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Exploring the relationship between age, executive abilities, and psychomotor speed

BETH A. KEYS AND DESIRÉE A. WHITE
Department of Psychology, Washington University, St. Louis, Missouri

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Abstract

Age-related declines in executive abilities have been widely reported and are thought to result from neuropathological changes in the prefrontal cortex. Some investigators have suggested that age-related changes in cognition may be the result of slowed information processing speed rather than declines in specific cognitive abilities. We examined the relationships among age, executive abilities, and psychomotor speed in 40 older adults and 46 young adults. Both verbal and nonverbal tasks were administered that measured 2 aspects of executive ability: set formation and set shifting. Executive and psychomotor speed tasks were paired based on similarities in basic task demands. Our results revealed that poorer executive performance was associated with increasing age. Further, although psychomotor speed attenuated the relationship, age accounted for a unique and significant proportion of variance in executive performance after controlling for psychomotor speed. These results suggest that age has an effect on prefrontally mediated executive abilities that cannot be explained solely in terms of psychomotor slowing. (*JINS*, 2000, *6*, 76–82.)

Keywords: Aging, Executive ability, Psychomotor speed, Prefrontal cortex

INTRODUCTION

Age-related declines in executive abilities have been widely reported (Brennan et al., 1997; Daigneault & Braun, 1993; Daigneault et al., 1992; Fisk & Warr, 1996). Whelihan and Lesher (1985) found that the neuropsychological profiles of young and older adults were best distinguished by examining performance on executive tasks. Similarly, Corey-Bloom et al. (1996) found that the neuropsychological profiles of older (65–84 years) and very old (greater than 84 years) adults could be distinguished almost exclusively by examining performance on executive tasks. Taken together, these results suggest that there may be a unique relationship between aging and changes in executive abilities.

It is likely that the diversity of structural and functional changes in the brain that occur with healthy aging result in concomitant changes in executive abilities (for a review, see West, 1996). Both reductions in brain volume and progressive tissue loss have been identified (Haug & Eggers, 1991; Ivy et al., 1992; Raz et al., 1997). More specifically, Haug and Eggers (1991) found that prefrontal and orbitofrontal areas undergo greater reductions in volume (43% and 25%, respectively) than parietal and occipital areas (11% and 13%, respectively). In addition, Ivy et al. (1992) cited evidence of marked neuronal atrophy with increasing age. This atrophic process results from dendritic loss and occurs most prominently in the frontal, temporal, and parietal lobes. Healthy aging has also been associated with synaptic loss (Liu et al., 1996) and decreases in dopamine transmission and synthesis (Goldman-Rakic & Brown, 1981). These synaptic alterations are most prominent in the prefrontal cortex.

Age-related alterations in brain function also occur. Shaw et al. (1984) analyzed patterns of cerebral blood flow and found reductions in oxygen utilization throughout the brain with increasing age. Using positron emission tomography, widespread decreases in glucose metabolism have also been identified (Petit-Taboue et al., 1998).

Although neuropathological alterations have been observed in a variety of brain regions, the bulk of evidence indicates that the prefrontal cortex is particularly susceptible to the effects of normal aging (Albert & Kaplan, 1980; Hochanadel & Kaplan, 1984; Raz et al., 1997; West, 1996).

Reprint requests to: Desirée A. White, Department of Psychology, Campus Box 1125, Washington University, St. Louis, MO 63130. E-mail: dawhite@artsci.wustl.edu

Results from numerous studies point to a link between frontal function and executive abilities (Fuster, 1997; Moscovitch & Winocur, 1995). Thus, it is not surprising that tasks measuring executive abilities are especially sensitive in detecting age-related changes in cognition.

