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Aging and Executive Control: Reports of a Demise Greatly Exaggerated

Paul Verhaeghen
Georgia Institute of Technology

Abstract

I report a series of meta-analyses on aging and executive control. A first set of analyses failed to find evidence for specific age-related deficits in tasks of selective attention (inhibition of return, negative priming, flanker, and Stroop) or tasks tapping local task-shifting costs (reading with distractors is an exception) but found evidence for specific age-related deficits in tasks of divided attention (dual tasking and global task-shifting costs). The second set examined whether executive control explained any age-related variance in complex cognition (episodic memory, reasoning, spatial abilities) over and beyond the effects of speed and working memory; it did not. Thus, the purported decline in executive control with advancing age is clearly not general, and it may ultimately play only a small role in explaining age-related deficits in complex cognition.

Keywords

cognitive aging; executive control; inhibition; speed of processing

It is a truism that as people grow older, performance on a large number of cognitive tasks declines. Such age-sensitive tasks include simple and choice reaction times (RTs), workingmemory tasks, tests of episodic memory, tests of spatial and reasoning abilities, mental rotation, and visual-search performance (e.g., Kausler, 1991; Salthouse, 1991). Given that the deficits are so widespread across the cognitive system, it is reasonable to assume that a limited number of mechanisms may be responsible.

One explanation that has recently gained some prominence is a purported age-related decline in cognitive or executive control, likely related to age-specific changes in the prefrontal cortex (Braver & West, 2008; Raz, 2000; West, 1996). Executive control can be

Corresponding Author: Paul Verhaeghen, Georgia Institute of Technology, School of Psychology, 654 Cherry Street, Atlanta, GA 30332-0170, verhaeghen@gatech.edu.

Recommended Reading
Hertzog, C., Kramer, A.F., Wilson, R.S., & Lindenberger, U. (2009), Enrichment effects on adult cognitive development, *Psychological Science in the Public Interest*, *9*, 1–65). Article for readers interested in the changeability of cognition in old age.
Salthouse, T.A. (1991). *Major issues in cognitive aging*. Oxford, England: Oxford University Press. Probably the most complete reference for theoretical and methodological concerns in cognitive aging; updates and revisits the same issues more concisely and perhaps more accessibly than the present article.

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loosely defined as the set of general-purpose mechanisms that modulate the operation of various cognitive subprocesses and regulates the dynamics of cognition (Miyake, Friedman, Emerson, Witzki, & Howerter, 2000). Implicit or explicit in the argument are two claims: (a) Older adults experience a breakdown in executive control processes, and (b) this breakdown causes some of the age-related deficits seen in more complex aspects of cognition. I argue here that both claims are (perhaps surprisingly and to the relief of all of us who are aging) greatly exaggerated. My evidence comes from a series of meta-analyses bundled in Verhaeghen (in press).

Is There a Breakdown in Executive Control in Old Age?

Age-related changes in executive control: the correct null hypothesis

The first observation to make is that it is hardly surprising that age differences are often observed in tasks requiring cognitive control—after all, just about any study in cognitive aging shows that age-related change is the rule, not the exception. The interesting question is not, “Are there age-related differences in executive control?” but rather, “Are there *unique* (i.e., *specific*) age-related deficits in executive control?”—that is, “Are the age-related differences observed in executive control tasks *larger than expected*?” The best way to answer this question is by examining tasks that have their own “expectation” built in—that is, to compare age differences on a given executive-control task with the age differences observed in a baseline version of the same task with the executive-control aspect removed. A good example is the well-known Stroop color-word task: We can compare age differences in the executive-control version of the task (where subjects report the ink color of “incompatible” color words—e.g., the word “red” shown in green type) with age differences in a neutral baseline (where subjects report the color of strings of *X*s).

