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The Executive Decline Hypothesis of Cognitive Aging: Do Executive Deficits Qualify as Differential Deficits and Do They Mediate Age-Related Memory Decline?*

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ABSTRACT

This paper reports the results of two studies which investigated whether aging is associated with a differential deficit in executive function, compared with deficits in general cognitive ability (Wechsler Adult Intelligence Scale-Revised performance). Further, the studies investigated the specificity of the executive decline hypothesis of memory and aging by examining whether declines in executive function mediate age-related memory decline over and above the variance in memory accounted for by general cognitive ability. The results of Study 1 showed no consistent evidence of a differential decline in executive function among a sample of participants aged between 18 and 75 years. The results of Study 2 indicated a differential decline in one indicator of executive function, the Modified Card Sorting Test, among an older sample aged between 60 and 89 years. Both studies demonstrated that measures of executive function accounted for age-related variance in free recall, recognition, and serial recall, even after controlling for general cognitive ability. However, in Study 1, once variance attributed to speed of processing was taken into account, executive function did not contribute further to the age-related variance.

A recent hypothesis suggests that age-related declines in memory may be due to a subclinical and selective decline in executive function which is thought to be associated with the functioning of the frontal lobes of the brain (Dempster 1992; Moscovitch & Winocur, 1992; Parkin, 1996; Parkin & Walter, 1992; Troyer, Graves, & Cullum, 1994). This hypothesis draws on evidence from neurobiological and neuropsychological research. Age-related changes in the neuroanatomy and neurochemistry of the brain appear more evident in the frontal lobes than in other cortical areas, suggesting that aging should be associated with declines in executive function (Fuster, 1989; Woodruff-Pak, 1997). Indeed, findings from neuropsychology support this claim because middle-aged and older adults typically perform more poorly than do younger adults on neuropsychological tests of executive function (Bryan & Luszcz, in press; Daigneault & Braun, 1993; Daigneault, Braun, & Whitaker, 1992; Mittenberg, Seidenberg, O'Leary, & DiGiulio, 1989). However, the demonstration of age-related deficits on tests of executive function provide only limited support for the assertion that aging is associated with a selective decline in executive function, because aging is associated with declines in many aspects of cognition. It is therefore important to demonstrate that aging is associated with a *differential* decline in the performance of tests of executive function. This paper reports the results of two studies which investigated whether aging is associated with a differential deficit in executive function, compared with deficits in general cognitive ability. Further, these studies investi-

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gated the specificity of the executive decline hypothesis of memory and aging by examining whether declines in executive function mediate age-related memory decline over and above that accounted for by general cognitive ability.

The first aim of the current studies was to investigate whether there are age-related declines on tests of executive function and whether these qualify as differential deficits. In both studies, participants completed batteries of tasks postulated to assess executive function. In addition, participants completed the Wechsler Adult Intelligence Scale-Revised (WAIS-R; Wechsler, 1981) in Study 1 and a short form of the WAIS-R in Study 2. The WAIS-R was used as a measure of general cognitive ability and as a standard against which to compare executive performance. The WAIS-R was chosen because it assesses a wide range of cognitive abilities, has well-established psychometric properties, and is relatively insensitive to executive dysfunction (Lezak, 1995; Parker & Crawford, 1992). If we are to conclude that older adults demonstrate differential executive decline, then age-related declines on the tests of executive function should be greater than age-related declines on WAIS-R performance.

The second aim of these studies was to investigate the extent to which performance on tests of executive function mediate the relationship between age and memory performance. It has been suggested that there is a remarkable consistency between the types of memory deficits experienced by people with frontal lobe lesions and by healthy older adults, because both display deficits on those memory tasks which rely heavily on strategic processes and therefore on executive function (Moscovitch & Winocur, 1992). As is the case for people with frontal lobe lesions, normal aging is associated with impaired free recall performance (Bryan & Luszcz, 1996; Craik & McDowd, 1987; Luszcz, 1992; Smith, 1996), sequencing of responses (Daigneault & Braun, 1993; Shimamura & Jurica, 1994), memory for spatiotemporal context, reflected in memory tasks such as serial recall (Craik, Morris, Morris, & Loewen, 1990; Kausler, Salthouse, & Saults, 1988; Spencer & Raz, 1994), and control of interference (Dempster, 1992; Hasher & Zacks, 1988). This has lead to the hypothesis that age-related memory decline may be a result of declines in executive function.