There is a growing literature defining the specific relationships among normal aging, prefrontal dysfunction, and deficits in executive abilities. More specifically, a frontal lobe hypothesis of aging has been proposed (e.g., Dempster, 1992). For example, it has been suggested that deficits in executive abilities such as planning (Daigneault et al., 1992), abstract concept formation and reasoning (Daigneault et al., 1992; Isingrini & Vazou, 1997), and behavior regulation (Daigneault et al., 1992) occur with increasing age because of deteriorating prefrontal function. Perfect (1997) proposed that parallels exist in the neuropsychological profiles of older adults and patients with frontal dysfunction on the basis of similarities in neuropathology.

Some researchers, however, have suggested that age-related changes in cognitive performance are not the result of declines within specific cognitive domains, but instead are the result of general declines in information processing speed. Salthouse postulated that these speed-related deficits limit the efficiency and accuracy of performing tasks across a range of cognitive domains (for a review, see Salthouse, 1996). In addition, results from a number of studies suggest that the effects of general slowing are more pronounced as task complexity increases (Cerella, 1990; Cerella et al., 1980; Hale et al., 1991; Salthouse, 1995). These findings are particularly relevant to the present discussion because most executive tasks are relatively complex and require the orchestration of multiple cognitive processes (Bolla et al., 1990; Bryan et al., 1997). Thus, it is possible that age-related deficits are actually the result of general slowing rather than frank deficits in executive abilities.

The current study was designed to further explore the relationships among age, executive abilities, and psychomotor speed. Two aspects of executive ability, set formation and set shifting, were examined using verbal and nonverbal tasks. We examined the unique contribution of age to executive performance by controlling for the contribution of psychomotor speed. To achieve this objective, young and older adults were administered pairs of tasks with parallel psychomotor demands. The first task of a pair was less cognitively demanding and was used as a measure of psychomotor speed. The second task of a pair was similar in terms of psychomotor demands but was more demanding in terms of set formation or set shifting. Our overall goal was to determine if age is uniquely related to changes in executive abilities or if such changes simply reflect reductions in psychomotor speed.

Our specific hypotheses are as follow. First, we predicted that age would significantly correlate with performance on all executive and psychomotor speed tasks administered, and that the performance of older adults would be poorer than that of younger adults across all tasks. Second, we predicted that after controlling for psychomotor speed there would be a unique and significant relationship between age and various executive abilities. This would corroborate previous research suggesting that the relationship between age and executive abilities can be best understood in the context of a frontal lobe hypothesis, rather than solely in the context of a general slowing hypothesis.

METHODS

Research Participants

Executive and psychomotor abilities were evaluated in 86 right-handed individuals, 46 healthy young adults (39 women and 7 men) between 17 and 23 years of age ($M = 19.61$, $SD = 1.32$) and 40 healthy older adults (27 women and 13 men) between 56 and 82 years of age ($M = 72.15$, $SD = 6.17$). A chi-square comparison revealed no significant difference in the distributions of sex between young and older groups, [$\chi^2(1, N = 86) = 3.58$, $p = .06$]. Mean years of education were 13.21 ($SD = 1.11$) for the young group and 13.98 ($SD = 2.28$) for the older group. There was no significant difference between groups in terms of education ($p > .05$). All participants were members of the St. Louis community and were recruited from participant pools maintained by the Department of Psychology at Washington University. Older adults were screened for neurological illness and physical limitations via telephone; all were found to be in good health. Young adults earned course credit and older adults received $10 for taking part in the study.

Materials

The following battery of executive and psychomotor tasks was administered:

1. *Cognitive status screen*: To rule out the possibility of wide-ranging cognitive deficits that could be due to a neurological disorder (e.g., dementia), all participants were administered the Neurobehavioral Cognitive Status Examination (Northern California Neurobehavioral Group, 1995). Abilities assessed included level of consciousness, orientation, attention, language, constructional ability, memory, calculations, and reasoning. All participants performed within normal limits on this screening measure and no one was excluded on the basis of cognitive status.
2. *Depression screen*: Because depression may affect psychomotor speed (White et al., 1997), all participants were administered the 21-item Beck Depression Inventory (Beck et al., 1961). Young adults with scores greater than 10 and older adults with scores greater than 12 were excluded. The slightly higher exclusion score for older adults was used because older individuals tend to report more somatic complaints that are not necessarily related to depression. Seven young adults and 10 older adults

were excluded on this basis. Mean depression scores for the remaining 86 participants were 4.97 ($SD = 3.08$) for the older adults and 3.85 ($SD = 2.99$) for the young adults. There was no significant difference between groups in terms of depression scores ($p > .05$).

