9 Executive Functioning as a Mediator of Age-Related Cognitive Decline in Adults

Dana Princiotta, Melissa DeVries, and Sam Goldstein

It is broadly accepted that even absent pathology, changes occur in cognitive functioning with advancing age. Decreased cognitive performance is noted among a variety of cognitive ability domains (Smith & Rush, 2006) and they are the result of age-related changes to brain structure and function. In this regard, the World Health Organization developed the term *aging-associated cognitive decline* which is defined as "(1) performance on a standardized cognitive test that is at least one standard deviation below age-adjusted norms in at least one of any of the following cognitive domains: learning and memory, attention and cognitive speed, language, or visuoconstructive abilities; (2) exclusion of any medical, psychiatric, or neurological disorder that could cause cognitive impairment; (3) normal activities of daily living and exclusion of dementia" (as cited in Levy, 1994).

Advancing age does not appear to impact all cognitive abilities equally, however. Certain cognitive abilities appear to be more affected than others; for example, significant declines have been reported in attention and memory (for review, see Glisky, 2007), general ability, and processing speed (Tucker-Drob, 2011) as a result of age-related processes. Though, the pattern does follow a somewhat linear trend, with increasing decline in very old age (e.g., Schaie, 2005). For example, the greatest declines have been noted past age 85 years (Baltes & Lindenberger, 1997), but the rate of decline varies dependent upon the cognitive domain and a number of other variables (Glisky, 2007). For this reason, it is useful to examine individual cognitive abilities and the interaction among groups of abilities thought to be closely related or those that interact with each other to have a mediating impact on performance. Overall it appears that tasks that are familiar and rely on existing knowledge are less impacted by advancing age as compared with tasks that involve the acquisition of new knowledge or novel problem solving (Zimprich et al., 2008).

Age-related changes in cognitive abilities also show substantial interindividual variability, although it has been suggested that individuals declining in one area are likely to be declining in other areas when compared to same age peers (Salthouse, 2004, 2009; Salthouse & Ferrer-Caja, 2003). One reason for individual differences could be *cognitive reserve* defined by Stern (2002) as the maximization of normal performance, as opposed to compensation for deficits, an efficient use of brain networks, or recruitment of alternative networks when needed to complete a task. This reserve may act as a protective factor against age-related cognitive decline. Corral, Rodriguez, Amenedo, Sanchez, and Diaz (2006) observed that individuals with higher cognitive

D. Princiotta • M. DeVries (✉) • S. Goldstein, Ph.D.
Neurology, Learning and Behavior Center, University of Utah School of Medicine, South 500 East, Suite 100 230, Salt Lake City, UT 84102, USA
e-mail: Melissa@samgoldstein.com; info@samgoldstein.com

S. Goldstein and J.A. Naglieri (eds.), *Handbook of Executive Functioning*,
DOI 10.1007/978-1-4614-8106-5_9,

reserve were 6 times less likely to demonstrate deficits on neuropsychological testing, which can begin to occur as early as the third to fourth decade of life.

One variable that confounds researchers' ability to study age-related cognitive change is that the abilities demonstrating the most significant decline (e.g., memory and general ability) are complex and may in fact be mediated by other factors, for example, processing speed, attention, or executive functioning. Minimal research has attempted to examine the amount of variance in age-related change that is accounted for by executive functioning, in particular, perhaps because of its elusiveness as an independent domain of cognitive functioning (Salthouse, 2005). As discussed in Chap. 1, there exist some 33 definitions of executive functioning and those tools purported to measure executive functioning, while significantly correlated with each other, do also correlate with other cognitive ability measures (Hedden & Yoon, 2006). It appears that many researchers agree that executive functioning has a mediating effect on several, if not all, other cognitive abilities. For example, Glisky (2007) proposed that executive processes involve planning, organizing, coordinating, implementing, and evaluating nonroutine activities and are particularly crucial to performance on novel tasks.

Existing Theories of Executive Functioning

Depending on your theoretical stance, the areas subsumed under the umbrella of executive functioning vary from researcher to researcher. You may recall from Chap. 1 that the definition included as many as 33 different components by the middle of the 1990s (Barkley, 2011).

The literature is thus inconclusive regarding the operational definition of executive functioning. Salthouse and colleagues indicated that EF should be conceptualized as a single construct and that there is a statistical association between executive functioning and age-related effects on measures of cognitive functioning (Salthouse, Atkinson, & Berish, 2003). EF may be a metaconstruct. Executive functions are not independent, but interactive and probably hierarchically organized in development (BDEFS Manual, p. 14, 2011).

The heterogeneity of executive functioning is as evident from its multiple definitions as it is from the number of diverse measures purported to assess it. Salthouse (2005) examined a variety of executive functioning measures in comparison with other nonexecutive cognitive ability measures and observed that executive functioning was closely related to reasoning and processing speed and that age-related influence of executive functioning was rarely statistically independent of age-related influence on the other cognitive abilities measures, suggesting that executive functioning is not an independent construct.

Our Working Definition of Executive Functioning

In alliance with Salthouse and colleagues, with varying views and definitions of executive functioning thus presented, modified, and altered over the last 3 decades, we are attempting to define executive functioning as efficiency. Congruent with the executive decline hypothesis, our proposed working definition of executive functioning focuses on a single entity premise rather than multiple factors and can be considered a mediator of other cognitive functions; executive functioning is the efficiency with which an individual applies his or her ability and knowledge in order to deal with everyday life.

Why Have a Chapter on Aging in a Book About Executive Functioning?

Revolving around this single construct, we could hypothesize that executive functioning, or efficiency, would demonstrate a relationship with aging as the other previous constructs presently had. Efficiency may represent the parsimoni ous explanation, replacing the overwhelmingly diverse group of previously proposed definitions. Summarizing the existent literature on age-related changes in executive functioning could prove useful not only in informing aging research but also in better defining and understanding executive functioning. Thus, our main goal of exploration in this chapter is to review what is known about age-related cognitive decline across a number of areas of functioning including executive functioning. Facet(s) of executive functioning typically emerges after 5 years of age, notably for working memory, shifting, and planning (e.g., Best, Miller, & Jones, 2009). Much less research exists to document when these abilities begin to decline.

