simultaneously. A multitude of approaches have been used to assess capacity and how it changes with age. In the following sections we review several prominent lines of research on capacity and the conclusions they afford.

Simultaneous Presentation Dual-Task Methodology

One way to assess an individual’s mental capacity is to see how performance degrades as the number of tasks is increased. The classic method is to compare performance when two tasks are presented simulta-
neously to performance when only one task is pre-

in processing speed. We will revisit this widely held but controversial hypothesis at several points. We conclude that although there are situations in which this proposal seems to hold, there are also replicated studies in which it does not.

Much of the research discussed here is based on the assumption that human cognition involves a series of distinct mental operations. Stimuli impinging on the sense organs (e.g., light on our retinas) are converted into neural signals, which then undergo a series of transformations, sometimes culminating in an observable response. Often these mental processes are modeled as discrete (strictly serial) stages, such as stimulus encoding, categorization, response selection, and response execution. This simplified stage framework allows one to ask whether and how specific stages are influenced by attention. One can also examine whether the effects of age are general (influencing all stages equally) or specific to certain stages.
costs for older than for younger adults. Furthermore, this difference increases as the secondary task difficulty increases. These results have been interpreted as evidence that older adults have decrements in attentional capacity. Craik and McDowd, for example, examined age differences in divided attention when participants performed a four-choice response time (secondary task) while simultaneously attempting to recall a list of words. Because dual-task costs were larger for older adults than for younger adults, Craik and McDowd concluded that older adults had fewer processing resources to allocate to word recall.

Although these conclusions seem reasonable, the interpretation of simultaneous presentation dual-task data is subject to certain conceptual problems. In this paradigm, people can trade performance between the two tasks (doing one better at the expense of the other). Such tradeoffs complicate interpretations of the data, especially when performance is reported for only one task (as is often the case). A further limitation of this paradigm is that the single-task and dual-task conditions are run in different blocks of trials. Consequently, these conditions differ not only in their capacity demands (dual-task vs. single-task), but also in the number of tasks that must be prepared and held in memory. The blocking of conditions also invites unwanted strategic differences between conditions (e.g., more effort or more cautiousness in dual-task blocks than in single-task blocks).

Sequential Presentation Dual-Task Methodology

Another dual-task methodology for assessing capacity is the sequential presentation method. The best-known and most widely used variant is the psychological refractory period (PRP) paradigm. In the PRP paradigm, two tasks (T1 and T2) are presented in close succession with a variable stimulus onset asynchrony (SOA). Participants are instructed to make speeded responses to T1 and T2 (denoted R1 and R2, respectively), and the response time (RT) for these two tasks is referred to as RT1 and RT2. Typically, RT1 is unaffected by SOA. A ubiquitous finding, however, is that RT2 increases as SOA decreases (i.e., as temporal overlap between tasks is increased). This increase in RT2 has been termed the PRP effect.

PRP findings generally support the central bottleneck model, shown in Figure 1. This model hypothesizes that peripheral processes (encoding and response execution) can proceed in parallel for T1 and T2, but central processes (e.g., response selection) cannot. Thus, at short SOAs, T2 central processes must wait for T1 central processes to finish. This waiting produces the PRP effect on T2.

Sequential presentation dual-task methods (such as the PRP paradigm) address the two conceptual complications mentioned in the previous section on simultaneous presentation dual-task methods. First, sequential presentation (typically with same task order on every trial) tends to encourage a consistent dual-task strategy. Often, interference is restricted to T1, so that there is no performance tradeoff between tasks. Second, this approach uses several different SOAs between the presentations of task 1 (primary task) and task 2 (secondary task), mixed within a single block of trials. Mixing minimizes unwanted strategic differences between conditions. Because participants must always prepare for both tasks and hold both tasks in memory, this paradigm makes it possible to isolate true dual-task costs from the costs of preparing and maintaining two task sets in working memory.

Most studies of aging and PRP effects have shown evidence of larger PRP effects for older adults than for younger adults. However, the theoretical interpretations for this interaction differ widely across studies. Allen et al. proposed an executive control deficit that decreases the efficiency of switching between T1 and T2. Hartley and Little argued that older adults do not have an executive control deficit, but rather are less efficient in managing input interference and output interference. Finally, Glass et al. proposed that older adults exhibit poorer task coordination strategies. Although the Allen et al. and the Glass et al. viewpoints both emphasize executive control deficits, they are based upon opposing interpretations of PRP effects (the former is based upon Pashler’s central bottleneck architecture and the lat-
ter is based upon Meyer and Kieras’s executive process interactive control [EPIC] model). Consequently, although there is some agreement that older adults have difficulty in task coordination or time-sharing, there is no consensus as to the specific mechanisms involved.