3. *Executive tasks*: As measures of verbal set formation, participants completed letter and category fluency tasks. Previous research has revealed age differences in category fluency but not in letter fluency (Crossley et al., 1997; Tomer & Levin, 1993). Both tasks were included in the current study to fully explore the contributions of age to performance on these widely used tasks. During the letter fluency task, participants were asked to generate words beginning with 'F', 'A', or 'S' as rapidly as possible (Borkowski et al., 1967). The number of novel words produced in 1 min was recorded for each letter. A composite letter fluency score was obtained that reflected the mean number of words produced per min across the three letters. During the category fluency task, participants were asked to rapidly generate animal names (Goodglass & Kaplan, 1972). The number of novel words produced in 1 min was recorded.

   As a measure of nonverbal set formation, participants completed a design fluency task adapted from Part I of the Ruff Figural Fluency Test (Ruff, 1985). Participants were presented with a page of 72 squares that each contained two vertical columns of four dots (a total of eight dots per square). They were instructed to produce a design in each square by connecting two or more dots as rapidly as possible. They were also instructed that the designs should be unnamable and as varied as possible. The number of novel designs produced in 1 min was recorded.

   As a measure of verbal set shifting, Trails B from the Trail Making Test was administered (U.S. Army, 1944). Participants were asked to connect an alternating and sequential series of numbers and letters as quickly as possible. A total of 25 stimuli appeared on a response page. The number of seconds to correctly connect all stimuli was recorded.

   As a measure of nonverbal set shifting, an experimental response inhibition task was administered. It should be noted that the paired psychomotor speed task was also administered as a component of this task. Participants were seated in front of a computer monitor and a row of three response buttons. Initially, participants observed a row of three unfilled circles on the monitor. To initiate each trial, participants pressed the center response button with their right hands, causing the center circle to fill with blue. Next, one of the target circles to the left or right filled with gray. In the psychomotor condition (*viz*., matching condition) participants were asked to depress the corresponding button to the left or right as quickly as possible. In the set shifting condition (*viz*., reversal condition), the response requirements were reversed; participants were asked to depress the left button when the right circle filled and to depress the right button when the left circle filled. To maximize set shifting demands, the matching and reversal conditions were blocked and alternated. Specifically, 10 matching trials were administered as a block, followed by 10 reversal trials. This alternating procedure continued for a total of 10 blocks. Reaction time (RT) and movement time (MT) were recorded for each trial. RT represented the time between appearance of a target and lifting the hand from the center button. MT represented the time between lifting the hand from the center button and pressing a peripheral button. RTs less than 100 ms or greater than 3000 ms were considered anticipatory errors and omission errors, respectively, and were excluded from analyses. In addition, RTs and MTs were used only from those trials on which an accurate response was made.

4. *Psychomotor speed tasks*: To account for psychomotor speed contributions to letter and category fluency, an articulation rate task was administered. Participants were asked to repeat a presented word as quickly as possible. One-, two-, and three-syllable words beginning with 'F' (*fire*, *flower*, *family*), 'A' (*arm*, *answer*, *apartment*), and 'S' (*sun*, *student*, *similar*) were presented. All words were defined as high frequency based on the Kucera and Francis corpus (1967). Using Sound Blaster 16 software (Creative Technology Limited, 1995), the time required for participants to complete 10 repetitions of each word was computed. A composite score was calculated that reflected the mean number of words articulated per min across all nine words.

To account for psychomotor speed contributions to design fluency, a line-drawing task was administered. Participants were presented with a page of 72 squares that each contained two dots. The dots were positioned to correspond to two of the eight dot positions used in the design fluency task. Participants were instructed to draw a line connecting the two dots in each square as quickly as possible. The number of seconds to complete the page was recorded. A transformation was made to reflect the number of lines produced in 1 min.