The outline of the chapter will be guided by a review of cognitive changes in the brain with age and a discussion of the literature that exists to explore changes specifically occurring in executive functioning with age, a discussion that would be incomplete without attention paid to the physical changes in the brain over time.

Brief Review of Physical Changes in the Brain Related to Executive Functioning (EF)

Although a plethora of research exists outlining the physical changes that occur in the human body over the life span, less is known about the brain and executive functioning, namely. Magnetic resonance imaging (MRI) and other neuroanatomical studies have, however, documented that the brain undergoes approximately a 50 % volume loss as a result of normal aging (Brickman, Habeck, Zarahn, Flynn, & Stern, 2007; DeCarli et al., 2005; Good et al., 2001; Resnick, Pham, Kraut, Zonderman, & Davatzikos, 2003), with accelerated change occurring after 50 years of age (DeCarli et al., 2005). Some specific noted changes include damage to white matter (often predicted by hypertension) or infarcts (Buckner, 2005). For example, white matter lesions have been found to correlate highly with memory deficits (Buckner, 2005); in fact, they are proposed to account for all age-related variance in speed and executive processing (Rabbitt et al., 2007). Reductions in myelination have also been significantly correlated with cognitive processing speed (Lu et al., 2011). The prefrontal cortex (PFC), cerebellum, and basal ganglia are the most common areas associated with executive functioning (Salthouse et al., 2003).

The PFC, specifically, has been cited as controlling these executive processes (see Chap. 1 for review). Neuroimaging of changes in frontal lobe structures has buttressed demonstrated declines in performance for neuropsychological tasks measuring executive functioning (Daniels, Toth, & Jacoby, 2006). Individuals diagnosed with Alzheimer's disease as well as individuals within the confines of "normal brain aging" are both "predisposed" to PFC impairment (Royall et al., 2004). Some researchers claim, "these findings reveal the cellular basis of age-related cognitive decline in dorsolateral PFC" (Wang et al., 2011).

Even without physical damage, the PFC has been found to be especially vulnerable to the aging process. The PFC is one of the first areas of the brain to demonstrate the results of degeneration (Ferrer-Caja, Crawford, & Bryan, 2002), showing a loss of function and volume (Raz, 2000). This degeneration has been identified as the cause of much age-related cognitive decline and has been coined the *frontal hypothesis of aging* (Andres & van der Linden, 2001; Crawford, Bryan, Luszcz, Obonsawin, & Stewart, 2000; Raz, 2000; Souchay, Isingrini, & Espagnet, 2000). Schretlen et al. (2000) evaluated whether age-related changes in fluid intelligence were related to declines in processing speed, the adverse impact of atrophy of frontal lobe structures on executive functioning abilities, or some combination of these two theories. Their data supported that declines in processing speed and changes in executive abilities, as supported by MRI data demonstrating declines in frontal lobe volume, accounted for 75 % of the variance in declining fluid abilities. PFC deficits progress over time, even in the absence of an abnormal mini mental status examination (Royall et al., 2004).

Recalling the case of Phineas Gage from Chap. 1, the destruction of much of Mr. Gage's PFC leads to behavioral/personality changes. Bekhterev (1905) reported that damage to the frontal lobes would result in a disruption of goal-directed behavior (Barkley, 2011). Along these lines, PFC impairment was added by the American Psychiatric Association to its working definition of dementia in 1994 (Royall et al., 2004). In summary, changes are evident in the "normal" aging brain with regard to physical structure. These include a loss of total volume, most often due to reduction in myelination of neurons. It has been proposed that when this occurs in the PFC, cerebellum, and basal ganglia, changes are observed in executive functioning.

A Brief Review of Changes that Occur in Cognitive Functioning as a Result of Normal Aging

Intelligence. Kaufman (2001) noted that verbal comprehension remains relatively stable in adulthood until the eighth decade, whereas perceptual reasoning peaks earlier in adulthood and declines steadily with age. Declines in full-scale intelligence with increasing age therefore are more likely due to slowed processing speed and reductions in perceptual reasoning because verbal comprehension and working memory tend to be better preserved despite increasing age (Miller, Myers, Prinzi, & Mittenberg, 2009). Ribot's (1882) law (as cited in Miller et al., 2009) argued that this was because cognitive abilities learned earliest and those that are more rehearsed were more resistant to aging. Several other studies have supported the verbal versus performance difference in age-related cognitive decline. Ryan, Sattler, and Lopez (2000, see Ardila refs) noted that aged individuals demonstrated worse performance on tasks measuring processing speed and perceptual reasoning when compared to younger adults, but virtually no age-related changes were observed on tasks measuring verbal comprehension. Lee et al. (2005) proposed that perceptual reasoning declines occurred linearly from the sixth decade on and were most closely related to cerebellar atrophy.

Memory. Research suggests that age correlates inversely with measures of memory (i.e., increases in age yield lower memory scores at a certain point in the life span) (Crawford et al., 2000). The correlation between memory decline and age has been proposed as either a single-factor model or a multiple-factor model. In the past decade, more emphasis has been directed to age-related decline in memory as it relates to declines in executive functioning (Crawford et al., 2000). Memory may be supported by attention as well as executive abilities. One theory is that tasks requiring more "mental effort" (e.g., working memory or free recall) will demonstrate age-related changes more so than activities requiring lower levels of mental effort (Connor, 2001).

Accelerated declines in memory and other cognitive functions are often associated with Alzheimer's disease. Under Dementia of the Alzheimer's Type in the DSM-IV-TR, memory impairment subsumes "the impaired ability to learn new information or to recall previously learned information" (APA, 2000). Alzheimer's disease may represent the acceleration of typical progressive memory loss related to aging or it may be a separate entity (Buckner, 2005). Through research with patients with Alzheimer's disease, the conceptualization of *cognitive reserve* suggests that certain factors like educational level or premorbid intelligence may result in decreased decline with age. Some factors are amenable to "retraining" to a degree, with cognitive training and better nutrition recommended as methods to decrease intellectual decline (Gunstad et al., 2006).

