7

The Aging of Executive Functions

Karen Daniels
Jeffrey Toth
Larry Jacoby

For many young adults, the idea of retirement brings to mind carefree days of rest and relaxation. Yet, speak to any retiree and the discussion is likely to revolve around more complex issues such as how best to maintain one's health or financial security. As these two topics attest, old age can be a time that requires decisions as large in number and importance as those faced by much younger adults. The ability to make such decisions effectively has been attributed to *executive functions*—a loosely defined set of cognitive skills and processes that appear critical for complex thought and behavior. In this chapter, we explore the issue of how best to define and measure executive functions and their change with age. The dominant approach to measuring executive functions can be described as *task-based*. That is, one chooses a task or set of tasks that one believes taps executive functions (e.g., Stroop, A-not-B, Wisconsin Card Sort Test [WCST]) and then sees if performance on such tasks is sensitive to childhood development, frontal lobe damage, or aging. This approach has served the field well by delineating the scope of executive functions and identifying a set of candidate processes that appear fundamental in mediating complex thought and behavior (processes such as working memory, inhibition, and set shifting; see Diamond, Chapter 6, this volume). In this chapter, however, we argue that there are limitations with task-based approaches and propose instead a greater focus on underlying processes, as well as formal modeling of these processes.

Our discussion is organized as follows. We begin by describing the origin of the concept of executive functions, noting how the concept has been operationalized in both cognitive and neuropsychological studies in terms of performance on specific tasks. We cite some of the studies that have compared young and older adults on such tasks, but focus mainly on whether task-based research has been (or will be) able to answer two critical questions: First, whether there are multiple executive functions or only one superordinate function (i.e., the unity/diversity question; see Duncan, Johnson, Swales, & Freer, 1997; Miyake, Friedman, Emerson, Witzki, & Howerter, 2000; Teuber, 1972); and, second, whether one or more of these functions decline with age (see Salthouse, Atkinson, & Berish, 2003; Wecker, Kramer, Wisniewski, Delis, & Kaplan, 2000). We find current answers to these questions unsatisfactory and trace our dissatisfaction to problems inherent with task-based approaches to executive functions, even those using latent-variable statistical techniques. As an alternative to task-based approaches, we next describe research and multinomial modeling done using the process-dissociation (PD) procedure. Although this research was initially directed at explaining age-related increases in various kinds of interference (proactive, Stroop, and retroactive), we argue that it is relevant to issues surrounding the concept of executive functions. As evidence for this relevance we describe research linking PD estimates of cognitive control to measures of fluid intelligence and metacognitive monitoring. We conclude with some general comments about how the PD approach can be combined with latent-variable techniques to better explicate the concept of executive functions and its change with age.

WHAT ARE EXECUTIVE FUNCTIONS?

The concept of executive functions has a long past, with its beginnings heavily influenced by neuropsychology (see Luria, 1966/1980; Stuss & Benson, 1986; Tranel, Anderson, & Benton, 1994). Historically, the concept can be traced to Hughling Jackson's (1884) hypothesis that "higher centers" of the brain controlled "lower centers"; to Jacobsen's work with monkeys (e.g., Jacobsen & Nissen, 1937) showing the importance of prefrontal cortex in holding information in mind and establishing a "mental set"; and to Goldstein's (e.g., 1936) notion of the "abstract attitude"—the ability to break down situations into their constituent parts (see Cronin-Golomb, 1990). However, most researchers would agree that the concept achieves its greatest importance with respect to the effects of frontal lobe damage on cognition, personality, and behavior—the case of Phineas Gage being the classic example (see Macmillan, 1986; Mesulam, 2002; Stuss & Benson, 1986; Stuss, Gow, & Heatherington, 1992).

As with Gage, damage to the prefrontal cortex produces an incredibly wide range of disturbances that encompass planning and organization, abstract thought, complex decision making, the regulation of emotions and impulses, the sequencing of goal-directed behavior, and the monitoring of thought and action (see Fuster, 1989; Luria 1966/1980; Lyon & Krasnegor, 1996; Stuss & Benson, 1986). Additional descriptions could include the imposing of cognitive structure on ill-structured situations (Pribram, 1973), dealing with novel cognitive demands (Norman & Shallice, 1986), mediating between cognition and emotion in the context of risk (Damasio, 1998), and maintaining personal autonomy in the context of social interaction (Lhermitte, 1986). In line with these proposals, Mesulam (2002) describes frontal lobe processes as important for overcoming a "default mode" of information processing—a mode that reflects primitive, disinhibited behavioral tendencies including the triggering of automatic reactions and a preference for immediate gratification.

All of these descriptions appear to be capturing part of the "truth" of executive functions. Yet it should also be clear that the scope of these descriptions makes it difficult to pinpoint any central feature of such functions. Is there one fundamental ability that underlies all executive abilities, or does *executive functions* refer to a class of similar, but theoretically distinct processes? Most important, how can these functions be measured?

TASK-BASED APPROACHES TO MEASURING EXECUTIVE FUNCTIONS

As with most cognitive abilities, executive functions have been operationalized in terms of task performance, although the specific tasks employed have differed in neuropsychology (where the concern with executive processes emerged) and cognitive psychology. For the former, a major goal was to identify tasks sensitive to frontal-lobe damage, with little emphasis placed on underlying processes beyond their rough categorization as involving, say, "planning." Cognitive psychologists, in contrast, view underlying processes as paramount and, until late, were unconcerned with the neural systems mediating performance. This difference in emphasis has resulted in a hodgepodge of tasks in use today that are thought to require executive or frontal processes. In the next two sections, we provide brief summaries of research with these tasks, in the service of answering the two questions noted above: unity versus diversity and age effects.

Neuropsychological Tasks

Older adults perform more poorly than younger adults on many classic neuropsychological tests of executive function, including the Wisconsin Card-Sorting Task (WCST: e.g., Kramer, Humphrey, Larish, Logan, & Strayer, 1994; Parkin & Walter, 1992), the color-word Stroop task (e.g., Brink & McDowd, 1999; Cohn, Dustman, & Bradford, 1984), Trails B (e.g., Salthouse & Fristoe, 1995), tests of verbal fluency (see Salthouse et al., 2003), and several tower tasks (e.g., Ronnlund, Lovden, & Nilsson, 2001). Coupled with neuroimaging studies showing changes in the structure and function of the frontal lobes with advancing age (see Prull, Gabrieli, & Bunge, 2000; Raz, 2000), these behavioral findings have led to a *frontal-lobe hypothesis* of cognitive aging (e.g., Albert & Kaplan, 1980; West, 1996). While likely true at some level, a problem with this hypothesis is its lack of specificity. The frontal lobe constitutes a large part of the brain and consists of anatomically specific regions that likely perform distinct cognitive functions; however, there is little consensus regarding the specific, age-related cognitive impairments that are associated with declines in frontal function.

Inconsistent behavioral findings with respect to the effects of age on neuropsychological tasks have also complicated our understanding of age-related changes in executive functioning. For example, numerous studies have either failed to find age-related effects on executive tasks (e.g., Boone, Miller, Lesser, Hill, & D'Elia, 1990) or have found observed effects to be eliminated when performance on nonexecutive-component processes such as perceptual/motor speed are taken into account (e.g., Fristoe, Salthouse, & Woodard, 1997; Parkin & Java, 1999; but see Dywan, Segalowitz, & Unsal, 1992). As well, correlations among neuropsychological measures of executive function are often small and nonsignificant (e.g., Burgess, Alderman, Evan, Emslie, & Wilson, 1998; Duncan et al., 1997; Lehto, 1996; Lowe & Rabbitt, 1997; Robbins et al., 1998), even among versions of the same basic task (e.g., Salthouse & Meinz, 1995; Shilling, Chetwynd, & Rabbitt, 2002). Although methodological limitations (small samples, low reliability) may partially explain these results, they are also consistent with two nonexclusive conclusions, both of which hint at problems with task-based approaches: First, that performance on "executive" tasks often reflects nonexecutive, idiosyncratic aspects of the task (aspects related to task materials and procedures, for example); and second, that the tasks are tapping distinct, separable forms of executive control.