To account for psychomotor speed contributions to Trails B performance, Trails A from the Trail Making Test (U.S. Army, 1944) was administered. Participants were asked to connect a sequence of 25 numbers as quickly as possible. Because both numbers and letters are used in Trails B, we also asked participants to connect a second sequence comprised of 25 letters. Performances on Trails A and the letter sequencing task were significantly correlated ($r = .83$). A composite score (Trails A+) reflected the mean number of seconds to correctly connect all stimuli across both tasks.

As noted earlier, the matching condition of the response inhibition task was administered to account for psychomotor speed contributions to performance in the reversal condition of this task.

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Procedure

Study tasks were administered during a 1-hr session in the following order: Neurocognitive Status Examination, letter fluency, category fluency, articulation rate, design fluency, line drawing, Trails A+, Trails B, response inhibition, and the Beck Depression Inventory.

RESULTS

Means and standard deviations for the scores of both groups on our study tasks are shown in Table 1. The results of group comparisons and the correlations of each task with age are also presented. In general, the pattern of results suggests that increased age is associated with poorer executive performance and slower psychomotor speed. There were several exceptional results that warrant comment. The correlation between age and performance on one executive task (i.e., letter fluency) was not significant; this was, however, the anticipated result based on previous findings of age differences in category fluency but not letter fluency (Crossley et al., 1997; Tomer & Levin, 1993). The contribution of age to one psychomotor speed variable (i.e., matching MT) also failed to reach significance. This variable was retained for further analyses because, although not significantly correlated with age, it was not contrary to our predictions. In addition, although the contribution of age to articulation rate was significant, this was due to a faster articulation rate for the older group; this was contrary to our expectation based on current literature (Kynette et al., 1990; Ramig, 1983; Smith et al., 1987). Because age did not account for variance in psychomotor speed in the manner predicted by previous literature, we believed it was unwise to retain this variable for further analyses. Specifically, we did not evaluate the contribution of performance on this task to performance on parallel executive tasks (animal and letter fluency) because of the potential for introducing poorly understood variance into the model.

We next examined the amount of variance shared between the remaining pairs of parallel executive and psychomotor speed tasks (see Table 2, Column 3). All pairs of tasks shared a significant amount of variance. Hierarchical regression analyses were then used to examine the contribution of age to performance on each executive task after controlling for performance on the parallel psychomotor speed task. Scores from the psychomotor speed tasks were entered in the first step of each model; age was entered in the second step. The unique contribution of age to executive performance after controlling for psychomotor speed is shown in Column 5 of Table 2. Age accounted for a unique and significant proportion of variance in executive performance on all tasks. By comparing the r^2y2 values to the sr^2y2.1 values, it is evident that psychomotor speed substantially attenuated the contribution of age to executive performance. Nonetheless, age made a unique and significant contribution to executive performance beyond that accounted for by psychomotor speed.

We addressed two additional questions that were related to age differences between subgroups of older adults and the influence of participant sex on age differences in psychomotor speed. Previous research has questioned whether there are age differences in neuropsychological performance between adults under and over the age of 75 years (e.g., Corey-Bloom et al., 1996; Greenwood & Parasuraman, 1994; Howieson et al., 1993). Because our older adult participants ranged from 56 to 82 years of age, we separated this group into two subgroups, adults under age 75 and adults 75 years or older. We conducted a multivariate analysis of variance (MANOVA) to determine if there were significant differences between subgroups in performance

Table 1. Mean, standard deviation, and correlation with age for all study variables