Although knowledge of pathology may direct understanding of the "atypical" population, what does this typical progressive memory loss look like in the "normal" population? In an effort to better comprehend the acceleration of memory loss, understanding the "typical" rate of memory loss is integral in discussing age-related functioning (Buckner, 2005).

Regarding different facets of memory, memory for content fairs much better than memory for context (Connor, 2001). Aging negatively affects memory retrieval more so than encoding or storage (Connor, 2001). However, data suggests that long-term retrieval demonstrates less developmental change than other cognitive abilities

(McGrew & Woodcock, 2001). Some memory abilities demonstrate peaks within the life span with declines thereafter; short-term memory peaks at approximately 25–30 (McGrew & Woodcock, 2001).

Popular neuropsychological measures of executive functioning (e.g., Modified Card Sorting Test, the Stroop Test, and the Tower of London Test) suggest that speed of processing declines with age (Crawford et al., 2000). In older individuals the trend for preserved performance with highly practiced skills (e.g., semantic and autobiographical information) (Buckner, 2005) is recognized. However, memory for newly acquired facts or recall of recent autobiographical experiences is more likely to be impaired.

In Gunstad and colleagues' work with adults with memory deficits, three clusters were discovered: a group with poor executive function, persons with reduced speed performance (attention, executive function, motor), and those with global cognitive decline (Gunstad et al., 2006). More notably, diminished executive functioning was noted compared to younger adults. In other words, memory deficits were never isolated, even in healthy subjects; rather they were mediated by other factors (Gunstad et al., 2006). In this particular study, researchers insisted that age-related memory impairment is not part of healthy aging (Gunstad et al., 2006). These results are somewhat consistent with the work of Naveh-Benjamin, Craik, Guez, and Kreuger (2005) who demonstrated that older adults did not demonstrate significant declines in memory performance so long as they could rely on semantic knowledge. Those adults who did appear to have declining memory performance were utilizing increased attentional resources at encoding and retrieval stages and were therefore likely using less effective strategies for memorization.

Working Memory. Working memory is the temporary holding of information in order to carry out a mental task (Huizinga, Dolan, & van der Molen, 2006). Working memory allows for the manipulation of information that is immediately available. According to Huizinga et al. (2006), working memory is still developing into young adulthood. More specifically an "adult level" of working memory is not readily established prior to 12 years of age (Huizinga et al., 2006). In their study, working memory was the strongest predictor of performance on the Wisconsin Card Sorting Task for youth 7–21 years of age, compared with inhibition and shifting (Huizinga et al., 2006). Goral (2004) supported these claims in establishing that working memory tasks demonstrate age-related differences with the exception of short-term memory.

Supported by declines in executive functioning, Wang et al. (2011) reported a marked loss of PFC in monkeys with age, specifically a decline in the firing rate of specific memory-related neurons. These memory-related neurons were purported to be associated with aging. It is unknown if these changes with normal aging alter the physiological substance of the PFC or not, although some research would suggest this is the case. Charlton et al. (2008) noted that reduced white matter integrity was correlated with age-related declines in working memory, although indirectly, as changes in working memory were mediated by reduced processing speed efficiency.

Self-Regulation/Attention. Attention abilities mediate all other cognitive domains, perhaps except for those tasks that are habitual or automatic. Therefore, one could assume that age-related declines in attention could significantly impact the functioning of older adults across a variety of domains (Glisky, 2007). Like other cognitive domains, however, all subcomponents of attention processes do not appear to be uniformly affected by normal cognitive aging. Glisky noted that older adults demonstrated the most significant impairments on attention tasks requiring switching or divided attention or flexibility of attention. Older adults were not differentially affected by distractibility although on the whole they were slower than younger adults on tasks measuring selective attention. Older adults also appeared generally similar to young adults on tasks measuring sustained attention or vigilance. Hartman and Stratton-Salib (2007) also noted that older adults struggled with selective attention under conditions where there were many stimulus items to choose from, which adversely affected their performance on tasks measuring concept formation. Thus, attention may serve as a mediating factor in age-related change among more complex ability areas such as concept formation and decision-making in healthy older adults (Isella et al., 2008).

Processing Speed. Processing speed declines with advanced age (Smith & Rush, 2006) and a plethora of research has demonstrated that age-related changes in processing speed are the catalyst for age-related changes in other cognitive domains (Finkel & Pedersen, 2000; Hertzog & Bleckley, 2001; Keys & White, 2000; Parkin & Java, 2000; Zimprich, 2002). The biological basis for processing speed changes is likely a reduction in myelination in areas such as the PFC and genu of the corpus callosum (Lu et al., 2011; Posthuma et al., 2003).

Ghisletta and Lindenberger (2003) noted that the influence of processing speed on changes in knowledge with increasing age was stronger than the influence of knowledge on changes in processing speed over time. Finkel, Reynolds, McArdle, and Pedersen (2007) indicated that declines in processing speed were responsible for changes in memory and spatial ability, but not verbal abilities. Lemke and Zimprich (2005) also noted that speed changes accounted for a portion of the variance in memory changes with age but cautioned that their data suggested no single-factor theory should be used to explain cognitive changes with age. Others have further challenged the notion that processing speed accounts for such a large portion of cognitive aging on the premise that processing speed itself was not clearly defined and measures of processing speed may, in fact, tap other abilities such as fluid reasoning (Parkin & Java, 1999).