An executive decline hypothesis of aging and memory has yet to be thoroughly investigated, beyond merely demonstrating an association between memory performance and performance on tests of executive function (Parkin, 1997). One investigation has come from Troyer et al. (1994), who examined the extent to which measures of executive function mediated the relationship between age and episodic memory performance among a sample of older adults aged between 60 and 91 years. They found that age predicted episodic memory performance before, but not after, measures of executive function were partialled out, suggesting a mediating role of executive function. However, although Troyer et al. (1994) measured general cognitive ability in the form of the Vocabulary and Digit Span subscales of the WAIS-R, performance on these tasks was not compared with performance on the executive tasks, and they were not included as possible mediators of age differences in memory performance. More recently, Bryan, Luszcz and Pointer (in press) investigated executive function and processing resources (speed and working memory) as predictors of free recall of word lists under different encoding conditions. They found that the ability to integrate words during a story generation strategy was accounted for by executive function and working memory, but not by speed of processing. Apart from the study by Bryan et al., little research has investigated the *specificity* of the executive decline hypothesis of memory and aging. If the executive decline hypothesis is to be upheld, it is essential to establish that measures of executive function mediate the relationship between age and memory performance after controlling for general cognitive ability or tasks which tap other cognitive functions.

The current studies aim to extend previous work in a number of ways. In Study 1, participants aged between 18 and 75 years completed a wider range of executive tasks than those employed by Troyer et al. (1994) and Bryan et al. (in press), the full WAIS-R, and three measures of memory performance: free recall, serial recall, and recognition. Free recall and serial recall performance is thought to be more sensitive than is recognition to declines in executive function; therefore it was expected that executive task performance would account for the age-related variance in free and serial recall to a greater extent than in recognition memory. Study 2 provides a partial replication of Study 1, but among an older sample of participants aged between 60 and 89 years.

To summarize, a number of predictions drawn from the executive decline hypothesis of memory and aging were tested in the present studies. 1. There would be a significant negative correlation between measures of executive function and age. 2. These correlations would significantly exceed the correlations between age and WAIS-R performance measures. This would be consistent with there being a differential deficit in executive function. 3. Measures of executive function would account for the age-related variance in memory performance. 4. Measures of executive function would continue to account for age-related variance in memory performance after controlling for general cognitive ability.

STUDY 1

METHOD

Participants

The 123 participants were aged between 18 and 75 years (M = 39.41, SD = 13.36 years). There were 75 females. The participants were volunteers from the Aberdeen (Scotland) community and were recruited as part of an as yet unpublished standardization study of executive function. They were recruited from a variety of sources such as local recreational clubs and community centers. Participants were screened prior to the commencement of the study for the absence of major systemic, neurological, and psychiatric disorders. Participants had experienced an average of 13.18 (SD = 2.85) years of education. To demonstrate possible cohort effects, descriptive statistics for years of education and scores on the Vocabulary subtest of the WAIS-R for four age ranges are presented in Table 1. Not surprisingly, participants aged between 18 and 30 years had experienced more years of education than those in the two older age groups. However, age groups did not differ on Vocabulary scores.

Measures

The participants undertook a battery of general cognitive ability, executive function, and memory tests.

General Cognitive Ability

All participants completed the WAIS-R (Wechsler, 1981). Scaled scores for all subtests were summed to produce a Full Scale measure. This composite was used for hypothesis testing, rather than IQs, because IQ scores are age scaled and the effect of age on general intelligence was of interest in this study. In addition, scores for the verbal subtests were summed to produce a Verbal Scale measure. Although no hypotheses have been made in relation to this measure, it was included in the analyses because verbal ability is related to performance on verbal memory tasks (Erber & Szuchman, 1996), and it contrasts with the effects produced by the Full Scale measure.

Tests of Executive Function

The tests used to assess executive function were chosen either because they are commonly used as

Table 1. Means and Standard Deviations for Years of Education and Vocabulary Scores.