	Young adults		Older adults		Group comparisons	Correlation with age
Variables	*M*	*SD*	*M*	*SD*	*t*	*r*
Executive						
Letter Fluency (words/min)	13.27	2.67	12.89	3.62	0.43	−.06
Category Fluency (words/min)	21.20	4.93	16.33	3.76	5.09*	−.49*
Design Fluency (designs/min)	13.46	4.28	9.68	3.58	4.41*	−.43*
Trails B (s)	47.04	16.66	80.94	26.17	7.04*	.64*
Reversal reaction time (ms)	367.42	57.01	605.38	148.29	9.55*	.74*
Reversal movement time (ms)	215.46	51.28	260.73	66.12	3.57*	.34*
Psychomotor speed						
Articulation rate (words/min)	115.34	27.14	127.92	20.70	2.38*	.29*
Line drawing (lines/min)	74.03	18.17	60.99	15.23	3.57*	−.36*
Trails A+ (s)	22.78	5.63	35.84	12.40	6.13*	.60*
Matching reaction time (ms)	331.61	39.46	482.54	183.41	5.10*	.49*
Matching movement time (ms)	210.80	56.08	222.01	54.90	0.93	.10

*$p < .01$.

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Table 2. Shared variance between executive performance and psychomotor speed (r^2y1), between executive performance and age (r^2y2), and between executive performance and age after controlling for psychomotor speed (sr^2y2.1)

			Age (2)	
Executive variables (*y*)	Psychomotor variables (1)	r^2y1	r^2y2	sr^2y2.1
Design Fluency	Line Drawing	.26*	.18*	.07*
Trails B	Trails A+	.67*	.41*	.03*
Reversal reaction time	Matching Reaction Time	.34*	.55*	.27*
Reversal movement time	Matching Movement Time	.67*	.12*	.06*

*$p < .01$.

on our executive and psychomotor speed tasks. The results of this analysis were not significant, indicating similar levels of performance across all experimental tasks for our subgroups of older adults.

We also addressed whether participant sex differentially affected executive and psychomotor speed performance between young and older groups. Some studies have suggested that women perform more slowly on psychomotor speed tasks than men, and that this relationship is more pronounced with advancing age (e.g., Mazaux et al., 1995). We conducted a MANOVA to determine if there was an interaction of Participant Sex × Group on our executive and psychomotor speed tasks. Results from this analysis were not significant, indicating that participant sex did not differentially affect executive or psychomotor speed performance between groups.

DISCUSSION

Increased age was associated with poorer performance on all of the expected executive tasks. Hierarchical regression analyses further revealed that the contribution of age to executive performance remained significant after controlling for the contribution of psychomotor speed. These results suggest that there is a unique relationship between executive abilities and the healthy aging process beyond that accounted for by psychomotor speed. This unique relationship was observed across two aspects of executive ability, set formation and set shifting, and across verbal and nonverbal tasks.

The unique contribution of age to executive performance varied considerably across tasks. There are several possible explanations for this finding. First, it is possible that some specific executive abilities are more susceptible to the effects of normal aging than others. West (1996) suggested that executive abilities vary from simple processes (e.g., maintaining commands on-line while performing tasks) to more complex processes (e.g., inhibiting prepotent responses or shifting between cognitive sets). Given the heterogeneity of executive abilities, it is not surprising that we observed differences in the degree to which age affected performance on different executive tasks.

Second, a related issue is that many researchers (e.g., Fuster, 1997) have conceptualized the prefrontal cortex as being comprised of functionally distinct subregions which in turn subserve different executive abilities. Evidence from nonhuman primate (Dias et al., 1996; Robbins, 1996) and functional neuroimaging studies in humans (e.g., D'Esposito et al., 1998) supports the notion of functional heterogeneity within the prefrontal cortex. For example, it has been suggested that the dorsolateral region subserves planning of behavior and temporal organization (Shimamura, 1994), whereas the orbital region subserves inhibitory control (Fuster, 1997). In our study, differences in the degree to which age affected performance on different executive tasks could be related to the fact that some subregions of the prefrontal cortex are more compromised by age than others.

Third, it is possible that differences in the contributions of age to performance on our different executive tasks occurred because, in some instances, our paired tasks shared variance that was related to factors other than psychomotor speed. If this were the case, controlling for psychomotor speed would disproportionately attenuate the relationship between age and executive performance. In future studies it may be helpful to use very simple reaction time tasks that parallel requirements on executive tasks, but that also have very minimal cognitive demands.