Along these lines, Zimprich and Martin (2002) explored the relationship between speed of processing and fluid reasoning in 417 adults aged approximately 62 years at baseline. Adults were tested over a 4-year period. The results of this study indicated that changes in processing speed and fluid reasoning were correlated at .53 over the 4-year period and shared only 28 % common variance. Tucker-Drob, Johnson, and Jones (2009) measured reasoning and speed abilities in individuals ages 65–89 to evaluate the *cognitive reserve hypothesis*; that individuals higher in experiential resources would exhibit higher levels of cognitive function later in life due to either (a) these resources playing a protective role against age-related declines or (b) the persistence of high functioning present in earlier life. They demonstrated that individuals demonstrating higher levels of cognitive functioning later in life were merely reflecting earlier life differences (their cognitive abilities were higher to begin with) rather than differences in rates of age-related decline. The findings of Deary, Johnson, and Starr (2010) further supported this claim by noting that individual differences in processing speed evident at age 70 years were consistent with individual differences present at age 11 and thus processing speed was not a statistically strong biomarker of age-related cognitive change. Genetic factors that impact cognitive abilities at older ages are the same factors impacting processing speed at younger ages. A combination of these factors and environmental influences is the likely cause of individual variation in later adulthood (Finkel, Reynolds, McArdel, Hamagami, & Pedersen, 2009). It has been suggested that at least 50 % of the variance in later life cognitive ability is accounted for childhood cognitive ability (Gow et al., 2011).

Although it appears that processing speed may be an important mediator of cognitive functioning in childhood, it may not be the case that this relationship remains stable throughout development and aging. Nettelbeck and Burns (2010) examined cognitive performance in children and adults of increasing age to see if the aging process and cognitive changes associated with that were a mirror opposite of the increases in cognitive functioning associated with development through younger to older childhood. They found that for children, increasing processing speed positively impacted working memory, which allowed for greater reasoning abilities. However, the reverse was not the case for aging adults. In that case, adults over 55 years of age demonstrated declining reasoning abilities as a result of slower processing speed, but also changes in working memory that appeared to be independent of processing speed.

To summarize the findings related to the impact of processing speed on cognitive decline among other cognitive abilities, Salthouse (1996) coined the term *processing speed hypothesis*. This idea was developed to explain a common etiology for various cognitive declines noted with advancing age. Salthouse (1996) based this idea on a noted trend in the literature whereby several cross-sectional studies, after statistically controlling for simple processing speed, demonstrated reduced significance of changes among other cognitive variables as a result of increasing age.

To further evaluate this phenomenon, Salthouse (1996) conducted a longitudinal study examining the cognitive performance of 303 participants, with a mean age of 77.2 years, over a 3-year period. The results were indicative of significant declines in episodic memory, verbal fluency, verbal comprehension, vocabulary, memory span, and attention. Examining the data from the point of cross-sectional age effects, Salthouse noted that individual differences in processing speed accounted for a large portion of the variance among changes in other cognitive domains. However, within-person longitudinal effects revealed that while processing speed was still noted to play a role in age-related change, it accounted for a far smaller portion of the variance in age-related cognitive change thus suggesting that cross-sectional data likely ovserestimates the role of processing speed as a major factor in age-related cognitive decline.

Visual-Spatial Ability. Jenkins, Myerson, Joerding, and Hale (2000) evaluated differences between younger and older adults on tasks of visually based processing speed, working memory, and paired associates learning versus verbally based processing speed, working memory, and paired associates learning tasks. Their results indicated that older adults' performance was worse than that of younger adults across all tasks, but the greatest decrements in performance were noted on visually based tasks, suggesting that verbal performance is less compromised with age. These results are consistent with other research demonstrating the resistance of verbal abilities (versus visual/performance abilities) to age-related changes (Miller et al., 2009; Ryan et al., 2000).

Language. Language is purported to be affected by age, though the problem appears to be related more to search and retrieval rather than linguistic information (Goral, 2004). More specifically, of the verbal abilities, word finding and spelling appear to demonstrate the greatest age-related declines (Burke & MacKay, 1997). Difficulties are noted for lexical retrieval during word production and comprehension of complex materials (Goral, 2004). Goral demonstrated this by comparing individuals of different age brackets (30s, 40s, 50s, 60s, and 70s). Findings suggested age was a significant predictor of overall scores on the Norton Naming Tasks and the Action Naming Tests (Goral, 2004). The steepest drop in scores was observed in individuals 70 and above, though decline can be observed as early as 50 years of age (Goral, 2004). Supporting this finding, Barresi et al. (2000) investigated impaired lexical access (defined as failure to name before and after cues were given) and semantic degradation (defined here as early successful naming with later failures), both explanations for age-related declines in naming. Adults in their 70s demonstrated more difficulty with semantic degradation for object naming than other age brackets (Barresi et al., 2000).

Analyses of speech have demonstrated declines in later life in grammatical complexity, attributed to working memory decline (Kemper, Thompson, & Marquis, 2001). Vocabulary and syntax remain intact across the life span of adults. Similarly, Barresi et al. (2000) proposed that vocabulary definitions remain stable over the life span while naming pictures begins to decline after age 30 (Barresi et al., 2000). Education (e.g., professional language use, professional reading, and reduced television viewing) and age both influence naming ability (Barresi et al., 2000). The question is why some language and memory factors are more vulnerable to aging than others (Burke & MacKay, 1997). Difficulties arise for researchers and clinicians through the span of the human life in attempting to understand abilities that are preserved versus impaired and the typical patterns that emerge (Burke & MacKay, 1997).

Achievement. In 2004, Grissom demonstrated a negative relationship between academic achievement and age that remains constant over time

(Duncan, Brooks-Gunn, & Klebanov, 1994; Walker, Greenwood, Hart, & Carta, 1994). Achievement is predicted in neuropsychology by measured executive skills. The Woodcock-Johnson tests provide further insight into the developmental trajectories that occur over the life span in terms of cognitive functioning and achievement. The norming sample of both the Woodcock–Johnson Tests of Cognitive Abilities and Tests of Achievement includes data for individuals aged 2–90 (Mather & Woodcock, 2001). Subtests for both measures demonstrate growth and decline across the life span (McGrew & Woodcock, 2001). Divergent growth curves suggest unique abilities have different developmental trajectories over the life span (McGrew & Woodcock, 2001).