How to assess these age differences? At first blush, one could simply compare the absolute difference in performance between older and younger participants in both conditions. There is, however, one important complication with this method: Aging generally does not lead to an additive rescaling of latencies—older adults are not a constant *X* ms slower than younger adults. Rather, across a large number of tasks, latencies of older adults are much better (be it not perfectly) described as a fixed proportion of that of younger adults: Older adults are *X* times slower than younger adults (Cerella, 1985). This near-ratio relationship complicates the interpretation of absolute age differences across different tasks. A fictitious example might help here. Assume a baseline task that takes younger adults 750 milliseconds to perform; assume that adding an executive requirement yields a total latency of 1,000 ms. Assume that a group of older adults given the same tasks is 1.5 times slower across the board than the younger adults. These older adults would then need 1,125 ms for the baseline task and 1,500 ms for the executive-control version. The absolute age difference is thus 375 ms in the baseline version and 500 ms in the executive-control version—that is, the executive-control version of the task shows a larger absolute age difference, although the underlying deficit (a slowing factor of 1.5) is identical in the two conditions.

This example shows that the typical four-point assessment (two age groups by two conditions) is generally insufficient to determine age-sensitivity of a specific process. Instead, we need to map out the actual young–old relationship. One way to do this is by aggregating data from a large number of studies from the literature. The specific tool I use here is the Brinley plot (Brinley, 1965). A Brinley plot is a scatter plot with mean RT of younger adults plotted on the *x*-axis and mean RT of older adults on the *y*-axis; each condition within a study yields a single data point. In the fictitious example given above, we would have one study contributing two data points, one for the baseline task, at (750, 1,125), and one for the executive-control task, at (1,000, 1,500). Brinley plots typically yield linear functions, which can be fitted using linear regression. Although the parameters of these functions can be interpreted (e.g., Cerella, 1985, interprets its slope as the age-related slowing factor in central/computational processing), I use the technique here simply as a way to test the number of dimensions present in the data (Newell & Dunn, 2008). Concretely, within each of a number of executive-control tasks, I examine whether two lines —one for the executive-control version, one for the baseline version— can be reliably separated out. To do this, I use hierarchical linear modeling with data points nested within studies, as advocated by Sliwinski and Hall (1998); the presence of two lines is tested by the inclusion of separate intercept and slope terms for the executive-control version of the task. If two lines are needed, the conclusion is that there is a specific, unique age-related deficit associated with the executive-control process under study. If the two lines coincide, however, the conclusion is that the age-related deficit in the executive-control process is the same as the young–old difference exhibited in the baseline task.

Age-related changes in executive control: results

Executive control is not a unitary construct. Recent factor-analytic work (e.g., Engle, Tuholski, Laughlin, & Conway, 1999; Miyake et al., 2000; Oberauer, Süß, Schulze, Wilhelm, & Wittmann, 2000) suggests that control can be split into at least four interrelated but distinct aspects: (a) resistance to interference (also known as inhibition), (b) coordinative ability, (c) task shifting, and (d) memory updating. Too few studies exist to warrant a meta-analysis on updating, but the former types all can be analyzed using Brinley plots.

Resistance to interference—Resistance to interference has been a central explanatory construct in aging theories since the late 1980s (e.g., Hasher & Zacks, 1988). The assertion is that resistance to inference from irrelevant stimuli or tasks breaks down with advancing age and that this breakdown in turn leads to mental clutter in working memory, thereby limiting its functional capacity and perhaps also its speed of operation. I examined five tasks (Fig. 1).

A first measure of resistance to interference is *inhibition of return*. In a typical study, two boxes appear on a computer screen; one box is cued, and after a brief delay, a target appears in either the cued or uncued location. With delays longer than about 300 ms, RT for the cued location is slower than that for the uncued location—this is inhibition of return (the idea is that the cued location becomes inhibited to foster exploration of novel aspects of the visual environment). Figure 1 (top left panel) shows that the inhibition-of-return effect is larger for older adults than for younger adults—20 ms versus 14 ms. The Brinley analysis, however, shows that this effect is spurious: A single line suffices to explain the data, indicating that aging slows down the response to the cued location and the response to the uncued location to the same degree, and there is no specific breakdown in inhibition of return.