Cognitive Tasks

Unlike neuropsychological tasks, modern cognitive tasks are designed to more precisely measure specific processes. Prominent among the tasks believed to measure executive-control processes are those that place large demands on working memory (e.g., span tasks, *n*-back); those that require the inhibition of prepotent responses (e.g., Stroop, negative priming); and those that require the focusing, dividing, or switching of attention (e.g., task-switching paradigms). As with neuropsychological measures, older adults have been shown to perform more poorly than younger adults on a variety of tasks designed to tap these abilities (for reviews, see Park, 2000; Zacks, Hasher, & Li, 2000).

However, despite their intended specificity in terms of underlying processes, cognitive tasks appear vulnerable to many of the same empirical and interpretative limitations as neuropsychological tasks. For example, age-related deficits are often inconsistent across tasks, even those purported to measure a *single* executive function such as inhibition (see Kramer et al., 1994). As well, some age effects on executive-processing cognitive tasks are significantly reduced or eliminated when variance associated with more basic processes is first removed (e.g., Verhaeghen & De Meersman, 1998). More generally, although age-related declines in task performance are often interpreted as reflecting changes in *specific* executive processes, mediational analyses often show that the majority of decline can be accounted for by a common factor that is shared by all tasks, including tasks often considered "nonexecutive" (see Salthouse et al., 2003). Overall, then, while cognitive tasks arguably allow for a more process-specific analysis of executive functions, these tasks do not appear to get around the interpretive problems seen with neuropsychological tasks.

Part of the difficulty in interpreting relations among executive tasks and their changes with age may be traced to the more basic question of whether executive control reflects a single, unified ability or a family of distinct abilities. Some researchers have argued that executive control is very general (Duncan & Miller, 2002). Consistent with this perspective, Engle and colleagues have shown working memory tasks to predict a wide array of higher-order cognitive abilities, including comprehension, reasoning, and fluid intelligence (see Engle & Kane, 2004). Alternatively, dissociations among tasks, along with more theoretical considerations, have led other researchers to propose the existence of distinct executive processes (e.g., Miyake et al., 2000). Unfortunately, the few studies that have examined the validity of such fractionations have produced mixed results. For example, Salthouse et al. (2003) found little evidence that inhibition, updating (working memory), and time-sharing (switching) represent distinct aspects of executive control while Miyake et al. (2000) argued that very similar abilities (inhibition, updating, and shifting) were "clearly distinguishable" (p. 28).

Further complicating the picture, recent theorizing has hypothesized that each of the three executive processes described above can be further fractionated into constituent subprocesses. Thus, inhibition has recently been argued to consist of three distinct abilities: *access*, *deletion*, and *restraint* (Hasher, Zacks, & May, 1999; see also Friedman & Miyake, 2004). As well, at least two types of task-switching processes have been proposed—*local* (age insensitive) and *global* (age sensitive)—with a third switching-related measure (*focus switching*) on the horizon (see Verhaeghen, Cerella, Bopp, & Chandramallika, in press). Finally, it has been suggested that the executive control of working memory may reflect two distinct, interdependent mechanisms: *goal maintenance* and *conflict resolution* (Engle & Kane, 2004; Kane & Engle, 2003).

As should be apparent, the above studies and proposals paint a very complex picture of executive functions and their change with age. Such complexities have led some researchers to call for the development of new tasks that can more precisely measure relevant executive (sub-) processes (e.g., Conway, Kane, & Engle, 2003). However, as discussed in the next section, we question whether *any* task can achieve the level of process specificity required to answer the unity/diversity question, or the question of age-related changes in executive functions.

Executive Tasks and Executive Processes

A number of researchers have discussed the limitations with task-based approaches to defining and measuring executive functions (see especially Burgess, 1997; Rabbitt, 1997; Salthouse et al., 2003). One of the most worrisome is that ostensibly executive tasks are not process- or factor-pure in the sense that performance is determined not only by the targeted executive functions but also by one or more nonexecutive processes. As well, there is at least passing acknowledgment that, even if a task were process-pure, the measures obtained would still reflect variance associated with task materials and methods. Here we would like to further emphasize what could be called the *portion-of-variance* problem. In particular, there appears to be little concern with *how much* variability in task performance is due to executive processes relative to nonexecutive processes, despite the fact that this portion certainly differs across tasks and is also likely to change as a function of both practice and age (cf. Li et al., 2004).

Some of the problems associated with executive tasks can be addressed through latent-variable techniques. By reducing the impact of method-related variance, for example, and examining the relations among multiple tasks, these techniques have significantly broadened our understanding of executive functions (e.g., Miyake et al., 2000) and their change with age (e.g., Salthouse et al., 2003). Nevertheless, latent variables (and the conclusions they engender) are only as good as the measures used to estimate them; and, here again, basic problems with task-based measures emerge. One such problem is that latent-variable techniques are often predicated on the a priori selection of tasks thought to index-specific processes, yet there is often little agreement about the "true" process(es) involved.

Even more problematic, however, is the possibility that performance on executive tasks may be determined by more than one executive process. Most complex tasks—whether cognitive, neuropsychological, or real-world—are likely to reflect a number of executive-control processes, including planning, sequencing, shifting, monitoring, and error correction. Indeed, monitoring and error correction are particularly interesting as they are likely to play a role in a variety of tasks (cf. Garavan, Ross, Murphy, Roche, & Stein, 2002; Rabbitt, 2002). Thus, assuming complex tasks engage multiple processes, more than one of which may be plausibly described as "executive," to which latent factor does such a task belong? Task performance measures are usually used to define one factor; but if tasks engage multiple processes, then this approach would necessarily lose or mischaracterize the variance associated with these other executive processes. We believe a more appropriate strategy is to separate processes *within a task* prior to examining the relations of such processes to each other and to individual-difference variables such as age.

A PROCESS-DISSOCIATION APPROACH TO THE MEASUREMENT OF EXECUTIVE PROCESSES

The process dissociation (PD) procedure (Jacoby, 1991) was developed in the context of dual-process models of memory and attention that distinguish between cognitively controlled and more automatic bases for thought and action. Although not always described as such, we see *cognitive control* in the context of dual-process theories as being coextensive with *executive processes*. A key assumption underlying the PD procedure is that most tasks reflect a mixture of controlled and automatic processes. Thus, rather than associating executive processes with performance on particular tasks, the goal of the procedure is to isolate those aspects of *any* task that reflect executive control. We believe the strategy of isolating and measuring control *within* tasks, regardless of whether they are designated "executive," is an improvement over task-based approaches to the measurement of executive processes, especially given the likely possibility that tasks require multiple forms of control.

The PD approach has been quite successful in producing theoretically meaningful estimates of controlled and automatic processes as a function of variables generally agreed to be related to executive functions. In the context of memory, for example, both dividing attention at study and forcing faster responses at test have been shown to reliably decrease estimated recollection—a controlled form of memory—but to have no influence on estimated familiarity, a more automatic form of memory (e.g., Jacoby, 1999; Schmitter-Edgecombe, 1999; Toth, 1996). Aging has also been found to dissociate the two processes with older adults consistently showing lower estimates of recollection than younger adults, while estimates of familiarity are often equivalent in the two groups (e.g., Jacoby, 1999; Jennings & Jacoby, 1997). This pattern of results is consistent with theories suggesting that aging is associated with deficits in executive control, while more automatic processes remain relatively intact (e.g., Braver & Barch, 2002; Jacoby, Jennings, & Hay, 1996).

In this section, we describe research showing how the PD procedure has been used to estimate executive processes operating in memory and attention tasks. We then describe research from a new "I told you . . ." task to show how the procedure can be used to separate *multiple* executive processes operating within a single task. Next, we describe research showing that process estimates can be used as individual difference measures. We end by suggesting how the PD approach can be combined with latent-variable techniques to address questions about the unity versus diversity of executive functions and how such functions change with age.