To name a few, both cognitive and academic fluency clusters seem to follow different developmental trajectories; cognitive fluency demonstrates less growth overall than academic fluency (McGrew & Woodcock, 2001). In contrast, the change noted from age 5 to 90 for comprehension-knowledge suggests a different story, with greater change observed (McGrew & Woodcock, 2001). In terms of academic achievement, reading and writing abilities are increasing during formal schooling (ages 5–18) and do not demonstrate a dramatic decline with age. The Oral Expression cluster does not peak until age 50–60 (McGrew & Woodcock, 2001). Single-word reading/decoding, or phonics abilities, is highly correlated with overall cognitive functioning but is also relatively insensitive to aging and early dementias (McGurn et al., 2004).

What Does the Current Literature Tell Us About What Happens to Executive Functioning with Age?

It is known that many conditions involve difficulties with executive functioning: autism spectrum disorders, attention deficit-hyperactivity disorder, conduct disorder, oppositional defiant disorder, obsessive-compulsive disorder, depression, and anxiety. Developmental issues at each point in the life span can be better addressed with an understanding of executive functioning from young childhood to late adulthood (Best et al., 2009). Often times, the research that explains executive functioning is primarily aimed towards school age children and discussions surrounding attention deficits. While this may better explain the prevalence rates for ADHD among school age children, in more recent years, the importance of examining executive functioning across the life span has become a focus, not only in this chapter (e.g., Best et al., 2009). For example, older adults do not perform as well as their younger counterparts for tasks measuring executive functioning (e.g., Wisconsin Card Sorting Task, Trails B, Tower of London tasks, and Stroop tasks) (Daniels et al., 2006). In the 1980s, Hasher and Zacks suggested that decreased performance in older adults was the outcome of inefficient inhibition, thus increasing the effort necessary to concentrate and avoid distraction (Goral, 2004).

In the past, working memory, attention, and inhibition have been linked to playing major roles in cognitive aging (Salthouse et al., 2003). On one side of the argument, a general reduction in resources for cognitive processing has been proposed as a viable explanation rather than the view that declines exist for *specific* components of executive functioning. One hypothesis explaining the foundation for *general cognitive slowing* explains that deficiencies may rest within impaired processing ability (see earlier discussion of processing speed). This view that coined a *general reduction hypothesis* has been supported by many researchers during the past 30 years (e.g., Daigneault & Braun, 1993; Daigneault, Braun, & Whitaker, 1992; Mittenberg, Seidenberg, O'Leary, & DiGiulio, 1989; Crawford et al., 2000), and so too may processing speed mitigate changes in executive abilities. Stewart, Scarisbrick, and Golden (2011, August) noted that executive functioning increases with age, while processing speed shows age-related declines and noted that processing speed may mediate the relationship between age-related changes in executive functioning. "Problematic, however, is the possibility that performance on executive tasks may be determined by more than one executive process" (Daniels et al., 2006).

Beginning in middle adulthood to expiration, executive functioning, memory, and attention begin to decline (Gunstad et al., 2006). As early as the mid-twenties, deterioration may occur in the "biological framework of thinking and reasoning" (Gunstad et al., 2006). Crawford et al. (2000) investigated the *executive decline hypothesis of cognitive aging*. They conducted two studies with adults aged 18–75 years and 60–89 years, respectively, to examine whether aging was associated with changes in executive functioning independent of performance changes in other cognitive domains. Although the studies were cross-sectional in nature, which have been criticized as resulting in overly robust findings (see discussion of processing speed above), Crawford and colleagues noted that there was no apparent differential decline in executive functioning as compared with measures of general cognitive ability (as measured by the WAIS-R; Wechsler, 1981). Although executive functioning was linked to age-related declines in measures of memory, processing speed appeared to be the mediating variable. Furthermore, executive functioning and general cognitive ability accounted for similar amounts of variance in age-related memory declines, with executive functioning making only a small unique contribution.

In summary, it appears that executive functioning, as it is currently measured (by tasks such as the Wisconsin Card Sorting Test and Tower of London Test), may demonstrate declines with age (Daniels et al., 2006), although it may only make a few independent contribution to changes in other cognitive functions as a result of normal aging (Crawford et al., 2000).

Implications

Earlier we discussed executive functioning, or *efficiency*, not only as a single entity but also as a mediator of other cognitive functions (i.e., the efficiency with which an individual applies his or her knowledge or ability to deal with everyday life). Given what we know about age-related changes in other areas of cognitive functioning, where might we posit that executive functioning is playing a role? Is it the case that true declines are observed in intelligence (specifically perceptual reasoning; Ryan et al., 2000), memory for context and retrieval of that contextual information more so than encoding or storage (Connor, 2001), working memory (Goral, 2004), selective and divided attention (Glisky, 2007; Hartman & Stratton-Salib, 2007), processing speed (Salthouse, 1996; Finkel & Pedersen, 2000; Hertzog & Bleckley, 2001; Keys & White, 2000; Parkin & Java, 2000; Zimprich, 2002), and language abilities, specifically naming (Barresi et al., 2000; Goral, 2004)? Or is it that executive functioning changes as the consequence of normal aging has reduced our capacity to utilize our innate abilities to effectively deal with everyday life, solve novel problems, and perform in alliance with our younger counterparts? Let us consider, for example, the work of Gunstad et al. (2006) who demonstrated that memory performance declines with age was mediated by others factors (one of which was executive functioning). Age-related changes in nonverbal reasoning (evident from research demonstrating reductions in perceptual reasoning on measures of intelligence; Ryan et al., 2000) could very well be the result of reduced *efficiency*, or executive functioning, in utilizing what we have to solve these problems, whereas tasks that are more knowledge based (tasks measuring verbal reasoning) remain more stable over time. The research we have reviewed overall appears to generally support that much of our knowledge remains intact over time, but our abilities are altered for the worse. We utilize innate abilities to acquire knowledge and we coordinate these two areas, via executive functioning, to solve everyday problems and perform higher order tasks. Once this performance becomes more habitual, or overlearned, our abilities are not as necessary for performance, and the tasks become more knowledge based. Thus, we could propose that the role of executive functioning, as we have defined it, is only necessary for tasks that are newly learned and that therefore, declines in executive functioning with age would result in difficulty performing tasks that are newly learned or still required the integration of knowledge and abilities, which is consistent with some of the existing literature (e.g., Buckner, 2005; Naveh-Benjamin et al., 2005).