Another major advantage of the sequential presentation method is that it provides an independent set of analytical tools to assess capacity – locus-of-slack logic. This logic allows one to determine which mental operations are capacity limited (i.e., are subject to the processing bottleneck) and which are not. For instance, to determine if a particular T2 process is subject to the bottleneck, one can manipulate the duration of that stage and measure the interaction with SOA. If the manipulated T2 stage occurs at or after the bottleneck, the effects should be constant across SOAs (an ‘additive’ interaction; see Figure 2A). If the manipulated T2 stage occurs before the bottleneck, the effects should decrease as SOA decreases (an ‘underadditive’ interaction, also known as ‘absorption’ of a factor effect into ‘cognitive slack’; see Figure 2B). Thus, by examining whether a manipulation has additive or underadditive effects with SOA, one can determine whether the corresponding stage of T2 is subject to the bottleneck (capacity limited).

Research using locus-of-slack logic with younger adults has revealed that perceptual processing (up to identification, in the case of letters) is generally not subject to the bottleneck. However, many subsequent processes are subject to the bottleneck, including response selection, memory retrieval, memory encoding, mental rotation, and lexical access.

With these findings in mind, it is interesting to ask whether the bottleneck has the same locus for younger and older adults. Given the hypothesis of reduced capacity for older adults, one might assume that they would have a longer list of bottleneck processes. In fact, the opposite appears to be true. Allen et al. reported a study in which T1 was tone discrimination and T2 was a lexical decision task (word vs. non-word). The difficulty of T2 lexical access was manipulated by choosing words with either high or low frequencies of use in the English language. Although word frequency effects on RT2 were roughly additive with SOA for younger adults, they were underadditive for older adults. These results suggest that lexical access was subject to the bottleneck for younger adults, but not for older adults. Furthermore, older adults actually showed shorter dual-task RTs than younger adults, after appropriately controlling for generalized slowing. Thus older adults actually demonstrated greater capacity than younger adults, at least with respect to the lexical access stage. One explanation for this surprising finding is that older adults have automatized lexical access due to their far greater cumulative experience with words.

An important question to address is why older adults appear to exhibit capacity decrements in simultaneous presentation dual-task paradigms yet can exhibit capacity advantages in sequential presentation dual-task paradigms. One possible explanation is that simultaneous presentation methods confound executive control effects (preparing for two tasks, deciding which to do first) and capacity effects (resource conflicts), whereas the sequential presentation methods allow one to isolate capacity effects. Perhaps much of the age deficit found in simultaneous presentation divided attention tasks is due to executive control effects rather than capacity effects. Consistent with this hypothesis, task-switching studies (see later section on executive task control) have generally revealed evidence of executive control deficits in older adults.

**Coactivation**

In the dual-task studies described previously, each stimulus required a separate response. What would happen if multiple, redundant stimuli were presented, each pointing to the same response (as when using multiple clues to solve an entry in a crossword puzzle)? In a laboratory study, for example, participants might be asked to press a button if any stimulus in the display is the letter ‘T’; will they respond more quickly when there are two Ts in the display, rather than just one? Typically, they do. This benefit of multiple targets is commonly known as a ‘redundant signals effect’ or just ‘redundancy gain.’

One possible explanation for redundancy gain is that the redundant target stimuli are processed in parallel, and the first one to reach the central executive triggers the corresponding response. In other words, there is a sort of race between the stimuli. The more runners in the race (the more target stimuli), the faster the race will be completed (triggering a response). As an analogy, if a businessman sends two copies of a package, one by FedEx and one by UPS, he has two chances to get a quick delivery. This source of redundancy gain is typically referred to as ‘statistical facilitation.’