Recollection as Executive Control over Proactive Interference

Proactive interference (PI) refers to an impairment in the ability to remember an item or event because of its similarity to other items or events that were encountered earlier. A classic laboratory paradigm of PI is the A-not-B task, often used in research with infants and young children (see Diamond, Chapter 6, this volume), although examples of PI in the everyday lives of adults can also be easily identified. In trying to remember the location of our keys, for example, PI can often lead us to initially search where we *usually* put our keys rather than where we put them most recently.

To explain PI, the PD approach distinguishes between recollection and automatic influences of memory expressed as *accessibility bias*. *Recollection* refers to a controlled use of memory whose impairment is largely responsible for age-related declines in memory. Recollection and accessibility bias serve as alternative bases for responding. The notion is that when people are unable to recollect a past event, they "guess" with the first response that comes to mind, thereby showing effects of accessibility bias. If this characterization is correct, then two predictions follow. First, PI can result from a decrease in recollection without a concomitant increase in accessibility bias. Second, PI can result from an increase in the accessibility of interfering information without a concomitant decrease in recollection of the target event.

To test these predictions, Jacoby, Debner, and Hay (2001) varied accessibility bias in an initial training phase by exposing young and older adults to pairs of associatively related words. Critically, each cue word was paired with two different responses and the probability of each pairing was varied over trials. For example, in a 75% condition, the typical response "bone" appeared with the cue word "knee" on 75%

of the training trials, whereas the atypical response "bend" appeared with the cue on only 25% of the trials. For a 50% condition, the two cue-response pairs were presented equally often. After training, participants were presented with short lists of to-be-remembered pairs followed by a cued-recall test for those pairs. Test trials consisted of a cue word and a fragmented version of the response ("knee b_n_") and participants were told to complete the fragment with the response presented in the immediately preceding study list, guessing if necessary. The fragments were such that they could be completed with *either* of the two responses paired with the cue in training.

For *congruent* test pairs, the response presented in the study list was the one presented most frequently during training ("bone"), making recollection and accessibility congruent in dictating the same response. As shown in Figure 7.1A, correct recall could result either from recollection (R) of the studied word or when recollection failed, from reliance on the accessibility bias (A) developed during training: P (correct recall|congruent) = R + (1–R)A. For *incongruent* test pairs, in contrast, accessibility and recollection were placed in opposition by having participants study the response presented least frequently during training ("bend"). For these pairs, false recall (saying "bone" when "bend" was studied) would occur when participants failed to recollect the study pair, but instead relied on accessibility: P (false recall|incongruent) = (1–R)A.

Results reported by Jacoby and colleagues revealed dissociations that provided strong support for their dual-process model (see Table 7.1). Most important, in experiment 2, aging negatively influenced recollection (thereby increasing PI in the older adults) but left estimated accessibility bias unchanged. That is, older adults were less able to recollect the target response presented in the study list just prior to testing, but did

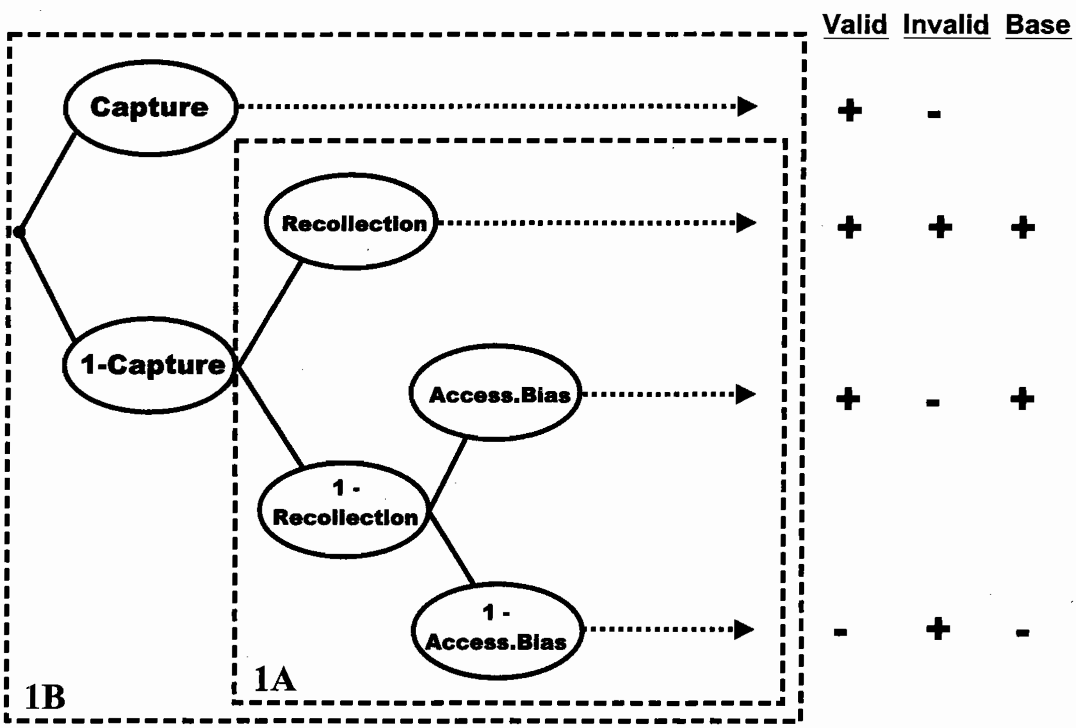

FIGURE 7.1. Multinomial model tree showing the Recollection/Accessibility-Bias model (1A) used to fit the data in Jacoby et al. (2005) and the Capture model (1*B*) used to fit the data in Jacoby et al. (2005). Branches lead to correct recall (+) and false recall (-) for valid (or congruent), invalid (or incongruent), and baseline conditions.

not differ from young adults in their reliance on accessibility bias when recollection failed. In contrast, the training manipulation (experiment 1) produced an opposite dissociation such that, relative to the 50% condition, training in the 75% condition increased accessibility bias (thereby increasing interference) but had no effect on a participant's ability to recollect the target information. These findings point to deficits in recollection, not inhibition, as the reason for older adults' increased susceptibility to PI.

Analogous findings were recently reported by Daniels (2003) in the context of working memory (WM). She found that individuals low in WM capacity as measured by span tasks ("low spans") showed elevated PI relative to individuals high in WM capacity ("high spans") a result also reported by Rosen and Engle (1998; Kane & Engle, 2000). However, just as Jacoby and colleagues (2001) found for older adults, Daniels found that the low spans' increased interference was entirely attributable to a selective decrease in recollection.

Note the implications of these findings for studies in which task-based measures of PI (i.e., observed performance in interference conditions) are entered into latent-variable analyses to identify "inhibitory" factors (cf. Friedman & Miyake, 2004). First, they show that nonexecutive processes such as accessibility bias are contributing to (contaminating) the index of PI. Second, they strongly imply that the resultant latent factor is inappropriately described as inhibitory because the relevant executive process—the process that determines whether and to what degree PI is exhibited—is not inhibition but recollection. The findings of Jacoby et al. (2001) and Daniels (2003) suggest that more theoretical traction would be gained by using estimates of recollection as the basis for latent-variable analyses of PI.

Inhibitory Control in the Stroop Task

Although the PD procedure revealed no evidence of inhibitory processes in the control of PI (but see the work on RI, below), inhibitory-like processes do appear to be involved in performing the Stroop task. The Stroop task has been taken to represent a clear executive-control task because it requires the avoidance of habitual but goal-irrelevant responses (word reading) in favor of less-practiced but goal-relevant ones (naming the color in which the word appears). As noted earlier, older adults often demonstrate greater Stroop interference effects than younger adults. However, from a task-based perspective, it is difficult to tell whether elevated Stroop interference reflects decreased color naming, increased word-reading processes, or a combination of the two.