Despite all of this, the database of literature examining age-related changes in executive functioning is still very much in its infancy and is clearly not without its own limitations.

Limitations to Current Knowledge

Virtually the same factors that limit the study of executive functioning as an independent construct also limit our ability to understand the impact of age-related change. The number of variables proposed (Salthouse, 2005) to be subsumed under the heading of executive functioning is astounding and creates a substantial deficit in the existing literature because so many of these variables have gone unexplored as they relate to normal aging. Additionally, the measurement of executive functioning is elusive because of the correlation that exists between these measures and those tapping other cognitive abilities (Hedden & Yoon, 2006; Salthouse et al., 2003; Salthouse, 2005).

Summary and Conclusions

A multitude of research studies support that cognitive functioning does not remain stable over time and that a number of declines are observed in light of advancing age, particularly in older adulthood. This research also supports the notion that different domains of functioning decline at varying rates and acquisition of new knowledge and novel problem solving appear to decline at faster rates than existing knowledge (Zimprich et al., 2008). If this were true, it would be congruent with our proposed definition of executive functioning, the efficiency with which we utilize our knowledge and abilities to deal with everyday life. This may be a more simplistic yet more sensible way to define and understand executive functioning and its impact on other cognitive abilities, which we use to acquire new knowledge as opposed to the vast number of other definitions that have been proposed. Studies of biological changes correlated with age-related decline have demonstrated volume loss in the brain due to reduced myelination. The brain areas in which this occurs most often have been proposed as those responsible for controlling executive functioning. However, as previously discussed, the concept of executive functioning and the tools suggested to measure it are poorly defined and in some ways based in circular logic. Any definition proposed in the future, including our own, will need to be subjected to rigorous research demonstrating its convergent and divergent validity (Salthouse et al., 2003).

References

American Psychiatric Association. (2000). *Diagnostic and statistical manual of mental disorders* (4th ed., text rev.). Washington, DC: American Psychiatric Association.

Andres, P., & van der Linden, M. (2001). Age-related differences in supervisory attentional system functions. *Journal of Gerontology: Psychological Science, 55B*, P373–P380.

Ardila, A. (2007). Normal aging increases cognitive heterogeneity: Analysis of dispersion in WAIS-III scores across age. *Archives of Clinical Neuropsychology, 22,* 1003–1011.

Baltes, P. B., & Lindenberger, U. (1997). Emergence of a powerful connection between sensory and cognitive functions across the adult life span: A new window to the study of cognitive aging? *Psychology and Aging, 12*, 12–21.

Barkley, R. A. (2011). *Barkley deficits in executive functioning scale (BDEFS)*. New York, NY: Guilford Press.

Barresi, B. A., Nicholas, M., Connor, L. T., Obler, L. K., & Albert, M. L. (2000). Semantic degradation and lexical access in age-related naming failures. *Aging, Neuropsychology, and Cognition, 7*(3), 169–178.

Bekhterev, V. M. (1905). Fundamentals of brain function (7 vols.). St. Petersburg.

Best, J. R., Miller, P. H., & Jones, L. L. (2009). Executive functions after age 5: Changes and correlates. *Developmental Review, 29*(3), 180–200.

Brickman, A. M., Habeck, C., Zarahn, E., Flynn, J., & Stern, Y. (2007). Structural MRI covariance patterns associated with normal aging and neuropsychological functioning. *Neurobiology of Aging, 28*, 284–295.

Buckner, R. L. (2005). Memory and executive function review in aging and AD: Multiple factors that cause decline and reserve factors that compensate. *Neuron, 44*, 195–208.

Burke, D. M., & MacKay, D. G. (1997). Memory, language, and aging. *Philosophical Transactions of the Royall Society, Biological Sciences, 352*, 1845–1856.

Charlton, R. A., Landau, S., Shiavone, F., Barrick, T. R., Clark, C. A., Markus, H. S., et al. (2008). A structural equation modeling investigation of age-related variance in executive function and DTI measured white matter change. *Neurobiology of Aging, 29*, 1547–1555.

Connor, L. T. (2001). Memory in old age: Patterns of decline and preservation. *Seminars in Speech and Language, 22*, 117–125.

Corral, M., Rodriguez, M., Amenedo, E., Sanchez, J. L., & Diaz, F. (2006). Cognitive reserve, age, and neuropsychological performance in healthy participants. *Developmental Neuropsychology, 29*, 479–491.

Crawford, J. R., Bryan, J., Luszcz, M. A., Obonsawin, M. C., & Stewart, L. (2000). The executive decline hypothesis of cognitive aging: Do executive deficits qualify as differential deficits and do they mediate age-related memory decline? *Aging, Neuropsychology, and Cognition, 7*, 9–31.

Daigneault, S., Braun, C. M. J., & Whitaker, H. A. (1992). Early effects of normal aging on perseverative and non-perseverative prefrontal measures. *Developmental Neuropsychology, 8*, 99–114.

Daigneault, S., & Braun, C. M. J. (1993). Working memory and the self-ordered pointing task: Further evidence of early prefrontal decline in normal aging. *Journal of Clinical and Experimental Neuropsychology, 15*, 881–895.

Daniels, K. A., Toth, J. P., & Jacoby, L. L. (2006). The aging of executive functions. In E. Bialystok & F. I. M. Craik (Eds.), *Lifespan cognition: Mechanisms of change* (pp. 96–111). New York: Oxford University Press.

Deary, I. J., Johnson, W., & Starr, J. M. (2010). Are processing speed tasks biomarkers of cognitive aging. *Psychology and Aging, 1*, 219–228.

DeCarli, C., Massaro, J., Harvey, D., Hald, J., Tullberg, M., Auf, R., et al. (2005). Measures of brain morphology and infarction in the Framingham Heart Study: Establishing what is normal. *Neurobiology of Aging, 26*, 491–510.