According to the race model just described, each target stimulus is processed separately. In theory, even more efficient parallel processing would be possible if evidence from the different input channels could be combined together (as when a police detective combines multiple lines of evidence to conclude that a suspect is guilty). This summation of
Figure 2  Predictions of a central bottleneck models. (A) Prolonging the central bottleneck stage in task 2 delays R2 at both short and long SOAs. (B) Prolonging the prebottleneck stage in task 2 delays R2 at long SOAs but not at short SOAs. 1A, 1B, and 1C are, respectively, the prebottleneck, bottleneck, and postbottleneck stages of task 1. 2A, 2B, and 2C are the corresponding processes for task 2. S1, stimulus for task 1; S2, stimulus for task 2; R1, response for task 1; R2, response for task 2; SOA, stimulus onset asynchrony.
evidence is referred to as ‘coactivation.’ To provide evidence of coactivation, it is important to first show that the redundancy gain exceeds the amount of statistical facilitation that could be produced by a race between separate processes. Miller’s ‘race model inequality’ provides just such a test:
\[ P(\text{RT} < t | S_1 \text{ and } S_2) \leq P(\text{RT} < t | S_1) + P(\text{RT} < t | S_2) \]  

The race model inequality provides a very conservative test of the race model. It gives the maximum amount of facilitation that a race could produce under the most extreme assumptions (i.e., perfect negative correlation between target detection times). Despite the conservative nature of the test, violations of this inequality have been frequently observed (at least for simple tasks). In these cases, race models can be discarded in favor of coactivation models.

Coactivation effects are thought to arise from combined activations in decision stages. These are the very stages that Cerella, in an influential meta-analysis of age-related slowing, hypothesized to be at the core of age deficits. Accordingly, one might expect older adults to show less redundancy gain and less evidence for coactivation. In actuality, older adults tend to show larger redundancy gains than younger adults. In 2005, Bucur et al. specifically looked for evidence of coactivation in older and younger adults. This study used the original paradigm of Miller with a visual target (an asterisk) and an auditory target (a tone). Interestingly, older adults and younger adults both showed large violations of the race model inequality, suggesting that both groups benefited from coactivation. These results have now been replicated and extended to conditions in which targets were defined along two dimensions of a visual target (e.g., shape and color).

The preserved redundancy gain and coactivation in older adults suggest that they have not lost any capacity to process multiple targets in parallel. Note that this is the same conclusion reached by PRP studies using locus-of-slack logic. These findings contradict the widely held belief that age-related slowing is due primarily to reductions in capacity. We return to this issue in the conclusions section.

**Capacity as Speed**

According to one school of thought, the slowing of cognitive processing with advanced age is a direct consequence of a decline in processing capacity. One could argue that this statement is circular, though, because there typically is no independent measure of capacity other than processing speed. A way to sidestep this circularity problem is to simply assume that processing speed is synonymous with attentional capacity. Evidence in favor of this view comes from studies assessing statistical mediation using hierarchical regression, path analysis, or structural equation modeling (SEM). The critical finding is that processing speed (e.g., as measured by a digit-symbol substitution task) mediates dual-task performance.

Not all attention studies find that processing speed mediates age effects, however. Many studies continue to find age × task complexity interactions even after a measure of processing speed has been co-varied out. Furthermore, Allen et al. re-analyzed earlier data reported by Salthouse and colleagues using SEM techniques and showed that direct age effects persisted independent of effects mediated by a common factor (such as processing speed). Although the situation is complicated, there is now conclusive evidence that common factors in SEM aging research are not consistent across studies and that processing speed is not a parsimonious synonym for attentional capacity.

**Neurophysiology**

Neurophysiological measures provide a direct window into central nervous system (CNS) function (more so than RT and accuracy measures) and have been profitably used to assess capacity and other aspects of human attention. Three functional measures are widely used: (1) event-related brain potentials (ERPs), (2) positron emission tomography (PET) scanning, and (3) functional magnetic resonance imaging (fMRI). Whereas ERPs have good temporal resolution but poor spatial resolution, both PET and fMRI methods have poor temporal resolution but good spatial resolution. In some cases, researchers employ both ERP and fMRI techniques to simultaneously obtain good spatial and good temporal resolution (this is referred to as multimodal imaging).

The ERP is a measure of electrical activity on the scalp triggered by a particular event (e.g., the activity following a stimulus or the activity leading up to a response). Because the signal-to-noise ratio is low, many trials must be averaged together to produce reliable data. The resulting average waveform consists of a series of positive and negative deflections. Often this waveform is summarized in terms of the amplitude and location of the individual peaks (also known as components). The most investigated ERP component is the P300 (a peak in positive amplitude approximately 300 ms after stimulus onset), thought to primarily reflect encoding and categorization processes but not response processes.