Using a model of Stroop performance that postulates independent processes of color naming and word reading (Lindsay & Jacoby, 1994), Spieler, Balota, and Faust (1996) showed that, once speed differences were taken into account, age-related deficits in Stroop performance could be completely described in terms of elevated word-reading estimates in older adults. A selective increase in estimated word reading has also been found for low-spans as compared to high-spans (Daniels, 2003). Although estimates of word reading likely reflect processes associated with word reading per se, age- and span-related increases in this parameter are also consistent with the idea of decreased in-

TABLE 7.1. Hits, false alarms (FAs), and process estimates for recall performance in Jacoby et al. (2001)

	Recall		*Process Estimates*	
	Congruent (Hits)	*Incongruent (FAs)*	*Recollection*	*Accessibility*
Expt 1: PC				
PC50	.72	.32	.40	.54
PC75	.83	.40	.43	.69
Expt 2: Age				
Young	.80	.35	.44	.63
Old	.73	.44	.29	.62

hibitory efficiency (see Jacoby, McElree, & Trainham, 1999; Spieler et al., 1996) or, alternatively, with deficits in the ability to maintain the goal of color naming (see De Jong, 2001; Kane & Engle, 2003).

Executive Processes in a Retroactive-Interference ("I told you . . .") Paradigm

To this point, we have argued that the PD approach can purify measures of executive (and nonexecutive) processes operating in memory and attention tasks. However, one of the main reasons for advocating a PD approach to the study of executive processes is the possibility that tasks may often engage multiple executive processes (e.g., Garavan et al., 2002). In this section, we describe research using an "I told you . . ." procedure (Jacoby, Bishara, Hessels, & Toth, 2005) that we believe exemplifies such a task.

The "I told you . . ." procedure shares similarities with misinformation paradigms of the sort examined by Loftus (e.g., 1975) and others (e.g., Karpel, Hoyer, & Toglia, 2001). One of the reasons for our interest in misinformation effects is the possibility that such effects could be exploited to scam older adults. In one scam, for example, an unscrupulous repairman attempts to overcharge an older adult by falsely claiming, "*I told you* that it would cost X [a much higher price than was originally quoted], and you agreed to pay." The scam is most effective if its victim falsely remembers having agreed to pay the much higher price. In the research described below, we have found evidence suggesting that such a possibility is quite real—that a misleading cue, similar to a false "I told you . . ." claim, can result in older adults' showing levels of false remembering that are dramatically higher than those shown by younger adults. Moreover, such high levels of false remembering do *not* stem from age-related deficits in recollection of the sort found for PI (Jacoby et al., 2001); rather, they appear to reflect age differences in the likelihood of being "captured" by the false "I told you . . ." claim. Such capture appears to reflect an attention-related (inhibitory or goal-maintenance) deficit such that the "I told you . . ." claim preempts the older adult's attempt to recollect the relevant past event.

The general procedure for these experiments involves presenting pairs of related words for study (e.g., "knee bone"), with memory then tested by providing participants with a cued word along with a fragment of the response word ("knee b_n_"). The critical manipulation involved presenting a prime word just prior to presentation of the recall cue (word + fragment) pair. This prime was either the same as the target word (a *valid* prime: "bone"), an alternative to the target word (an *invalid* prime: "bend"), or a neutral nonword stimulus (a *baseline* prime: "&&&&").

In one experiment of this sort, young and older adults were required to give a response to each test cue, and then were asked to report on the basis of their response saying "remember," "familiar," or "guess." Similar to research by Gardiner and colleagues (Gardiner & Richardson-Klavehn, 2000), participants were to respond "remember" only when they could clearly recollect details of studying the target word. "Familiar" judgments were to be made when the participants *knew* that their response word was old but could not recollect details about studying it. Finally, "guess" judgments were to be made if the participants were purely guessing, with no idea of whether their response was the correct answer.

Results are shown in Table 7.2. Note that the recall performance of the young and older adults on neutral baseline trials was nearly identical (.70), a pattern achieved by giving older adults more study time for each word pair (3 seconds vs. 1 second). Nevertheless, despite this equivalence, performance on primed trials differed significantly for the young and older adults. For young adults, the interference produced by invalid primes was perfectly offset by the facilitation produced by valid primes; that is, performance in the prime conditions was symmetrical around that in the baseline condition. In contrast, the older adults showed a larger effect of the primes than did the young, and performance in the prime conditions was not symmetrical around baseline. The asymmetry would be expected if older adults were sometimes captured by the primes, thereby giving the prime as a response rather than engaging in recollection.

Consistent with this account, we fit the recall data from the above experiment with a multinomial model that combined the recollection/accessibility-bias (RA) model used by Jacoby et al. (2001) with an inhibition-deficit model of the sort used by Lindsay and Jacoby (1994) to describe Stroop performance. The combined model (Figure 7.1B) differs from the simpler RA model (Figure 7.1A) only in that a *capture* parameter precedes recollection. The notion is that being captured by a highly accessible response sacrifices the opportunity to engage in recollection in the same way

TABLE 7.2. Recall and "remember" judgments in Jacoby et al. (2005)

	Prime Condition		
	Valid	*Neutral*	*Invalid*
Target Recall			
Young	.89	.70	.51
Old	.93	.70	.31
Correct "Remember"			
Young	.38	.36	.30
Old	.77	.58	.24
False "Remember"			
Young	.01	.04	.04
Old	.03	.13	.43

that, in the Stroop task, reading the irrelevant word sacrifices the opportunity to name that word's color. This capture model provided a good fit to the above recall data, with only the capture parameter differing for young and older adults. That is, the best fits were obtained when the capture parameter was set to zero for the young adults (no capture), consistent with the symmetry in their valid-/invalid-prime data. For the older adults, in contrast, the capture parameter was substantial (.38). This suggests that older adults often "recalled" the false "I told you . . ." prime, accepting it as veridical without even attempting recollection. Such a failure could be described as a form of disinhibition, or goal neglect.

Table 7.2 also shows the subjective-report data. For young adults, the probability of a "remember" response was little affected by presentation of a prime, as would be expected if such responses reflected the probability of recollection, which was unchanged by presentation of a prime. In contrast, older adults were much more likely to claim to "remember" than were young adults, and presentation of a prime had a large effect on their responses. This difference was particularly dramatic for invalid primes (false "remembering"). That is, the probability of falsely recalling an invalid prime and saying "remember" was only .04 for young adults, but was .43 for older adults, a difference that remained when remember responses were conditionalized on reporting an invalid prime (.09 vs. .59).

These subjective-report data were fit using an extended version of the capture model, referred to as the attribution threshold (AT) model (Figure 7.2). For this model, being captured by a prime was assumed to result in a high-confidence ("remember" or "familiar") response, as does recollection. In contrast, responding on the basis of accessibility bias was assumed to result in a "remember" or "familiar" response only when an attribution "threshold" is exceeded; otherwise, the participant would "guess." This model was able to closely fit the subjective-report data with only two parameters differing for the young and older adults. First, as in the model used to fit the recall data, older adults had a higher capture parameter than the younger adults. Second, the older adults also had a higher AT parameter than the younger adults, indicating a more lenient criterion for saying that their responses were "remembered" or "familiar".

The subjective-report results suggest that, relative to the young, older adults have deficits in monitoring the source and appropriateness of their responses. In a follow-up experiment, Jacoby et al. (2005) showed that they are also more willing than the young to *act* on their subjective experience even when not forced to do so. That is, we compared the performance of young and older adults in the same "I told you . . ." paradigm described above, but under conditions of free versus forced responding (Koriat & Goldsmith, 1994). For the free-responding condition, participants were instructed to not guess. The results replicated many of the findings reported in the previous experiment; older adults were more likely to falsely recall an invalid prime than were young adults when recall was forced. Most interesting, however, was the reduction in false recall that was achieved when participants were allowed to withhold responses. That is, when given the option to pass (free-responding condition), young participants were more likely to do so in the invalid prime condition than were older participants (.28 vs. .11). By not responding, younger adults greatly reduced their probability of falsely recalling invalid primes as compared to when responding was forced (.28 vs. .48). For the older adults, in contrast, false recall of invalid primes was nearly identical in the free- and forced-responding conditions (.59 vs. .62), a finding that agrees with the previous results showing that older adults are much more likely to falsely "remember" invalid primes. Also consistent with the subjective-report results, we were able fit the young and older adults' free- and forced-response data with our attribution threshold model (Figure 7.2) by assuming that "guesses" were equivalent to passes and "remember/familiar" (R/F) judgments were equivalent to emitted responses.