Duncan, G. J., Brooks-Gunn, J., & Klebanov, P. K. (1994). Economic deprivation and early-childhood development. *Child Development, 65*, 296–318.

Ferrer-Caja, E., Crawford, J. R., & Bryan, J. (2002). A structural modeling examination of the executive decline hypothesis of cognitive aging through reanalysis of Crawford et al.'s (2000) data. *Aging, Neuropsychology, and Cognition, 9*, 231–249.

Finkel, D., & Pedersen, N. L. (2000). Contribution of age, genes, and environment to the relationship between perceptual speed and cognitive ability. *Psychology and Aging, 15*, 56–64.

Finkel, D., Reynolds, C. A., McArdel, J. J., Hamagami, F., & Pedersen, N. L. (2009). Genetic variance in processing speed drives variation in aging of spatial and memory abilities. *Developmental Psychology, 45*, 820–834.

Finkel, D., Reynolds, C. A., McArdle, J. J., & Pedersen, N. L. (2007). Age changes in processing speed as a leading indicator of cognitive aging. *Psychology and Aging, 22*, 558–568.

Ghisletta, P., & Lindenberger, U. (2003). Age-based structural dynamics between perceptual speed and knowledge in the Berlin Aging Study: Direct evidence for ability dedifferentiation in old age. *Psychology and Aging, 18*, 696–713.

Glisky, E. L. (2007). Changes in cognitive function in human aging. In D. R. Riddle (Ed.), *Brain aging: Models, methods, mechanisms* (pp. 1–15). Boca Raton, FL: CRC Press. Retrieved July 30, 2009, from http://www.ncbi.nlm.nih.gov/bookshelf/br.fcgi?book=frbrainage&part=ch1

Good, C. D., Johnsrude, I. S., Ashburner, J., Henson, R. N., Friston, K. J., & Frackowiak, R. S. (2001). A voxel-based morphometric study of ageing in 465 normal adult human brains. *NeuroImage, 14*, 21–36.

Goral, M. (2004). First-language decline in healthy aging: Implications for attrition in bilingualism. *Journal of Neurolinguistics, 17*(1), 31–52.

Gow, A. J., Johnson, W., Pattie, A., Brett, C. E., Robersts, B., Starr, J. M., et al. (2011). Stability and change in intelligence from age 11 to ages 70, 79, and 87: The Lothian birth cohorts of 1921 and 1936. *Psychology and Aging, 26*, 232–240.

Gunstad, J., Paul, R. H., Brickman, A. M., Cohen, R. A., Arns, M., Roe, D., et al. (2006). Patterns of cognitive performance in middle-aged and older adults: A cluster analytic examination. *Journal of Geriatric Psychiatry and Neurology, 19*, 59–64.

Hartman, M., & Stratton-Salib, B. C. (2007). Age differences in concept formation. *Journal of Clinical and Experimental Neuropsychology, 29*, 198–214.

Hedden, T., & Yoon, C. (2006). Individual differences in executive processing predict susceptibility to interference in verbal working memory. *Neuropsychology, 20*, 511–528.

Hertzog, C., & Bleckley, M. K. (2001). Age differences in the structure of intelligence: *Influences of information processing speed. Intelligence, 29*(3), 191–217.

Huizinga, M., Dolan, C. V., & van der Molen, M. W. (2006). Age-related change in executive function: Developmental trends and a latent variable analysis. *Neuropsychologia, 44*(11), 2017–2036.

Isella, V., Mapelli, C., Morielli, N., Pelati, O., Franceschi, M., & Appollonio, I. M. (2008). Age-related quantitative and qualitative changes in decision making ability. *Behavioural Neuropsychology, 19*, 59–63.

Jenkins, L., Myerson, J., Joerding, J. A., & Hale, S. (2000). Converging evidence that visuospatial cognition is more age-sensitive than verbal cognition. *Psychology and Aging, 15*, 157–175.

Kaufman, A. S. (2001). WAIS-III Iqs, Horn's theory and generational changes from young adulthood to old age. *Intelligence, 29*, 131–167.

Kemper, S., Thompson, M., & Marquis, J. (2001). Longitudinal change in language production: Effects of aging and dementia on grammatical complexity and propositional content. *Psychology and Aging, 16*, 600–614.

Keys, B. A., & White, D. A. (2000). Exploring the relationship between age, executive abilities, and psychomotor speed. *Journal of the International Neuropsychological Society, 6*, 76–82.

Lee, J. Y., Lyoo, I. K., Kim, S. U., Jang, H. S., Lee, D. W., Jeon, H. J., et al. (2005). Intellect declines in healthy elderly subjects and cerebellum. *Psychiatry and Clinical Neurosciences, 59*, 45–51.

Lemke, U., & Zimprich, D. (2005). Longitudinal changes in memory performance and processing speed in old age. *Aging, Neuropsychology, and Cognition, 12*, 57–77.

Levy, R. (1994). Aging-associated cognitive decline. *International Psychogeriatrics, 6*, 63–68.

Lu, P. H., Lee, G. J., Raven, E. P., Tingus, K., Khoo, T., Thompson, P. M., et al. (2011). Age-related slowing in cognitive processing speed is associated with myelin integrity in a very healthy elderly sample. *Journal of Clinical and Experimental Neuropsychology, 33*(10), 1059–1068.

Mather, N., & Woodcock, R. W. (2001). *Examiner's manual. Woodcock-Johnson III tests of achievement*. Itasca, IL: Riverside Publishing.

McGrew, K. S., & Woodcock, R. W. (2001). *Technical Manual. Woodcock-Johnson III*. Itasca, IL: Riverside Publishing.

McGurn, B., Starr, J. M., Topfer, J. A., Pattie, A., Whiteman, M. C., Lemmon, H. A., et al. (2004). Pronunciation of irregular words is preserved in dementia, validating premorbid IQ estimation. *Neurology, 62*, 1184–1186.

Miller, L. J., Myers, A., Prinzi, L., & Mittenberg, W. (2009). Changes in intellectual functioning associated with normal aging. *Archives of Clinical Neuropsychology, 24*, 681–688.