The majority of our results point to a significant relationship between age and executive ability that is independent of psychomotor speed. This was in spite of the fact that psychomotor speed attenuated the relationship between age and executive performance. These results are consistent with the view that speed factors contribute to age-related deficits in cognition (e.g., Cerella, 1990; Hale et al., 1991; Salthouse, 1985), but are inconsistent with the view that speed factors are the sole contributors to age-related deficits in cognition. It appears that age makes a unique contribution to changes in cognitive abilities (at least executive abilities) beyond that accounted for by general slowing. This supports previous reports demonstrating the efficacy of using executive tasks to detect age-related deficits that may be related to neuropathological changes in the prefrontal cortex (e.g., Brennan et al., 1997; Daigneault & Braun, 1993; Daigneault et al., 1992; Dempster, 1992; Fisk & Warr, 1996). In addition, these results suggest that age differences in executive abilities may be best understood in the context of a frontal lobe hypothesis of aging.

It is important to note that research on age differences in executive abilities is more than just a theoretically relevant issue. For example, measurements of executive abilities help to predict functional autonomy in older adults (Kaye et al., 1990). Grigsby et al. (1998) suggested that age-related deficits in executive abilities are associated with declines in functional living skills in healthy older adults. Willis et al. (1998) found that performance on executive tasks predicted the degree of functional independence reported by older adults with mild to moderate levels of dementia of the Alzheimer type (DAT). Studies such as these indicate that the integrity of executive abilities may have significant implications for the functional independence of older adults.

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REFERENCES

Albert, M. & 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. 403–429). Hillsdale, NJ: Lawrence Erlbaum Associates.

Beck, A.T., Ward, C.L., Mendelson, M., Mock, J., & Erbaugh, J. (1961). An inventory for measuring depression. *Archives of General Psychiatry*, *4*, 53–63.

Bolla, K.I., Lindgren, K.N., Bonaccorsy, C., & Bleecker, M.L. (1990). Predictors of verbal fluency (FAS) in the healthy elderly. *Journal of Clinical Psychology*, *46*, 623–628.

Borkowski, J.G., Benton, A.L., & Spreen, O. (1967). Word fluency and brain damage. *Neuropsychologia*, *5*, 135–140.

Brennan, M., Welsh, M.C., & Fisher, C.B. (1997). Aging and executive function skills: An examination of a community-dwelling older adult population. *Perceptual and Motor Skills*, *84*, 1187–1197.

Bryan, J., Luszca, M.A., & Crawford, J.R. (1997). Verbal knowledge and speed of information processing as mediators of age differences in verbal fluency performance among older adults. *Psychology and Aging*, *12*, 473–478.

Cerella, J. (1990). Aging and information processing rates in the elderly. In J.E. Birren & K.W. Schaie (Eds.), *Handbook of the psychology of aging* (3rd ed., pp. 201–221). New York: Academic Press.

Cerella, J., Poon, L.W., & Williams, D. (1980). Age and the complexity hypothesis. In L.W. Poon (Ed.), *Aging in the 1980s: Psychological issues* (pp. 332–340). Washington, DC: American Psychological Association.

Corey-Bloom, J., Wiederholt, W.C., Edelstein, S., Salmon, D.P., Cahn, D., & Barrett-Connor, E. (1996). Cognitive and functional status of the oldest old. *Journal of the American Geriatrics Society*, *44*, 671–674.

Crossley, M., D'Arcy, C., & Rawson, N.S.B. (1997). Letter and category fluency in community-dwelling Canadian seniors: A comparison of normal participants to those with Dementia of the Alzheimer or Vascular type. *Journal of Clinical and Experimental Neuropsychology*, *19*, 52–62.

Daigneault, S. & Braun, C.M. (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.

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

Dempster, F.N. (1992). The rise and fall of the inhibitory mechanism: Toward a unified theory of cognitive development and aging. *Developmental Review*, *12*, 45–75.