Negative priming refers to a slowing down of RT when identifying a target that has previously been ignored. It is often measured by presenting pairs of stimuli: one marked as a target to be responded to, the other as a distractor to be ignored. In the baseline version of the task, distractors and targets do not repeat; in the executive-control version, the distractor on a given trial becomes the target on the next trial. The data show no age effect in negative priming: 21 ms for younger adults versus 18 ms for older adults; a single line suffices to capture the Brinley data (Fig. 1, top right panel), indicating there is no specific age-related deficit in negative priming.

A third task is the *Eriksen flanker test*. In this test, subjects respond to a central target that is surrounded by distractors signifying a response that is either compatible or incompatible with the target. A typical paradigm uses right- or left-pointing arrows, with participants indicating which direction the arrow is pointing; a compatible display would be →→→, and an incompatible display would be ←→←. The flanker effect is larger for older adults (61 ms vs. 48 ms), but a single line suffices to explain the data in the Brinley plot (Fig. 1, middle left panel), indicating the absence of a specific age-related deficit in the flanker effect.

A fourth test of resistance to interference is *reading with distractors* (Connely, Hasher & Zacks, 1991). Subjects read a brief passage that either is or is not interspersed with distractor text, typically indicated by a different font. Age differences in the reading-with-distractors task are quite large, as Figure 1 (middle right panel) shows, and the Brinley plot reliably splits out into two lines, indicating a specific age-related effect for reading with distractors. The critical reader, however, may note the small number of studies.

A final task is the aforementioned *Stroop task*. Although the Stroop effect is much larger in older than younger adults (480 ms/item vs. 254 ms/item), a single line suffices to capture the Brinley data (Fig. 1, bottom panel), indicting that there is no specific age-related deficit in Stroop performance.

Ability to coordinate—The ability to coordinate distinct tasks is often measured using a dual-task paradigm. In dual-task paradigms, performance on a single task is compared to performance on the same task when a second task is performed concurrently (e.g., a visual RT task with or without a concurrent auditory RT task). The dual-task cost is larger in older adults than in younger adults (216 ms vs. 105 ms), and the Brinley plot (Fig. 2, top left panel) shows two parallel lines, indicating a reliable but relatively small age difference of 36 ms (Verhaeghen, Steitz, Sliwinski, & Cerella, 2003).

Task shifting—Finally, task shifting (Wasylyshyn, Verhaeghen, & Sliwinski, in press) is typically measured by having participants switch between tasks. A *local task-shifting cost* is calculated within task-switching blocks, comparing RT on trials in which a switch is required with RT on nonswitch or repeat trials. This cost is an indication of the control process associated with the actual switching. A *global task-shifting cost* is calculated by comparing performance on blocks when only a single task is performed with performance on blocks where the subject does switch between tasks. It likely reflects a set-up cost, much like a dual-task cost. As shown in Figure 2, global task switching is age-sensitive—two lines are needed in the Brinley plot (bottom left panel)—but local task switching is not (bottom right panel). Figure 2 also includes results from a neuropsychological test sometimes considered a measure of task switching and/or coordination: the Trail Making test. In this test, subjects connect the dots of 25 consecutive targets. In the baseline version, Trails A, the targets are all numbers (1, 2, 3, etc.); In the executive-control version, Trails B, the targets alternate between numbers and letters (1, A, 2, B, 3, C, etc.). This test too shows no specific age-related deficits: A single line captures both Trails A and B (top right panel).

Meta-analyses of age differences in executive control: conclusions

The meta-analyses lead to two conclusions, each at a different level of observation. First, at the level of absolute age differences—the level older adults deal with in their daily lives—there are indeed near-universal deficits: Absolute age differences are typically larger for task versions requiring executive control than for versions with minimal control demands. This stands in stark contrast to the second level, the level of underlying mechanisms as revealed by Brinley plots. Here the picture is much more nuanced: Most executive-control tasks do not showdeficits over and beyond those already present in their low-control or no-control baseline version. Perhaps most surprisingly given the attention this explanation has received in the literature, most tasks involving resistance to interference showed no age-sensitivity in the control process (reading with distractors was the only exception). Neither did tasks tapping local task switching. In contrast, global task switching and coordinative ability did show specific age deficits. At a broad level of generalization, one could then conclude that tasks of selective attention are mostly spared and that reliable age differences emerge in tasks that involve divided attention and/or the maintenance of two distinct mental task sets.