	Age group							
	18-30 years n = 39		31-45 years n = 50		46-60 years n = 23		61-75 years n = 11	
	M	(SD)	M	(SD)	M	(SD)	M	(SD)
Years of education[a]	14.17	(2.38)	13.33	(2.57)	12.09	(3.29)	11.27	(3.44)
Vocabulary	11.21	(2.40)	10.80	(2.55)	10.48	(3.29)	11.73	(2.94)

[a] Significant age group difference (see text).

measures of executive function (Modified Card Sorting Test, Controlled Oral Word Association Test, Stroop Test) due to their sensitivity to focal frontal lesions, or because they have been devised as tests of executive function but have not yet been used to assess age differences (Tower of London Test, Cognitive Estimates, Uses for Common Objects; Bryan & Luszcz, in press).

The Modified Card Sorting Test (MCST; Nelson, 1976). The MCST was administered and scored according to standard procedures. This test is a variant on the Wisconsin Card Sorting Test (WCST; Grant & Berg, 1948). The test requires participants to sort cards according to three attributes (color, form, and number of items depicted). The sorting rule changes throughout the administration, thereby assessing participants' ability to shift cognitive set. The MCST differs from the original WCST in that (a) the cards to be sorted share a maximum of one attribute with a key card and (b) participants are told when the sorting rule is changed. Six consecutive correct sorts is deemed to be a category achieved. The number of categories achieved was used as the MCST variable in the present study.

The Controlled Oral Word Association Test (Benton, 1968; Benton & Hamsher, 1976). In this test, which is also referred to as initial letter verbal fluency, participants undertook three 60-s trials, orally producing as many words as possible beginning with the letters *F*, *A,* and *S.* Participants were informed that proper nouns, numbers, and the same words ending with different suffixes (e.g. fast, faster) were not acceptable. To ensure comprehension, a practice trial with the letter *C* was administered with the examiner providing examples and asking participants to provide their own; examples of incorrect words were also provided. The total number of words produced, summed across all three trials, was used as the measure of verbal fluency. The alternate-form reliability of this test was moderate to good ($\alpha = .84$).

The Stroop Test (Stroop, 1935). In this version of the Stroop Test (Golden, 1978), participants were given three pages of 100 words. On the first page, color names were printed in black ink and participants were asked to read the names of the colors. On the second page, color names were printed in congruent colored ink and participants were asked to name the color of the ink. On the third page, color names were printed in incongruent colored ink and participants were asked to name the color of the ink. The time taken to read the color names was recorded for each trial. Scores for this test represent a measure of interference based on the ratio of the time taken to name the colors of words printed in congruent colored ink and the time taken to name the colors of words printed in incongruent colored ink. The Stroop Test is often included in batteries of tests aimed to assess executive function (e.g., Daigneault et al., 1992; Dempster, 1992) due to its purported assessment of proneness to interference.

The Tower of London Test (TOL; Shallice, 1982). This test, derived from an oriental puzzle, the Tower of Hanoi, measures problem solving and forward planning (Shallice, 1982; Shallice & Burgess, 1991). Participants were required to move colored beads on pegs from an initial position to a set of 12 predetermined target positions in the smallest number of possible moves. The smallest number of moves that could be used to solve each problem was indicated to the participants. Participants were allowed one minute per problem. The number of trials successfully completed (minimum of 0, maximum of 12) was recorded. To be counted as successfully completed, a trial must have been completed within the required number of moves, and must have been completed within 60 s. For each trial, each participant received a score of 0, 1, 2, or 3. A score of 3 indicates that the trial was completed within 15 s; 2, that the trial was completed within 30 s; 1, that the trial was completed within 60 s; and 0, that the trial was not completed within 60 s (i.e., an incomplete trial). Therefore, scores for this test represent the sum of the scores obtained across the 12 trials (minimum of 0, maximum of 36). The internal reliability of this test was low to moderate ($\alpha = .54$).

The Cognitive Estimates Test (Shallice & Evans, 1978). The Cognitive Estimates Test was administered according to standard procedures. It consists of 15 questions for which precise answers are unavailable (e.g., What is the length of an average person's spine?). Therefore, in order to generate an appropriate response, participants must formulate a cognitive plan, execute it, and check the reasonableness of their output. Responses on each item were scored using a 4-point scale (0, 1, 2, and 3), representing 0, 1, 2, and 3 standard deviations from the mean, derived from the range of scores obtained from control data (Shallice & Evans, 1978). A score of 0 represents normality (i.e., does not differ from the mean of the control data) and a score of 3 is classified *very extreme* (i.e., responses align with three standard deviations away from the mean of the control data). In the standard scoring system, high scores therefore indicate poor performance. Cognitive Estimates Test scores were reflected so that higher scores represented better performance in line with the other tests. O'Carroll, Egan, and MacKenzie (1994) report internal reliability of $\alpha = .40$, and interrater reliability of .91.