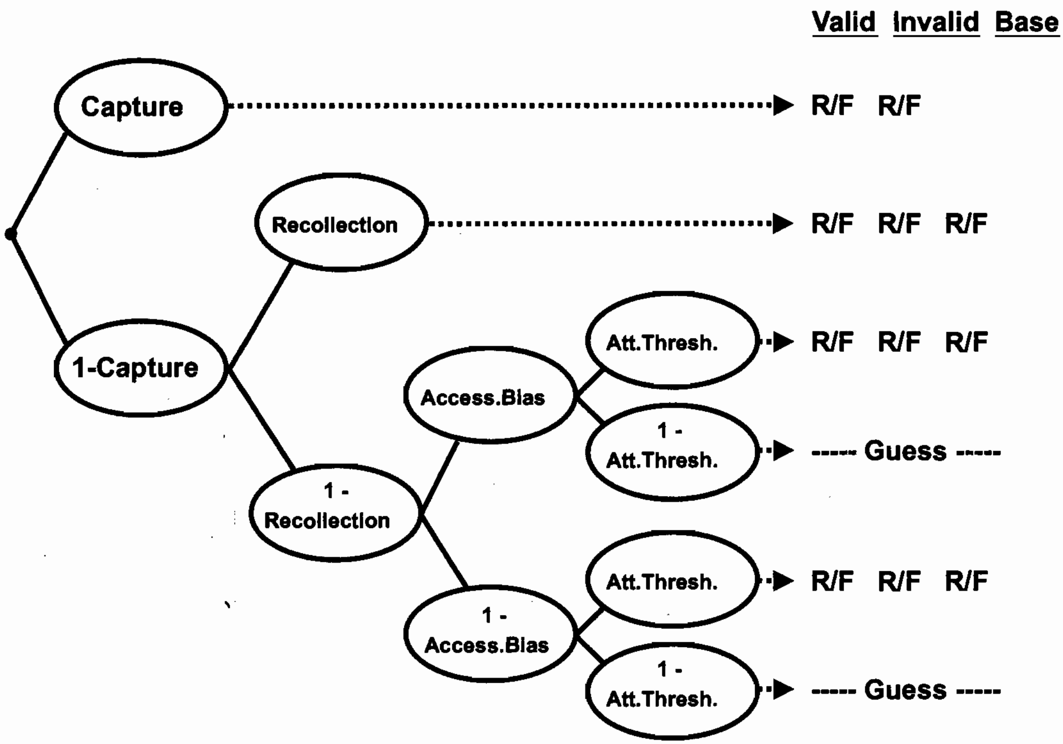

FIGURE 7.2. The Attribution Threshold model (cf. Figure 1B). Branches lead to subjective reports of "Remember" or "Familiar" ("R/F") or "Guess."

The above results thus give reason for worry that older adults are indeed more susceptible to "I told you . . ." scams than are younger adults. More relevant to the present chapter, the results showed older adults to have deficits in two distinct forms of executive control. First, they were more likely to be captured by the prime, suggesting an attentional deficit in maintaining the goal of recollecting studied words. Second, they showed deficits in the ability to monitor the accuracy of their responses. It is worth noting that a third control process—conscious recollection—was also operating in this task. Although older adults generally exhibit deficits in recollection (see PI task above), differential study rates were used in the "I told you . . ." experiments to equate young and older adults on this process. Overall, then, the successful fit of the attribution threshold model suggests that three distinct executive control processes were operating *within the same task* and that appropriate characterization of age-related changes in executive processes requires reference to all three.

PD Estimates as Individual Difference Measures of Executive Control

So far, we have argued that a process-based approach, exemplified by the PD procedure, may hold advantages over task-based approaches for defining and measuring executive functions. However, our case would be stronger if it could be shown that process estimates derived from the procedure are correlated with measures of higher-order cognition, such as fluid intelligence (*gF*) and metacognitive monitoring. This section describes studies relevant to this issue.

An early study by Jennings and Hay (1994, cited in Jacoby et al., 1996) showed that process estimates can be used to predict the frequency of people's everyday memory errors. They examined the relationship between estimates of controlled and automatic processes obtained from a standard recognition task and responses on a questionnaire of everyday memory complaints (Broadbent, Cooper, FitzGerald, & Parkes, 1982; Reason, 1993). The correlation between overall recognition performance and the questionnaire measure was only moderate ($r = .33$). By contrast, memory complaints correlated highly with the estimate of recollection derived from recognition performance ($r = .56$) while the correlation with automatic estimates was near zero ($r = .08$). Thus, isolating control processes afforded greater predictive power.

In a more recent study, Daniels (2003) used the PD procedure to compare estimates of controlled and automatic influences in PI and Stroop tasks as a function of working-memory capacity as indexed by span measures. Most notably in the present context, she found that estimates from both tasks correlated significantly with Raven's Progressive Matrices, a measure of fluid intelligence. That is, recollection estimates were positively related to Raven's (r's of .52 to .67) while word-reading estimates were negatively related to Raven's (r's of -.35 to -.39) as would be expected if word-reading estimates provided an index of inhibitory efficiency. These findings support the notion that PD parameters can provide a valid index of executive control. Indeed, the recollection-based correlations were as large as those produced by the span measures.

Predictive relations between process estimates and measures of cognitive control have also been found in the context of prejudice research. Payne (2001, 2003) used the PD procedure to derive estimates of cognitive control and stereotype accessibility for two tasks. The first was a weapon-identification task where subjects were asked to identify pictures as either guns or tools after being primed with a picture of a black or white face. The second was an evaluative-flanker task that required participants to classify words (e.g., *wonderful, terrific, nasty, horrible*) as either positive or negative when presented simultaneously with a black or white face. Payne found that the control estimates from these tasks correlated significantly with performance on a common measure of attentional control, the antisaccade task (r's were .35 and .19, respectively).

Finally, Salthouse, Toth, Hancock, and Woodard (1997) examined relations between estimates of control and automaticity derived from a cued-recall task and a spatial Stroop task, and performance on a wide range of additional tasks both executive and non-executive. They found good reliability for all of the process estimates (> .75), thus confirming that such estimates can be used as individual difference measures. Most notably, however, almost all of the experimental tasks and the control estimates loaded reliably on a common factor that was negatively related to age. In contrast, automatic estimates from the two tasks showed no (cued recall) or slightly negative (spatial Stroop) loadings on the common factor. We take these results as showing the plausibility of using process estimates in multivariate statistical analyses. They also indicate the need for additional research, examining the relation among process estimates, task-based measures of executive control, and age.

IMPLICATIONS FOR THE EARLY DEVELOPMENT OF EXECUTIVE FUNCTIONS

A major goal of the present volume is to encourage greater theoretical cross-talk between researchers studying development and those studying aging. Toward that end, this section describes some of the implications of our research for understanding the early development of executive functions.

One observation that stands out from sampling the developmental literature is that, as with much research with adults, research with children is predominantly task-centered (see Diamond, Chapter 6, this volume). A problem with tasks as the unit of analysis is that performance is often attributed to specific processes, based on qualitative or intuitive assessments of task demands. For example, as noted above, increased proactive interference (PI) as a function of old age or low working-memory capacity has often been attributed to an impairment in the ability to inhibit previously learned information (e.g., Hasher & Zacks, 1988; Engle & Kane, 2004). That explanation has intuitive appeal because (it is reasoned) if only the person could inhibit the previously learned, interfering information (e.g., the A-B pair), the individual would then be able to "get to" the sought-after target information (the A-C pair). An alternative, albeit less intuitive, possibility is that prior learning exerts little or no influence on a person's ability to recollect target information and thus does not need to be inhibited; yet, when recollection is unsuccessful (e.g., when target information is not well learned because of age or divided attention), prior learning will often be expressed because of its influence on accessibility bias (see Jacoby et al., 2001, 2004, experiment 1). The difference between these two explanations is important because recollection deficits and inhibitory deficits implicate distinct cognitive and neural mechanisms, and would likely lead to very different training or rehabilitative strategies.