ERPs have been used to study the effects of age on cognitive performance. Bashore et al. conducted a
meta-analysis of studies that used P300 measures and RT measures for a group of simple cognitive tasks. They summarized the results using a Brinley plot of older adults’ performance versus younger adults’ performance. For RT, the Brinley plot showed a slope greater than one (1.27), but for P300 amplitude values, the Brinley plot showed a slope close to equality (0.95). This dissociation suggests that age-related slowing with more-complex tasks is due to response processes that take place after the central operations that produce the P300. Note that the P300 data did show an elevated intercept for older adults, suggesting an encoding decrement that was insensitive to task complexity.

Although ERPs have excellent temporal resolution, they have poor spatial resolution. When researchers are interested in the spatial locus of brain activity, they often utilize PET and fMRI. PET methods measure regional cerebral blood flow, whereas the blood oxygenation level-dependent (BOLD) response in fMRI measures oxygen uptake from small blood vessels that nourish neurons. PET methods are relatively invasive – they require either injection or inhalation of radionuclides and relatively long scanning times. fMRI methods are noninvasive and therefore are now generally preferred.

In a study of age differences in attention, Madden et al. found that older adults in a dual-task condition showed greater regional cerebral blood flow in prefrontal cortex areas than did younger adults. These findings, which have been replicated in several other studies of executive control, have been interpreted as a compensatory mechanism on the part of older adults – recruiting prefrontal areas to make up for deficiencies in other brain areas. Similarly, Cabezza found that older adults show bilateral prefrontal asymmetry in cortical activation, whereas younger adults show prefrontal lateral asymmetry. He concluded that older adults recruit neurons from both prefrontal hemispheres to compensate for less efficient encoding. In 2005, Springer et al. provided additional fMRI support for this hypothesis. For younger adults, higher levels of education were associated with greater medial temporal cortical activation; for older adults, higher levels of education were associated with greater prefrontal activation. These findings, along with those of Cabezza and DiGirolamo et al., suggest that older adults recruit prefrontal regions so that executive control can compensate for less-efficient peripheral processing.

In contrast to the many studies showing increased prefrontal activity in older adults, West reported evidence of prefrontal deficits in older adults. Part of this discrepancy might stem from changes in activity in subcortical areas connected to the prefrontal ar-

Adult Age Differences in Selectivity

Thus far, we have focused on capacity, which is often operationalized as the ability to process multiple stimuli at the same time. In this section, we now turn to the issue of attentional selectivity, which is operationalized as the ability to process relevant stimuli while ignoring irrelevant stimuli. Most of the research discussed here concerns selection of visual stimuli, as when searching for a specific visual target among distractors (see Perception (00148)). Researchers often attribute the enhanced processing of targets to the application of ‘spatial attention’ (often described as a ‘spotlight’) to the location of the target object. There is still disagreement, however, regarding whether selective attention is directed to spatial locations or to entire objects.

A distinction is often made between two qualitatively different modes of selection: top-down (directed by the observer) and bottom-up (drawn by stimuli in the environment). Bottom-up selection is often referred to as ‘attention capture.’ It has been shown that certain salient visual cues, such as a flash of light, can automatically pull spatial attention toward their location. It is considered automatic (not initiated by top-down mechanisms) because it occurs (1) very quickly (perhaps in less than 100 ms) and (2) even when the observer knows with 100% certainty that the location could never contain a target. A central issue concerns how endogenous (top-down) and exogenous (bottom-up) control interact. A fairly general consensus is that even though bottom-up control of spatial attention is involuntary, it occurs only for stimuli that match top-down control settings. When looking for a red object (say, a red car in a parking lot), other red objects can capture spatial attention. When looking for a new object to appear (e.g., a person to come around a corner), any other abrupt visual onset can capture spatial attention.

Next we describe how selective attention changes as adults age. A common finding is that older adults show performances similar to those of younger adults when top-down guidance is used and general
slowing is taken into account. However, in conditions where there is less top-down guidance, older adults may show poorer performance than younger adults even after controlling for generalized slowing.

**Top-Down Guidance of Visual Selection**

When searching for an object, it often helps to have advance information about the target (e.g., when looking for one’s keys, it helps to know where they might be and what they look like). Research suggests that older adults are just as able (if not more able) to utilize this top-down guidance of visual search as younger adults. For instance, older adults are just as able to use spatial cues that narrow down the possible target locations. Older adults also can benefit just as much as younger adults from knowledge of the likely identity of a target. An important question is why older adults benefit so much from top-down attentional control relative to purely bottom-up attentional control. One possibility is that top-down control allows older adults to take advantage of their greater expertise in attentional search from a lifetime of experience. An alternative explanation is that cuing and singletons simply make tasks easier so that age differences are lessened because task difficulty is lessened.