The Uses for Common Objects Test. This task is a modified version of Getzels and Jackson's (1962) Uses for Objects Test. Participants were required to report as many uses as possible for a *brick* and a *bottle.* Participants were allowed 90 s for each trial. Scores represent the total number of different uses generated over the two trials. The alternate-form reliability for this test was moderate to good ($\alpha = .87$).

Memory Tests

For all memory tests, word lists were orally presented once to participants. For the free recall test, participants were required to freely recall two lists of 15 common nouns, immediately after presentation. For the recognition test, following each free recall test, participants were required to recognize 7 of the words presented in the free recall trials. These were presented among 8 distracters in a list of 15 common nouns. For the serial recall test, 15 common nouns were read aloud. Participants were then presented with 15 cards, each displaying one of the previously presented words. Participants were required to arrange the cards in the order in which they were originally presented. Scores for free recall and recognition were the number of words correctly recalled and recognized. Scores for serial recall were the Spearman correlations between the serial order of items specified by the participant, and their original presentation order. Average free recall, recognition, and serial recall across the two trials of each memory measure were used.

Procedure

Participants were tested in two sessions at the neuropsychology laboratory at the University of Aberdeen. In the first session, participants completed the WAIS-R. In the second session the executive function and memory tasks were completed in the following order: Recall Trial 1, Recognition Trial 1, MCST, Recall Trial 2, Recognition Trial 2, Stroop, Cognitive Estimates, Serial Recall Trial 1, TOL, Verbal Fluency, Serial Recall Trial 2, Uses for Common Objects.

RESULTS

Prior to testing the substantive hypotheses, distributions of scores were examined for normality and linearity. Inspection of distributions and z tests of skewness and kurtosis (Tabachnick & Fidell, 1989) revealed one instance of departure from normality. This was for the number of categories on the MCST which was negatively skewed. Data for this variable were transformed using reflect and logarithmic transformation, but there was no difference in the results of analyses using transformed, compared with untransformed, scores. Therefore original scores on the MCST were used in all analyses.

Hierarchical regression analyses were performed to determine if there were nonlinear components in the relationship between age and any of the cognitive measures. The cognitive measures were regressed on age. Subsequent addition of quadratic and cubic functions of age to the regression models did not produce a significant increase in R^2. Thus there was no evidence that the relationships deviated from linearity, thereby simplifying the subsequent analyses.

Means and standard deviations for Full Scale and Verbal Scale scores, and memory and executive tests appear in Table 2. As noted, the correlation between the order of presentation and the order constructed by a participant constitutes the score for the serial recall task. The mean correlation for serial recall, presented in Table 2, was obtained by converting all scores to Fisher's Z scores, averaging, and converting back.

Pearson correlations between the executive tasks, Full Scale scores, Verbal Scale scores, Full Scale IQ and age appear in Table 3. As expected, age had a significant negative correlation with the number of categories on the MCST, with Stroop interference, and with TOL scores. Contrary to expectations, age did not correlate significantly with Verbal Fluency, Cognitive Estimates, or Uses for Common Objects. Age correlated negatively with Full Scale scores, but not significantly with Verbal Scale scores. Importantly, age did not correlate with Full Scale IQ, which is adjusted for age, showing that there was no association between age and age-adjusted intelligence. Also of note were the moderate to high correlations between the executive tasks and the WAIS-R indexes.

Table 2. Means and Standard Deviations for Wechsler Adult Intelligence Scale-Revised Full Scale and Verbal Scale Scores, and Memory and Executive Function Tasks.