And, indeed, research using process-dissociation and multinomial-modeling techniques indicates that recollection, rather than inhibition, may often be the primary source of increased PI in older adults (Jacoby et al., 2001) and those working with low working-memory capacity (Daniels, 2003).

Similar analyses may be applicable in the developmental literature. Consider, for example, theory-of-mind tasks that require child A to distinguish between a true state of affairs (e.g., where a recently moved object is currently hidden) and what child B believes (where the object was initially hidden when child B was last in the room). Diamond (Chapter 6, this volume) states that successful performance on such tasks requires "inhibiting the impulse to give the veridical answer" (p. 77). To the extent that there is an impulse to give veridical answers, this explanation may be essentially correct; veridical answers may sometimes capture a child's attention and thus need to be inhibited. An alternative possibility, however, is that success requires the spontaneous (unrequested) recollection of the initial location; when such recollection does not occur, the child simply responds with the most accessible answer (i.e., the object's current location). That is, analogous to PI in older adults and low-span participants, children's performance on theory-of-mind tasks may be akin to the processing structure represented in the RA model rather than the capture model (see Figure 7.1). Note that we are *not* claiming that children's failures on theory-of-mind tasks reflect deficits in recollection rather than inhibition; our point is simply that the two explanations are difficult to untangle at the task (success vs. failure) level.

An encouraging exception to the task-centered approach that typifies developmental research is a recent study by Zelazo, Craik, and Booth (2004; see also Anooshian, 1999). These researchers used the process-dissociation procedure, implemented in the form of a word-stem cued-recall task, to estimate cognitive control across the lifespan (8–10-year-olds vs. young adults vs. older adults). Zelazo and colleagues found that estimates of control (recollection) exhibited a highly symmetrical inverted-U shape across the three age groups while estimates of automatic influences (accessibility bias) were age invariant. Moreover, significant negative correlations were found between control estimates and perseverations on a card-sorting task that required the flexible use of two incompatible rules. In addition to its being generally consistent with the recollection account of theory-of-mind performance given above, we see this study as a good example of how formal process models can be used to better understand the "rise and fall" of cognitive control as a function of age. We believe that additional process-oriented studies, especially those directed at multiple forms of control (similar to the "I told you . . ." paradigm) have the potential to tell us a great deal about the development of executive functions.

Developmental studies may also be important, if not indispensable, in understanding the breakdown of executive functions with advancing age. If we are correct in asserting that many tasks require multiple control processes, then a critical issue that can be answered only with developmental research is whether these processes start off as distinct abilities or, instead, emerge out of a single, unified ability. Relevant here is research suggesting that many high-level cognitive abilities are initially undifferentiated in childhood, become more distinct or modular in adulthood, and are then reintegrated (dedifferentiated) during senescence (Li et al., 2004). This possibility raises a number of interesting questions about the developmental trajectory of cognitive control. For example, in what order do executive functions (control processes) become efficacious during development? And does the differentiation of one control process depend on the maturation of others (analogous to sensory systems)? Not only are these issues interesting from a developmental perspective, but they will also likely inform our understanding of age-related declines in cognitive control. That is, although there are certainly qualifications to the idea that old age entails a journey back to childhood (see, e.g., Li et al., 2004), knowing how executive functions initially develop will likely inform our thinking about their later decline in old age. We believe that a focus on processes, coupled with the use of formal process models, can help better integrate studies of development and senescence.

CONCLUSIONS: TOWARD A GREATER UNDERSTANDING OF EXECUTIVE FUNCTIONS AND AGE

Two general approaches have been used to study executive functions, their change with age, and their relation to other cognitive abilities such as general fluid intelligence: a microanalytic approach that employs the methods and goals of experimental psychology and that focuses on the processes operating *within* a task; and a macroanalytic approach that employs latent-factor techniques and that focuses on relations *across* tasks. A number of researchers have called for a greater integration of these two approaches for understanding executive control, a perspective that we fully endorse. At the same time, we believe that the results from our PD experiments suggest important qualifications for how that integration should proceed; and new directions for research on executive functions and their changes with age.

With respect to qualifications, most instructive are the results from the "I told you . . ." experiments. These experiments showed that older adults were more likely than the young to be captured by a prime, thus indicating an age-related deficit in inhibition or goal maintenance. Older adults also showed monitoring deficits both in their memory judgments (false "remember" responses) and in their actions (using the prime as a response even when given the opportunity to pass). Coupled with the success of the capture and attribution threshold models (which included a third control process of recollection), these findings suggest that multiple forms of executive control are required for successful performance in this paradigm.

We believe that the above conclusion is a very general one: that most complex tasks require multiple forms of control. The possibility that task performance can reflect multiple forms of control (multiple executive functions) has a number of important implications. First, it supports the idea that executive control can be fractionated into separable components. Second, it suggests caution in interpreting prior correlations among task-based measures of executive functions including "process-specific" measures of working memory, inhibition, and switching. Third, and perhaps most important, it illustrates the importance of using formal models to estimate relevant processes *prior to* the use of latent-variable techniques for determining how control processes contribute to different tasks.

With regard to future directions, we believe that PD estimates can be fruitfully used as individual-difference measures of executive functions. This is important because, although working-memory span tasks (for example) appear to provide a relatively clean index of executive control, few researchers would claim that such tasks are pure measures of such control. From our perspective, executive control processes are ubiquitous in task performance. Thus, the nature of such processes, their ability to predict performance, their relation to control processes in other tasks, and their change with maturation and advanced aging will require methods that can extract such processes across a variety of tasks, regardless of whether they were explicitly designed to engage working memory or executive processes. We believe that the PD procedure has the potential to provide such a method.

References

Albert, M. S., & Kaplan, E. (1980). Organic implications of neuropsychological deficits in the elderly. In L. W. Poon, J. L., Fozard, L. S. Cermak, D. Arenberg, & L. W. Thompson (Eds.), *New directions in memory and aging* (pp. 403–432). Hillsdale, NJ: Lawrence Erlbaum Associates.

Anooshian, L. J. (1999). Understanding age differences in memory: Disentangling conscious and unconscious processes. *International Journal of Behavioral Development*, 23, 1–17.

Boone, K. B., Miller, B. L., Lesser, I. M., Hill, E., & D'Elia, L. (1990). Performance on frontal tests in healthy, older individuals. *Developmental Neuropsychology*, 6, 215–223.

Braver, T. S., & Barch, D. M. (2002). A theory of cognitive control, aging cognition, and neuromodulation. *Neuroscience & Biobehavioral Reviews*, 26, 809–817.

Brink, J., & McDowd, J. (1999). Aging and selective attention: An issue of complexity or multiple mechanisms? *Journals of Gerontology: Psychological Sciences*, 54B, 30–33.

Broadbent, D. E., Cooper, P. F., FitzGerald, P., & Parkes, K. R. (1982). The Cognitive Failures Questionnaire (CFQ) and its correlates. *British Journal of Clinical Psychology*, 21, 1–16.

Burgess, P. W. (1997). Theory and methodology in executive function research. In P. Rabbitt (Ed.), *Methodology of frontal and executive functions* (pp. 81–116). Hove, UK: Psychology Press.

Burgess, P. W., Alderman, N., Evans, J., Emslie, H., & Wilson, B. A. (1998). The ecological validity of tests of executive function. *Journal of the International Neuropsychological Society*, 4, 547–558.