Mittenberg, W., Seidenberg, M., O'Leary, D., & DiGiulio, D. (1989). Changes in cerebral functioning associated with normal aging. *Journal of Clinical and Experimental Neuropsychology, 11*, 918–932.

Naveh-Benjamin, M., Craik, F. I. M., Guez, J., & Kreuger, S. (2005). Divided attention in younger and older adults: Effects of strategy and relatedness on memory performance and secondary task costs. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 31*, 520–537.

Nettelbeck, T., & Burns, N. R. (2010). Processing speed, working memory and reasoning ability from childhood to old age. *Personality and Individual Differences, 48*, 379–384.

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

Parkin, A. J., & Java, R. I. (2000). Determinants of age-related memory loss. In T. J. Perfect & E. A. Maylor (Eds.), Models of cognitive aging (pp. 188–203). Oxford, UK: Oxford University Press.

Posthuma, D., Baaré, W. F. C., Pol, H. E. H., Kahn, R. S., Boomsma, D. I., & de Geus, E. J. C. (2003). Genetic correlations between brain volumes and the WAIS-III dimensions of verbal comprehension, working memory, perceptual organization, and processing speed. *Twin Research, 6*, 131–139.

Rabbitt, P., Scott, M., Lunn, M., Thacker, N., Lowe, C., Pendleton, N., et al. (2007). White matter lesions account for all age-related declines in speed but not intelligence. *Neuropsychology, 21*, 363–370.

Raz, N. (2000). Aging of the brain and its impact on cognitive performance: Integration of structural and behavioural findings. In F. I. M. Craik & T. Salthouse (Eds.), *Handbook of aging and cognition* (2nd ed., pp. 1–90). Mahwah, NJ: Erlbaum.

Resnick, S. M., Pham, D. L., Kraut, M. A., Zonderman, A. B., & Davatzikos, C. (2003). Longitudinal magnetic resonance imaging studies of older adults: A shrinking brain. *Journal of Neuroscience, 23*, 3295–3301.

Ribot, T. (1882). Diseases of memory. New York: Appleton-Century-Crofts.

Royall, D. R., Palmer, R., Chiodo, L. K., & Polk, M. J. (2004). Declining executive control in normal aging predicts change in functional status: the Freedom House Study. *Journal of the American Geriatrics Society, 52*(3), 346–352.

Ryan, J. J., Sattler, J., & Lopez, S. J. (2000). Age effects on Wechsler adult intelligence scale-III subtests. *Archives of Clinical Neuropsychology, 15*, 311–317.

Salthouse, T. A. (1996). The processing-speed theory of adult age differences in cognition. *Psychological Review, 103*, 403–428.

Salthouse, T. A. (2004). Localizing age-related individual differences in a hierarchical structure. *Intelligence, 32*, 541–561.

Salthouse, T. A. (2005). Relations between cognitive abilities and measures of executive functioning. *Neuropsychology, 19*, 532–545.

Salthouse, T. A. (2009). When does age-related cognitive decline begin? *Neurobiology of Aging, 30*, 507–514.

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, 132*(4), 566–594.

Salthouse, T. A., & Ferrer-Caja, E. (2003). What needs to be explained to account for age-related effects on multiple cognitive variables? *Psychology and Aging, 18*, 91–110.

Schaie, K. W. (2005). What can we learn from longitudinal studies of adult development? *Research in Human Development, 2*, 133–158.

Schretlen, D., Pearlson, G. D., Anthony, J. C., Aylward, E. H., Augustine, A. M., Davis, A., et al. (2000). Elucidating the contributions of processing speed, executive ability, and frontal lobe volume to normal age-related differences in fluid intelligence. *Journal of the International Neuropsychological Society, 6*, 52–61.

Smith, G., & Rush, B. K. (2006). Normal aging and mild cognitive impairment. In D. K. Attix & K. A. Welsh-Bohmer (Eds.), *Geriatric neuropsychology: Assessment and intervention* (pp. 27–55). New York: Guilford Press.

Souchay, C., Isingrini, M., & Espagnet, L. (2000). Aging, episodic memory feeling-of-knowing, and frontal functioning. *Neuropsychology, 14*, 299–309.

Stern, Y. (2002). What is cognitive reserve? Theory and research application of the reserve concept. *Journal of the International Neuropsychological Society, 8*, 448–460.

Stewart, J., Scarisbrick, D., & Golden, C. J. (2011). *Mediating role of processing speed on age-related declines in executive functioning*. Presented at Annual Conference of the American Psychological Association (August, 2011), Washington, DC.

Tucker-Drob, E. M. (2011). Global and domain-specific changes in cognition throughout adulthood. *Developmental Psychology, 47*, 331–343.

Tucker-Drob, E. M., Johnson, K. E., & Jones, R. N. (2009). The cognitive reserve hypothesis: A longitudinal examination of age-associated declines in reasoning and processing speed. *Developmental Psychology, 45*, 431–446.

Walker, D., Greenwood, C., Hart, B., & Carta, J. (1994). Prediction of school outcomes based on early language production and socioeconomic factors. *Child Development, 65*, 606–621.

Wang, M., Gamo, N. J., Jin, L. E., Wang, X. J., Laubach, M., Mazer, J. A., et al. (2011). Neuronal basis of age-related working memory decline. *Nature, 476*, 210–213.

Wechsler, D. (1981). *Wechsler adult intelligence scale-revised*. San Antonio, TX: Psychological Corporation.

Zimprich, D. (2002). Cross-sectionally and longitudinally balanced effects of processing speed on intellectual abilities. *Experimental Aging Research, 28*, 231–251.

Zimprich, D., & Martin, M. (2002). Can longitudinal changes in processing speed explain longitudinal age change in fluid intelligence? *Psychology and Aging, 17*, 690–695.

Zimprich, D., Martin, M., Kliegel, M., Dellenback, M., Rast, P., & Zeintl, M. (2008). Cognitive abilities in old age: Results from the Zurich longitudinal study on cognitive aging. *Swiss Journal of Psychology, 67*, 177–195.