Tasks	*M*	(*SD*)
Full Scale scores	112.86	(21.18)
Verbal Scale scores	64.46	(12.66)
Words recalled (maximum 15)	7.41	(1.72)
Words recognized (maximum 7)	6.19	(0.72)
Serial recall	0.53	(0.07)
MCST categories	4.90	(1.58)
Verbal Fluency	32.19	(9.49)
Stroop	50.37	(8.57)
Tower of London	26.33	(4.32)
Cognitive Estimates	4.55	(3.53)
Uses for Common Objects	15.49	(5.91)

Note. MCST = Modified Card Sorting Test.

To examine whether increasing age was associated with a differential decline in executive function, compared with declines in general cognitive ability, Williams' (1959) significance test for the difference between nonindependent correlations was applied. This tested whether the differences between the correlations of the executive measures and age were significantly greater than the correlations between the WAIS-R indexes and age. The Williams test has been endorsed as the most appropriate test for differences between nonindependent correlations (Dunn & Clark, 1971; Steiger, 1980) and yields a *t* value which is evaluated for significance with $N - 3$ degrees of freedom. In calculating *t*, the correlation between all the variables involved is factored in. Thus, in the present case, the correlations between the executive measures and the WAIS-R indexes need to be computed (these correlations are presented in the second and third columns of Table 3).

Table 4 contains the results of applying the Williams test. The table shows that the correlations between age and the executive function measures did not differ significantly from the correlations between age and Full Scale scores

Table 3. Pearson Correlations among Executive Tasks, Wechsler Adult Intelligence Scale-Revised (WAIS-R) Full Scale, Verbal Scale, and Full Scale IQ Scores and Age.

Tasks	Age	Full Scale	Verbal Scale
Executive tasks			
MCST categories	–.28**	.62***	.54***
Verbal Fluency	–.08	.52***	.52***
Stroop	–.20*	.30***	.24**
Tower of London	–.19*	.36***	.24**
Cognitive Estimates	–.10	.58***	.62***
Uses for Common Objects	–.14	.49***	.46***
WAIS-R scores			
Full Scale scores	–.28***		
Verbal Scale scores	–.13		
Full Scale IQ	.06		

Note. MCST = Modified Card Sorting Test.
* $p < .05$. ** $p < .01$. *** $p < .001$.

or age and Verbal Scale scores, with one exception. The correlation between age and Full Scale scores was significantly higher than the correlation between age and Verbal Fluency; this latter result runs directly counter to the executive decline hypothesis.

Table 5 contains Pearson correlations between age, Full Scale and Verbal Scale scores, memory measures, and executive measures (some of the correlations which appeared in Table 3 are also presented in Table 5 for ease of interpretation). Age correlated negatively and moderately with memory measures, such that increasing age was associated with lower memory performance. There were small to moderate intercorrelations among the executive measures.

The mediating effect of executive task performance on the relationship between age and memory was assessed using a series of hierarchical multiple regression analyses. Specifically, the regression models were designed to determine whether executive function accounted for age-related variance in memory over and above that accounted for by either general cognitive ability (Full Scale scores) or general verbal ability (Verbal Scale scores). To avoid overmodeling of the data, scores for all executive tasks were converted to z scores and summed, resulting in a single composite measure of executive function which was used in the regressions.

The results from the regression analyses appear in Table 6. Eight regression models were evaluated for each of the three memory measures. In the first of these (Model 1), age was entered as the sole predictor to determine the amount of age-related variance in memory performance. Model 2 examined whether the executive function index accounted for a significant proportion of memory variance and whether prior entry of this variable reduced the contribution of age to a nonsignificant amount. The same procedure was repeated for Models 3 and 6 except that Full Scale scores and Verbal Scale scores replaced the executive function index. Models 4 and 7 examined whether, with prior entry of Full Scale and Verbal Scale scores respectively, the executive function index continued to account for a significant amount of memory variance. Models 5 and 8 examined whether Full Scale and Verbal Scale scores continued to predict memory after executive function had been controlled. The crucial question here was whether, if age continued to account for a significant proportion of the variance in Models 3 and 6, this would still be the case in those models in which executive function was included as a mediator, that is, in Models 4, 5, 7, and 8. Also included in the table is the percentage of age-related variance accounted for by the mediating variables. This figure represents the difference in the amount of age-related variance in memory before, compared with after, mediating variables had been entered, divided by the amount of age-related variance before mediators had been entered, multiplied by 100.