Cohn, N. B., Dustman, R. E., & Bradford, D. C. (1984). Age-related decrements in Stroop color-word test performance. *Journal of Clinical Psychology*, 40, 1244–1250.

Conway, A. R. A., Kane, M. J., & Engle, R. W. (2003). Working memory capacity and its relation to general intelligence. *Trends in Cognitive Sciences*, 7, 547–552.

Cronin-Golomb, A. (1990). Abstract thought in aging and age-related disease. In F. Boller & J. Grafman

(Eds.), *Handbook of neuropsychology* (Vol. 4, pp. 279–309). Amsterdam: Elsevier.

Damasio, A. (1998). The somatic marker hypothesis and the possible functions of the prefrontal cortex. In A. C. Roberts, T. W., Robbins, & L. Weiskrantz (Eds.), *The prefrontal cortex: Executive and cognitive functions* (pp. 36–50). London: Oxford University Press.

Daniels (2003). *Control, automaticity, and working memory: A dual-process analysis.* Manuscript submitted for publication.

De Jong, R. (2001). Adult age differences in goal activation and goal maintenance. *European Journal of Cognitive Psychology, 13,* 71–89.

Duncan, J., Johnson, R., Swales, M., & Freer, C. (1997). Frontal lobe deficits after head injury: Unity and diversity of function. *Cognitive Neuropsychology, 14,* 713–741.

Duncan, J., & Miller, E. K. (2002). Cognitive focus through adaptive neural coding in the primate prefrontal cortex. In D. T. Stuss & R. T. Knight (Eds.), *Principles of frontal lobe function* (pp. 278–291). London: Oxford University Press.

Dywan, J., Segalowitz, S. J., & Unsal, A. (1992). Speed of processing, health, and cognitive performance in older adults. *Developmental Neuropsychology, 8,* 473–490.

Engle, R. W., & Kane, M. J. (2004). Executive attention, working memory capacity, and a two-factor theory of cognitive control. *The psychology of learning and motivation* (Vol. 44, pp.145–199). Oxford: Academic Press.

Friedman, N. P., & Miyake, A. (2004). The relations among inhibition and interference control functions: A latent variable analysis. *Journal of Experimental Psychology: General, 133,* 101–135.

Fristoe, N., Salthouse, T. A., & Woodard, J. L. (1997). Examination of age-related deficits on the Wisconsin Card Sorting Test. *Neuropsychology, 11,* 428–436.

Fuster, J. (1989). *The prefrontal cortex: Anatomy, physiology, and neuropsychology of the frontal lobe* (2nd ed.). New York: Raven Press.

Garavan, H., Ross, T. J., Murphy, K., Roche, R. A. P., & Stein, E. A. (2002). Dissociable executive functions in the dynamic control of behavior: Inhibition, error detection, and correction. *NeuroImage, 17,* 1820–1829.

Gardiner, J. M., & Richardson-Klavehn, A. (2000). Remembering and knowing. In E. Tulving & F. I. M. Craik (Eds.), *The Oxford handbook of memory* (pp. 229–244). New York: Oxford University Press.

Goldstein, K. (1936). The significance of the frontal lobes to mental performance. *Journal of Neurology & Psychopathology, 17,* 27–40.

Hasher, L., & Zacks, R. T. (1988). Working memory, comprehension, and aging: A review and a new view. In G. H. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory* (Vol. 22, pp. 193–225). San Diego: Academic Press.

Hasher, L., Zacks, R. T., & May, C. P. (1999). Inhibitory control, circadian arousal, and age. In D. Gopher & A. Koriat (Eds.), *Attention and performance XVII* (pp. 653–675). Cambridge, MA: MIT Press.

Jackson, J. H. (1844). Croonian lectures on evolution and dissolution of the nervous system. *Lancet, 1,* 555–558, 649–652, 739–744.

Jacobsen, C. F., & Nissen, H. W. (1937). Studies of cerebral function in primates: IV. The effects of frontal lobe lesions on the delayed alternation habit in monkeys. *Journal of Comparative Psychology, 23,* 101–112.

Jacoby, L. L. (1991). A process dissociation framework: Separating automatic from intentional uses of memory. *Journal of Memory & Language, 30,* 513–541.

Jacoby, L. L. (1999). Deceiving the elderly: Effects of accessibility bias in cued-recall performance. *Cognitive Neuropsychology, 16,* 417–436.

Jacoby, L. L., Bishara, A. J., Hessels, S., & Toth, J. P. (2005). *Aging, subjective experience, and cognitive control: Dramatic false remembering by older adults. Journal of Experimental Psychology, 134,* 131–148.

Jacoby, L. L., Debner, J. A., & Hay, J. F. (2001). Proactive interference, accessibility bias, and process dissociations: Valid subjective reports of memory. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 27,* 686–700.

Jacoby, L. L., Jennings, J. M., & Hay, J. F. (1996). Dissociating automatic and consciously controlled processes: Implications for diagnosis and rehabilitation of memory deficits. In D. J. Hermann, C. McEvoy, C. Hertzog, P. Hertel, & M. K. Johnson (Eds.), *Basic and applied memory research: Theory in context* (Vol.1, pp. 161–190). Mahwah, NJ: Lawrence Erlbaum Associates.

Jacoby, L. L., McElree, B., & Trainham, T. N. (1999). Automatic influences as accessibility bias in memory and Stroop tasks: Toward a formal model. In D. Gopher & A. Koriat (Eds.), *Attention and performance XVII: Cognitive regulation of performance: Interaction of theory and application* (pp. 461–486). Cambridge, MA: MIT Press.

Jennings, J. M., & Jacoby, L. L. (1997). An opposition procedure for detecting age-related deficits in recollection: Telling effects of repetition. *Psychology and Aging, 12,* 352–361.

Kane, M. J., & Engle, R. W. (2000). Working memory capacity, proactive interference, and divided attention: Limits on long-term memory retrieval. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26*, 336–358.

Kane, M. J., & Engle, R. W. (2003). Working memory capacity and the control of attention: The contributions of goal neglect, response competition, and task set to Stroop interference. *Journal of Experimental Psychology: General, 132*, 47–70.

Karpel, M. E., Hoyer, W. J., & Toglia, M. P. (2001). Accuracy and qualities of real and suggested memories: Nonspecific age differences. *Journals of Gerontology: Psychological Science & Social Science, 56B*, 103–110.

Koriat, A., & Goldsmith, M. (1994). Memory in naturalistic and laboratory contexts: Distinguishing the accuracy-oriented and quantity-oriented approaches to memory assessment. *Journal of Experimental Psychology: General, 123*, 297–315.

Kramer, A. F, Humphrey, D. G., Larish, J. F., Logan, G. D., & Strayer, D. L. (1994). Aging and inhibition: Beyond a unitary view of inhibitory processing in attention. *Psychology and Aging*, 9, 491–512.

Lehto, J. (1996). Are executive function tests dependent on working memory capacity? *Quarterly Journal of Experimental Psychology*, 49A, 29–50.

Lhermitte, F. (1986). Human autonomy and the frontal lobes. Part II: Patient behavior in complex and social situations: The "environmental dependency syndrome". *Annals of Neurology, 19*, 335–343.

Li, S-C, Lindenberger, U., Hommel, B., Aschersleben, G., Prinz, W., & Baltes, P. B. (2004). Transformations in the couplings among intellectual abilities and constituent cognitive processes across the life span. *Psychological Science, 15*, 155–163.

Lindsay, D. S., & Jacoby, L. L. (1994). Stroop process dissociations: The relationship between facilitation and interference. *Journal of Experimental Psychology: Human Perception and Performance, 20*, 219–234.

Loftus, E. F. (1975). Leading questions and the eyewitness report. *Cognitive Psychology, 7*, 560–572.

Lowe, C., & Rabbitt, P. (1997). Cognitive models of aging and frontal lobe deficits. In P. Rabbitt (Ed.), *Methodology of frontal and executive functions* (pp. 39–59). Hove, UK: Psychology Press.