D'Esposito, M., Ballard, D., Aguirre, G.K., & Zarahn, E. (1998). Human prefrontal cortex is not specific for working memory: A functional MRI study. *Neuroimage*, *8*, 274–282.

Dias, R., Robbins, T.W., & Roberts, A.C. (1996). Dissociation in prefrontal cortex of affective and attentional shifts. *Nature*, *380*, 69–72.

Fisk, J.E. & Warr, P. (1996). Age and working memory: The role of perceptual speed, the central executive, and the phonological loop. *Psychology & Aging*, *11*, 316–323.

Fuster, J.M. (1997). *The prefrontal cortex: anatomy, physiology, and neuropsychology of the frontal lobe* (3rd ed.). Philadelphia: Lippincott-Raven.

Goldman-Rakic, P.S. & Brown, R.M. (1981). Regional changes of monoamines in cerebral cortex and subcortical structures of aging rhesus monkeys. *Neuroscience*, *6*, 177–187.

Goodglass, H. & Kaplan, E. (1972). *Assessment of aphasia and related disorders*. Philadelphia: Lea & Febiger.

Greenwood, P.M. & Parasuraman, R. (1994). Attentional disengagement deficit in nondemented elderly over 75 years of age. *Aging & Cognition*, *1*, 188–202.

Grigsby, J, Kaye, K., Baxter, J., Shetterly, S.M., & Hamman, R.F. (1998). Executive cognitive abilities and functional status among community-dwelling older persons in the San Luis Valley Health and Aging Study. *Journal of the American Geriatrics Society*, *46*, 590–596.

Hale, S., Lima, S.D., & Myerson, J. (1991). General cognitive slowing in the nonlexical domain: An experimental validation. *Psychology and Aging*, *6*, 512–521.

Haug, H. & Eggers, R. (1991). Morphometry of the human cortex cerebri and corpus striatum during aging. *Neurobiology of Aging*, *12*, 336–338.

Hochanadel, G.S. & Kaplan, E. (1984). Neuropsychology of normal aging. In M. Albert (Ed.), *Clinical neurology of aging* (pp. 231–244). New York: Oxford University Press.

Howieson, D.B., Holm, L.A., Kaye, J.A., Oken, B.S., & Howieson, J. (1993). Neurologic function in the optimally healthy oldest old: Neuropsychological evaluation. *Neurology*, *43*, 1882–1886.

Isingrini, M. & Vazou, F. (1997). Relation between fluid intelligence and frontal lobe functioning in older adults. *International Journal of Aging and Human Development*, *45*, 99–109.

Ivy, G.O., Mac Leod, C.M., Petit, T.L., & Markus, E.J. (1992). A physiological framework for perceptual and cognitive changes in aging. In F.M. Craik & T.A. Salthouse (Eds.), *Handbook of aging and cognition* (pp. 273–314). Hillsdale, NJ: Lawrence Erlbaum Associates.

Kaye, K., Grigsby, J., Robbins, L.J., & Korzun, B. (1990). Prediction of independent functioning and behavior problems in geriatric patients. *Journal of the American Geriatrics Society*, *38*, 1304–1310.

Kucera, H. & Francis, W. (1967). *Computational analysis of present-day American English*. Providence, RI: Brown University Press.

Kynette, D., Kemper, S., Norman, S., & Cheung, H.T. (1990). Adults' word recall and word repetition. *Experimental Aging Research*, *16*, 117–121.

Liu, X., Erikson, C., & Brun, A. (1996). Cortical synaptic changes and gliosis in normal aging, Alzheimer's disease, and frontal lobe degeneration. *Dementia*, *7*, 128–134.

Mazaux, J.M., Dartiques, J.F., Letenneur, L., Darriet, D., Wiart, L., Gagnon, M., Commenges, D., & Boller, F. (1995). Visuospatial attention and psychomotor performance in elderly community residents: Effects of age, gender, and education. *Journal of Clinical and Experimental Neuropsychology*, *17*, 71–81.