**Visual Search**

There is some evidence for age effects in visual search for a target among distractors. Rabbitt, for example, reported a card-sorting study (a type of visual search task) with younger and older adults in which he varied display size. As display size increased, older adults performed progressively more poorly relative to younger adults. For instance, Rabbitt found that older adults were just as able to use spatial cues that narrow down the possible target locations. Older adults also can benefit just as much as younger adults from knowledge of the likely identity of a target. However, age differences in visual search are not always found. When tasks require searching multi-element displays in both static (non-moving) and dynamic (movement) conditions (distributed attention), there are many cases in which older adults continue to show preserved selective attention. Kramer et al., for instance, found efficient search for both younger and older adults in both static and dynamic conditions. Also, Atchley and Kramer found that older adults could search efficiently when a depth dimension was added. Hahn and Kramer found that older adults were able to divide their attention between two target locations while ignoring distractor stimuli. Madden found that older adults took longer to process spatial cues and shift their attention across display locations, although this slowing does not necessarily reflect selective attention deficits, per se.

**Inhibitory Control and Selection**

Rabbitt’s hypothesis that older adults exhibit a search deficit because they are more distracted by irrelevant stimuli than younger adults (a filtering deficit) was elaborated upon by Hasher and Zacks. These researchers proposed that the filtering deficit reflects a very general inhibitory control deficit. According to their theory, one consequence of this deficit is an increase in the amount of task-irrelevant stimuli stored in working memory. This issue has been extensively investigated using the well-known Stroop effect. The Stroop effect is when subjects take longer to name the ink color of a presented word when it is incongruent with the meaning of the word (e.g., when the word ‘green’ is presented in red ink) than when it is congruent (e.g., when the word ‘green’ is presented in green ink). Older adults consistently show filtering decrements in Stroop tasks, which has been interpreted as evidence for inhibitory deficits.

It is possible, however, that some filtering problems in older adults are due not to inhibitory deficits, but rather to enhanced automaticity. For example, older adults’ greater word-reading expertise (from a lifetime of practice) is likely to result in greater word activation and greater interference on a Stroop task, compared to younger adults. Interestingly, age differences in Stroop interference are strongly attenuated in a modified Stroop task in which the color and the word belong to separate perceptual objects (a color patch at one spatial location and a word at another). Thus, older adults do not have a problem inhibiting words when they are not the focus of attention. Kramer and colleagues found in a number of other filtering paradigms (e.g., negative priming and inhibition of return effects) that older adults do not show larger inhibitory control effects than younger adults. Finally, Allen et al. examined visual search in a two-position redundant signals paradigm using ‘go/no-go’ and two-choice tasks. A key prediction of an inhibitory control account of age differences in attention is that older adults should make significantly more false alarms on no-go trials than younger adults. Contrary to this prediction, Allen et al. found no age differences in no-go false alarms. They did, however, find age differences in go misses. Although the inhibitory control model of age differences in attention is an intriguing hypothesis, it does not appear that age differences in selective attention are due to a general inhibitory deficit.
Adult Age Differences in Executive Task Control

At each moment, we face a wide array of stimuli, each of which may afford a wide array of tasks. Thus, executive control is needed not only for selecting relevant stimuli, but also for selecting relevant tasks – those that help us to achieve our current goals. People have a remarkable ability to flexibly reconfigure their mental task set in accord with changing task demands. Although impressive, this executive control is not without limits. Studies have repeatedly shown that performance declines when people switch between two tasks compared to when they simply repeat the task. This switch cost persists regardless of how much time people have to prepare.

The classical method of studying task switching is to compare the performance of pure task blocks and alternating task blocks. As a concrete example, a pure task block might include several repetitions of an addition task, whereas an alternating task block might contain an alternating sequence of an addition task and a subtraction task. Rogers and Monsell proposed an alternating runs paradigm. In that paradigm, two tasks (‘A’ and ‘B’) are performed in a mixed task block with a task sequence such as AABBAABB, etc. One advantage of this design is that task switches and task repetitions can be compared within a single block of trials. Studies using this paradigm with younger adults have consistently found relatively small switch costs with univalent stimuli (associated with only one task), but large switch costs with bivalent stimuli (associated with both tasks). Bivalent stimuli provide no reliable task cue and therefore place a heavy burden on internal task control (e.g., inhibiting irrelevant task sets and/or activating relevant task sets).