Luria, A. R. (1966/1980). *Higher cortical functions in man*. New York: Basic Books.

Lyon, G. R., & Krasnegor, N. A. (1996). *Attention, memory, and executive function*. Baltimore, MD: Brookes.

Macmillan, M. B. (1986). A wonderful journey through skull and brains: The travels of Mr. Gage's tamping iron. *Brain & Cognition, 5*, 67–107.

Mesulam, M.-M. (2002). The human frontal lobes: Transcending the default mode through contingent encoding. In D. T. Stuss & R. T. Knight (Eds.), *Principles of frontal lobe function* (pp. 8–30). London: Oxford University Press.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., & Howerter, A. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41*, 49–100.

Norman, D. A., & Shallice, T. (1986). Attention to action: Willed and automatic control of behavior. In R. J. Davidson, G. E. Schwartz, & D. Shapiro (Eds.), *Consciousness and self-regulation* (pp. 1–18). New York: Plenum Press.

Park, D. C. (2000). The basic mechanisms accounting for age-related decline in cognitive function. In D.C. Park & N. Schwarz (Eds.), *Cognitive aging: A primer* (pp. 3–21). Philadelphia: Psychology Press.

Parkin, A. J., & Java, R. I. (1999). Deterioration of frontal lobe function in normal aging: Influences of fluid intelligence versus perceptual speed. *Neuropsychology, 13*, 539–545.

Parkin, A. J., & Walter, B. M. (1992). Recollective experience, normal aging, and frontal dysfunction. *Psychology & Aging, 7*, 290–298.

Payne, B. K. (2001). Prejudice and perception: The role of automatic and controlled processes in misperceiving a weapon. *Journal of Personality and Social Psychology, 81*, 181–192.

Payne, B. K. (2003). *Cognitive control in automatic attitude measurement*. Unpublished doctoral dissertation, Washington University in St. Louis.

Pribram, K. H. (1973). The primate frontal cortex: Executive of the brain. In K. H. Pribram & A. R. Luria (Eds.), *Psychophysiology of the frontal lobes* (pp. 293–314). Oxford: Academic Press.

Prull, M. W., Gabrieli, J. D. E., & Bunge, S. A. (2000). Age-related changes in memory: A cognitive neuroscience perspective. In F. I. M. Craik & T. A. Salthouse (Eds.), *The handbook of aging and cognition* (pp. 91–153). Mahwah, NJ: Lawrence Erlbaum Associates.

Rabbitt, P. (1997). Introduction: Methodologies and models in the study of executive function. In P. Rabbitt (Ed.), *Methodology of frontal and executive functions* (pp. 1–38). Hove, UK: Psychology Press.

Rabbitt, P. (2002). Consciousness is slower than you think. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology*, 55A, 1081–1092.

Raz, N. (2000). Aging of the brain and its impact on cognitive performance: Integration of structural and functional findings. In F. I. M. Craik & T. A. Salthouse (Eds.), *The handbook of aging and cognition* (pp. 1–90). Mahwah, NJ: Lawrence Erlbaum Associates.

Reason, J. (1993). Self-report questionnaires in cognitive psychology: Have they delivered the goods? In A. D. Baddeley & L. Weiskrantz (Eds.), *Attention: Selection, awareness, and control: A tribute to Donald Broadbent* (pp. 406–423). Oxford: Clarendon Press.

Robbins, T. W., James, M., Owen, A. M., Sahakian, B. J., Lawrence, L. D., McInnes, L., & Rabbitt, P. M. A. (1998). A study of performance on tests from the CANTAB battery sensitive to frontal lobe dysfunction in a large sample of normal volunteers: Implications for theories of executive functioning and cognitive aging. *Journal of the International Neurological Society, 4*, 474–490.

Ronnlund, M., Lovden, M., & Nilsson, L.-G. (2001). Adult age differences in Tower of Hanoi performance: Influence from demographic and cognitive variables. *Aging, Neuropsychology, & Cognition, 8*, 269–283.

Rosen, V. M., & Engle, R. W. (1998). Working memory capacity and suppression. *Journal of Memory and Language, 39*, 418–436.

Salthouse, T. A., Atkinson, T. M., & Berish, D. E. (2003). Executive functioning as a potential mediator of age-related cognitive decline in normal adults. *Journal of Experimental Psychology: General, 132*, 566–594.

Salthouse, T. A., & Fristoe, N. (1995). Process analysis of adult age effects on a computer-administered trail-making test. *Neuropsychology*, 9, 518–528.

Salthouse, T. A., & Meinz, E. J. (1995). Aging, inhibition, working memory, and speed. *Journals of Gerontology: Psychological Sciences, 50B*, P297–P306.

Salthouse, T. A., Toth, J. P., Hancock, H. E., & Woodard, J. L. (1997). Controlled and automatic forms of memory and attention: Process purity and the uniqueness of age-related influences. *Journals of Gerontology: Psychological Sciences, 52B*, P216–P228.

Schmitter-Edgecombe, M. (1999). Effects of divided attention and time course on automatic and controlled components of memory in older adults. *Psychology and Aging, 14*, 331–345.

Shilling, V. M., Chetwynd, A., & Rabbitt, P. M. A. (2002). Individual inconsistency across measures of inhibition: An investigation of the construct validity of inhibition in older adults. *Neuropsychologia, 40*, 605–619.

Spieler, D. H., Balota, D. A., & Faust, M. E. (1996). Stroop performance in healthy younger and older adults and in individuals with dementia of the Alzheimer's type. *Journal of Experimental Psychology: Human Perception and Performance, 22*, 461–479.

Stuss, D. T., & Benson, D. F. (1986). *The frontal lobes.* New York: Raven Press.

Stuss, D. T., Gow, C. A., & Heatherington, C. R. (1992). "No longer Gage": Frontal lobe dysfunction and emotional changes. *Journal of Consulting and Clinical Psychology, 60*, 349–359.

Teuber, H. L. (1972). Unity and diversity of frontal lobe functions. *Acta Neurobiologiae Experimentalis, 32*, 615–656.

Toth, J. P. (1996). Conceptual automaticity in recognition memory: Levels-of-processing effects on familiarity. *Canadian Journal of Experimental Psychology – Special Issue: Implicit Memory Research in 1996, 50*, 123–138.

Tranel, D., Anderson, S. W., & Benton, A. (1994). Development of the concept of 'executive function' and its relationship to the frontal lobes. In F. Boller & J. Grafman (Eds.), *Handbook of neuropsychology* (Vol. 9, pp. 125–148). Amsterdam: Elsevier.

Verhaeghen, P., Cerella, J., Bopp, K. L., & Chandramallika, B. (in press). Aging and varieties of cognitive control: A review of meta-analyses on resistance to interference, coordination and task switching, and an experimental exploration of age-sensitivity in the newly identified process of focus switching. Chapter to appear in R.W. Engle, G. Sedek, U. von Hecker, & D.N. McIntosh (Eds.), *Cognitive limitations in aging and psychopathology: Attention, working memory, and executive functions.* Cambridge, UK: Cambridge University Press.

Verhaeghen, P., & De Meersman, L. (1998). Aging and the Stroop effect: A meta-analysis. *Psychology & Aging, 13*, 435–444.

Wecker, N. S., Kramer, J. H., Wisniewski, A., Delis, D. C., & Kaplan, E. (2000). Age effects on executive ability. *Neuropsychology, 14*, 409–414.

West, R. L. (1996). An application of prefrontal cortex function theory in cognitive aging. *Psychological Bulletin, 120*, 272–292.

Zacks, R. T., Hasher, L., & Li, K. Z. H. (2000). Human memory. In F. I. M. Craik & T. A. Salthouse (Eds.), *The handbook of aging and cognition* (2nd ed., pp. 293–358). Mahwah, NJ: Lawrence Erlbaum Associates.

Zelazo, P. D., Craik, F. I. M., & Booth, L. (2004). Executive functions across the life span. *Acta Psychologica, 115*, 167–183.