Moscovitch, M. & Winocur, G. (1995). Frontal lobes, memory, and aging. In J. Grafman, K. Holyoak & F. Boller (Eds.), *Annals of the New York Academy of Sciences* (Vol. 769, pp. 119–150). New York: New York Academy of Sciences.

Northern California Neurobehavioral Group. (1995). *Manual for Cognistat (The Neurobehavioral Cognitive Status Examination)*. Fairfax, CA: Northern California Neurobehavioral Group.

Perfect, T.J. (1997). Memory aging as frontal lobe dysfunction. In M.A. Conway (Ed.), *Cognitive models of memory* (pp. 315–339). Cambridge, MA: MIT Press.

Petit-Taboue, M.C., Landeau, B., Desson, J.I., Desgranges, B., & Baron, J.C. (1998). Effects of healthy aging on the regional cerebral metabolic rate of glucose assessed with statistical parametric mapping. *Neuroimage*, *7*, 176–184.

Ramig, L.A. (1983). Effects of physiological aging on speaking and reading rates. *Journal of Communication Disorders*, *16*, 217–226.

Raz, N., Gunning, F.M., Head, D., Dupuis, J.H., McQuain, J., Briggs, S.D., Loken, W.J., Thornton, A.E., & Acker, J.D. (1997). Selective aging of the human cerebral cortex observed in vivo: Differential vulnerability of the prefrontal gray matter. *Cerebral Cortex*, *7*, 268–282.

Robbins, T.W. (1996). Dissociating executive functions of the prefrontal cortex. *Philosophical Transactions of The Royal Society of London Series B Biological Sciences*, *351*, 1463–1471.

Ruff, R.M. (1985). *Ruff Figural Fluency Test*. Odessa, FL: Psychological Assessment Resources.

Salthouse, T.A. (1985). Speed of behavior and its implications for cognition. In J.E. Birren & K.W. Schaie (Eds.), *Handbook of the psychology of aging* (2nd ed., pp. 400–426). New York: Van Nostrand Reinhold.

Salthouse, T.A. (1995). Differential age-related influences on memory for verbal-symbolic information and visual-spatial information. *Journal of Gerontology: Psychological Sciences*, *50B*, 193–201.

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

Shaw, T.G., Mortel, K.F., Meyer, J.S., Rogers, R.L., Hardenberg, J., & Cutaia, M.M. (1984). Cerebral blood flow changes in benign aging and cerebrovascular disease. *Neurology*, *34*, 855–862.

Shimamura, A.P. (1995). Memory and frontal lobe function. In M. Gazzaniga (Ed.), *The cognitive neurosciences* (pp. 803–813). Cambridge, MA: MIT Press.

Soundblaster 16 (Version 1.0). [Computer software]. (1995). Singapore: Creative Technology Limited.

Smith, B.L., Wasowicz, J., & Preston, J. (1987). Temporal characteristics of the speech of normal elderly adults. *Journal of Speech & Hearing Research*, *30*, 522–529.

Tomer, R. & Levin, B.E. (1993). Differential effects of aging on two verbal fluency tasks. *Perceptual and Motor Skills*, *76*, 465–466.

U.S. Army. 1944. *Army Individual Test Battery manual of directions and scoring*. Washington, DC: War Department, Adjutant General's Office.

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

Whelihan, W.M. & Lesher, E.L. (1985). Neuropsychological changes in frontal functions with aging. *Developmental Neuropsychology*, *1*, 371–380.

White, D.A., Myerson, J., & Hale, S. (1997). How cognitive is psychomotor slowing in depression? Evidence from a meta-analysis. *Aging, Neuropsychology, and Cognition*, *4*, 166–174.

Willis, S.L., Allen-Burge, R., Dolan, M.M., Bertrand, R., Yesavage, J., & Taylor, J.L. (1998). Everyday problem solving among individuals with Alzheimer's disease. *Gerontologist*, *38*, 569–577.