Do Age Differences in Executive Control Have Implications for Complex Cognition?

To answer the second critical question ("Do age differences in executive control have implications for complex cognition?"), I aggregated data from the literature (119 studies in total; only studies that examined a continuous age range were included) to construct a correlation matrix with the following variables: age, three basic aspects of cognition (speed-of-processing, typically measured using perceptual-speed tasks; short-term memory; working memory), three complex aspects of cognition (episodic memory, reasoning ability, spatial ability), and the two aspects of executive control for which sufficient data were available, namely resistance to interference and task shifting. Figure 3 (top panel) shows the result of one analysis, in which I examined the proportion of the age-related variance in the three complex cognitive variables that is explained by the two executive-control variables, with the explanatory power of the basic cognitive variables presented for comparison purposes. Both resistance to interference and task shifting explain a sizable proportion of age differences in complex cognition, but speed-of-processing and working memory explain even more. The bottom panel shows results from a structural equation model to test whether executive control explains any age-related variance in complex cognition over and beyond the mediating influence of speed and working memory/short-term memory. (This is a final model—that is, all included paths are significant, and none of the possible additional paths are significant when added.) The model shows no such role for executive control, at least as defined by resistance to interference and task shifting. First, all of the age-related variance in executive control is explained by age-related slowing in speed of processing. Second, executive control does not transmit any variance down the line.

General Conclusion

The meta-analyses reviewed here show a surprisingly modest role for executive control as an explanatory mechanism for cognitive aging. Executive control as related to selective attention (resistance to interference, local task shifting) does not show a specific age-related deficit. Divided-attention aspects of control (coordinative ability and global task shifting) do show specific age-related deficits. One mechanism, updating, remains woefully underresearched. Importantly, executive control (as defined by resistance to interference and task shifting) does not explain any age-related variance in complex cognition over and beyond the effects explained by simple speed of processing. For researchers in the field, this suggests that perhaps the larger urgency is to examine age-related deficits in divided attention (and possibly memory updating), as well as general mechanisms, notably those that underlie the basic phenomenon of cognitive slowing, such as dopamine loss (Bäckman, Nyberg, Lindenbegerer, Li, & Farde, 2006) and/or white matter abnormalities (Gunning-Dixon & Raz, 2000). For all of us who are aging, the simple message is that the rumors of age-related deficits in executive control are highly exaggerated.