In this section we discuss the effects of age on executive task control. One important distinction in these studies is that between the costs of task switching (repeat vs. switch) and the costs of task mixing. Mixing costs refer to slower task repetition performance in mixed task blocks than in pure task blocks (task A only or task B only); presumably, they primarily reflect the cost of maintaining two tasks in working memory rather than just one.

Mixing Costs

Although younger adults tend to produce little or no mixing costs, older adults often produce relatively large mixing costs. This difference in mixing costs is generally much larger than would be expected based on generalized slowing alone. Kray and Lindenberger proposed that the increased mixing costs reflect general impairments in working memory. Mayr, however, provided evidence that mixing costs are maximized when the tasks share the same stimuli and the same responses. Accordingly, he proposed that older adults have a specific difficulty in updating their internal control settings (differentiating between tasks).

These findings have important implications for dual task methodology. As noted previously, the simultaneous presentation method involves comparing dual task blocks to pure task blocks. Thus, the costs of mixing are confounded with the costs of temporal overlap in processing (reflecting capacity). Given that mixing costs increase with age, they alone might explain why overall dual task costs often increase with age. This consideration suggests that dual task and single task conditions should be mixed within a block, as in the sequential presentation method.

Switching Costs

Studies that isolated switch costs from mixing costs have yielded mixed results regarding the effects of age. Although a few studies have revealed age effects on task switching after taking generalized slowing into account, many others have not. Although the source of the discrepancy is unclear, there is some evidence that age effects are elevated for tasks that impose a high memory load.

Why do mixing costs generally increase with age even though switching costs do not? It is tempting to conclude that older adults have difficulty maintaining two task sets (due to reduced working memory capacity) but have no difficulty switching between them. Another (admittedly subtle) explanation, however, is that older adults do have difficulty task switching and that this difficulty spills over to task repetition trials as well. Consistent with this explanation, note that older adults’ task switch performance is generally very poor. It is only when one compares this poor task switch performance to the also poor task repetition performance (in the same block) that there appears to be little net switch cost. In this view, supposedly sophisticated attempts to isolate switch costs from mixing costs can produce misleading results. Arguably the best way to assess overall executive task control deficits in older adults is to study the sum of switch costs and mixing costs (i.e., compare task switch performance with task repetition performance from pure task blocks).

Conclusions

In the introduction to this article we noted that attention is not a unitary construct – rather, it consists of several distinct abilities, such as capacity, attent-
ional selection, and executive task control. It is perhaps not surprising, therefore, that unitary theories of attention and aging have not held up to further scrutiny.

Perhaps the most widely held view is that age differences in performance are mediated by processing speed (an operational definition of attentional capacity). Although processing speed clearly plays an important role, there are documented cases of age differences that are not mediated by processing speed. Further evidence against this view comes from findings of preserved capacity in older adults, demonstrated by locus-of-slack and coactivation studies. Thus, rather than simply alluding to a general common factor (speed), component cognitive processes (such as selective attention) must be taken into consideration.

Another widely held theory of age differences in selective attention is that older adults exhibit poorer inhibitory control (a filtering decrement). Although this approach does have some empirical support, there are many cases in which older adults did not demonstrate inhibitory control deficits. It appears that age effects are due not only to deficits in inhibition (filtering) but also to deficits in activation (focusing).

A third theory of age differences in attention is the frontal lobe decrement model, based upon the observation that older adults show loss of cerebral volume of the frontal lobes. The theory is supported by the finding of executive control deficits in certain task switching conditions. However, there is mounting evidence that older adults do not show frontal deficits. Both PET and fMRI imaging have revealed greater bilateral prefrontal lobe recruitment on the part of older adults, suggesting that older adults use greater frontal activation to compensate for decrements in other neural processing (e.g., temporal cortex processing). Perhaps, for older adults, part of what we refer to as expertise involves developing compensatory recruitment.

Since Rabbitt’s pioneering work on age differences in attention, much has been learned. The bad news is that age-related performance declines in capacity, executive task control, and selective attention do occur under many task conditions. The good news, however, is that there are also many cases of preserved attentional functioning. In fact, there are even documented cases of age-related improvement in expertise, automaticity, and top-down attentional guidance. Recognition of these positive influences of aging might lead to explanations for some of the lingering controversies in the study of aging and attention.

See also: Adaptation (00004), Perception (00148).

Further Reading