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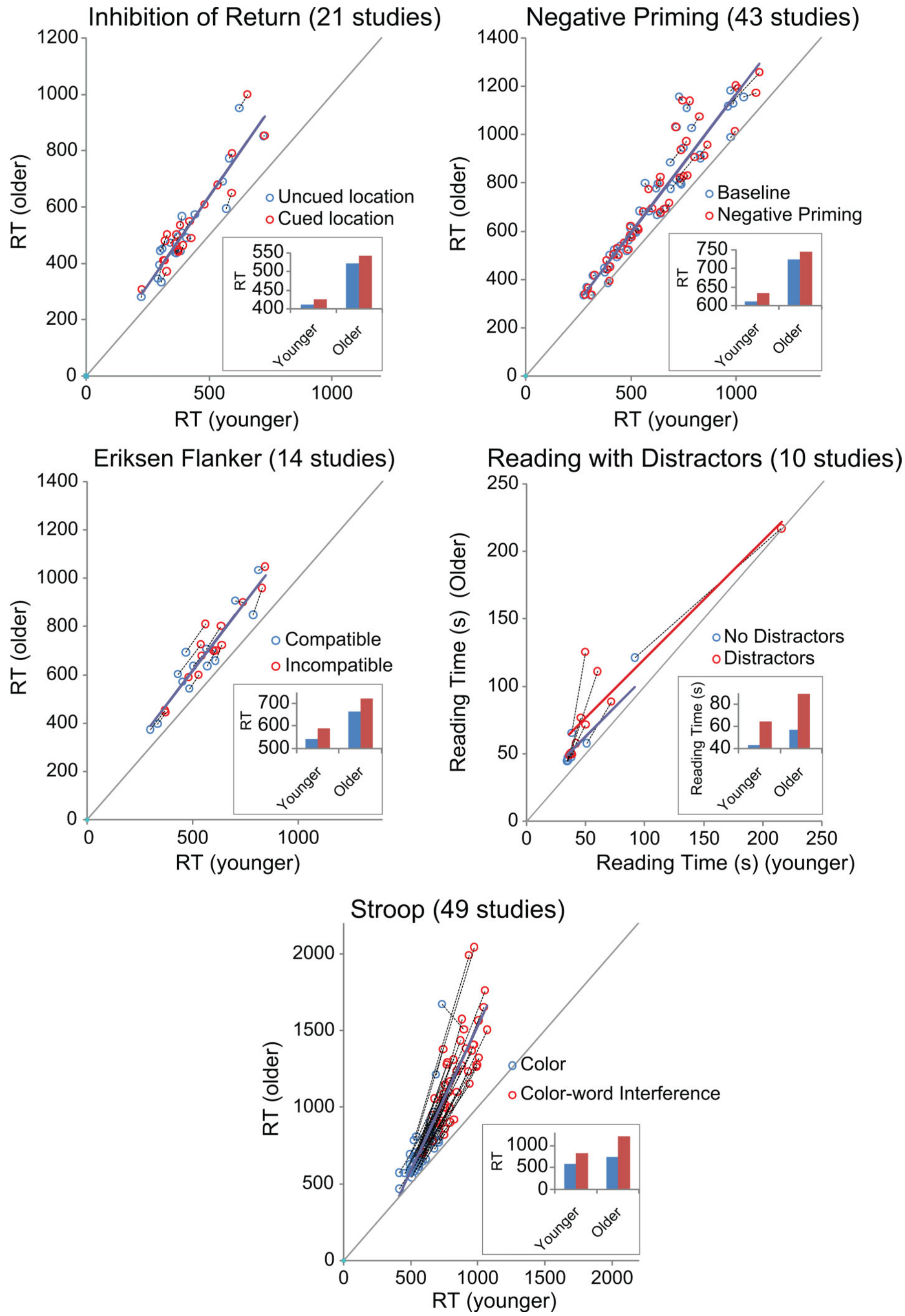

Fig. 1.

Results from meta-analyses (Brinley plots) of five different tasks of the resistance-to-interference aspect of executive control (inhibition of return, negative priming, Eriksen flanker task, reading with distractors, and Stroop), as well as average effects for younger and older adults (inserts). Lines indicate results from regression analyses using hierarchical linear modeling. A single line (in blue) indicates an absence of a specific age-related deficit in executive control; the presence of two lines (blue for baseline, red for executive-control conditions) indicates a specific age-related deficit in control (only reading with distractors shows such specific deficit). RT = reaction time. Data from Verhaeghen (in press) except when noted in the text.

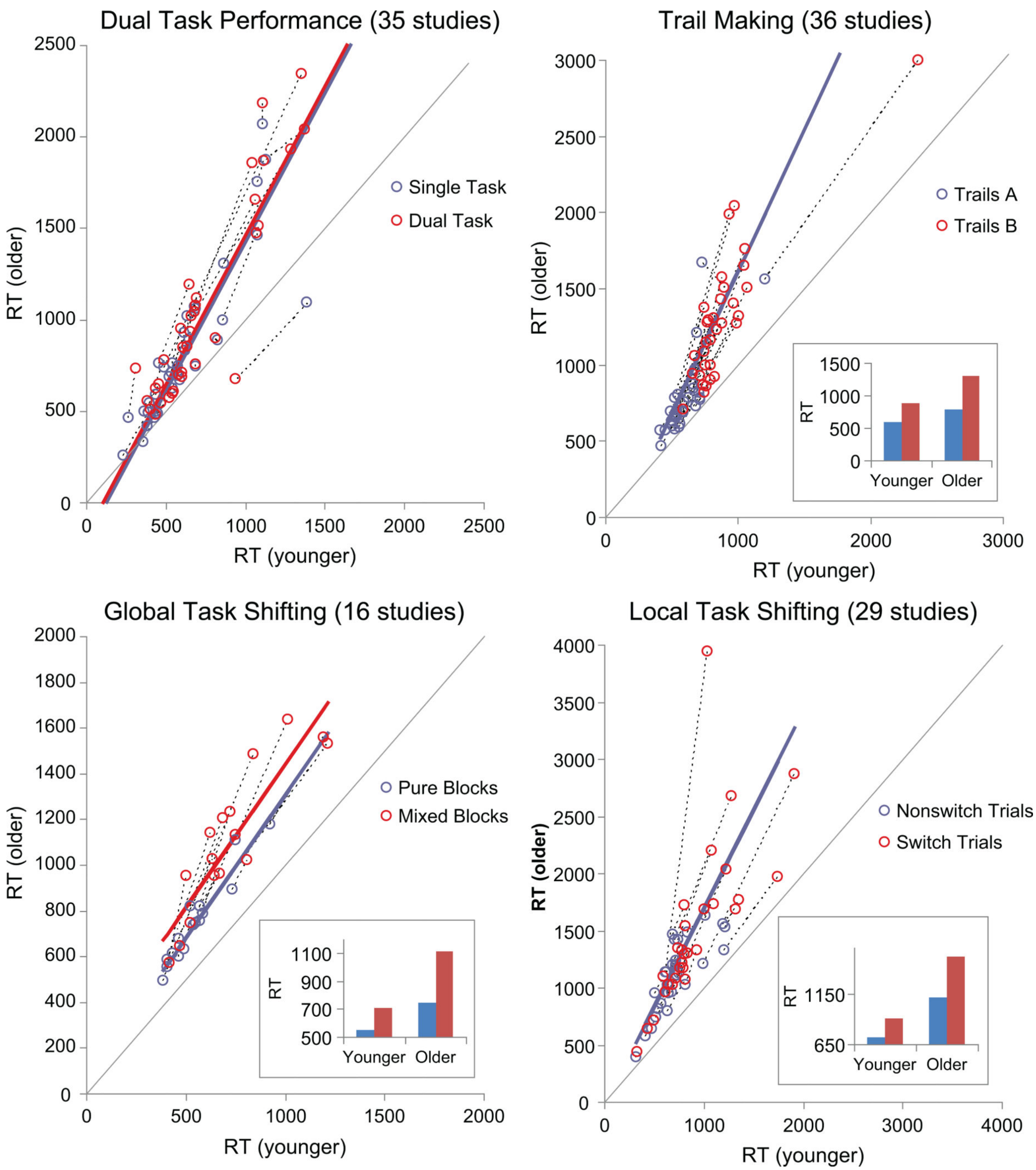

Fig. 2.

Results from meta-analyses (Brinley plots) of four different tasks of the coordination and task-switching aspects of executive control (dual–task performance, Trail Making, and global and local task shifting), as well as average effects for younger and older adults (inserts). Lines indicate results from regression analyses using hierarchical linear modeling. A single line (in blue) indicates an absence of a specific age-related deficit in executive control; the presence of two lines (blue for baseline, red for executive-control conditions) indicates a specific age-related deficit in control (only dual tasking and global task shifting show such specific deficit). Data from Verhaeghen (in press) except when noted in the text.

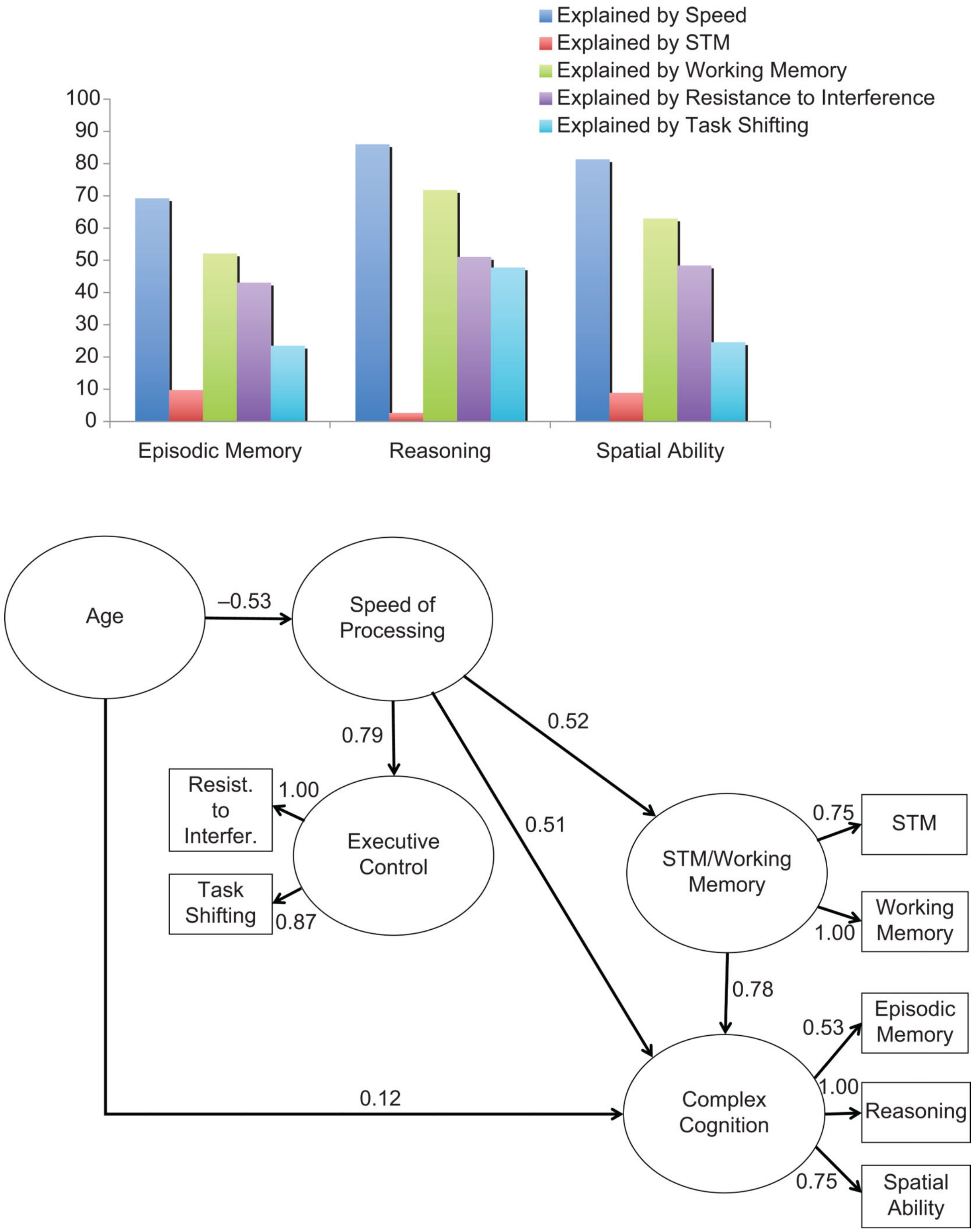

Fig. 3.

Analyses of a meta-analytically derived correlation matrix (119 studies in total). Top panel: percent of age-related variance in three aspects of complex cognition explained by basic aspects of cognition and executive-control measures. Bottom panel: best-fitting results from a structural equation model to explore the mediating role of basic cognition and executive control on complex cognition; all paths are significant and coefficients are standardized. STM = short-term memory.