Table 4. *t* Values and Significance Levels for the Differences between Dependent Correlations between Age and Executive Function Measures and Age and Full Scale and Verbal Scale Scores.

Task	*t* value	
	$r_{\cdot}$age/$r_{\cdot}$Full Scale	$r_{\cdot}$age/$r_{\cdot}$Verbal Scale
MCST categories	0.00	–1.78
Verbal Fluency	2.33*	0.56
Stroop	0.77	–0.63
Tower of London	0.90	–0.54
Cognitive Estimates	1.09	0.18
Uses for Common Objects	1.58	–0.11

Note. MCST = Modified Card Sorting Test.
* $p < .01$.

Table 5. Pearson Correlations between Age, Full Scale Scores, Verbal Scale Scores, Memory Measures and Executive Function Measures.

	Age	Full Scale	Verbal Scale	Free recall	Recognition	Serial recall	MCST categories	Tower of London	Stroop	Verbal Fluency	Cognitive Estimates
Full Scale scores	–.28**										
Verbal Scale scores	–.13	.92***									
Free recall	–.23**	.32***	.28**								
Recognition	–.21**	.23**	.17*	.35***							
Serial recall	–.36***	.32***	.27**	.33***	.27**						
MCST categories	–.28**	.62***	.54***	.37***	.19*	.30**					
Tower of London	–.19*	.36***	.24**	.21*	.07	.28**	.26**				
Stroop	–.20*	.30***	.24**	.15*	.19*	.23**	.29**	.26**			
Verbal Fluency	–.08	.52***	.52***	.27**	.23**	.19*	.39***	.24**	.27**		
Cognitive Estimates	.10	.58***	.62***	.24**	.13	.24**	.36***	.16*	.15	.32***	
Uses for Objects	–.14	.49***	.46***	.28**	.15*	.17*	.44***	.30***	.06	.46***	.36***

Note. MCST = Modified Card Sorting Test.
* $p < .05$. ** $p < .01$. *** $p < .001$.

Turning first to the results for free recall, age predicted 5.4% of the variance in free recall when entered alone (Model 1); this represents 100% of the age-related variance. Model 2 shows that executive function accounted for 15.7% of the variance in free recall and accounted for 66.6% of the age-related variance. Full Scale scores predicted 10.0% of the variance in free recall and accounted for 57.4% of the age-related variance (Model 3). Executive function (Model 4) added 5.7% to the variance in free recall after Full Scale scores had been entered, and both of these measures accounted for 68.5% of the age-related variance. Model 5 shows that Full Scale scores no longer predicted free recall after executive function had been entered. Model 6 shows that Verbal Scale scores contributed 7.9% to the variance in free recall and accounted for 25.9% of the age-related variance. After controlling for Verbal Scale scores, executive function added a significant 7.8% to the variance in recall, and both these measures accounted for 66.6% of the age-related variance (Model 7). Model 8 shows that Verbal Scale scores no longer predicted free recall after executive function had been entered. The hypothesis that executive function would account for age-related variance in free recall was supported, because age no longer predicted free recall after controlling for executive function. In addition, the results suggest that executive function and general ability both contribute to free recall performance and explain a similar amount of the age-related variance in free recall. The hypothesis that executive function would continue to account for age-related variance in free recall over and above that accounted for by general cognitive ability was supported, because more of the age-related variance in free recall (68.5%) was explained by both Full Scale scores and executive function than by Full Scale scores alone (57.4%). Furthermore, the mediation of age-related variance in free recall by general ability was accounted for by executive function, because Full Scale and Verbal Scale scores no longer predicted free recall after controlling for executive function.

For recognition, Model 1 shows that age accounted for 4.4% of the variance in recognition performance when entered alone. As predicted, Model 2 shows that executive function accounted for 6.1% of the variance in recognition and accounted for 50% of the age-related variance. Full Scale scores predicted 5.4% of the variance and 47.7% of the age-related variance in recognition (Model 3). Model 4 shows that executive function did not significantly add to the variance in recognition once Full Scale scores had been entered. Likewise, after executive function had been entered, Full Scale scores did not predict recognition (Model 5). Executive function and Full Scale scores together accounted for 54.5% of the age-related variance in recognition (Models 4 and 5). Verbal Scale scores predicted a nonsignificant 2.8% of the variance and accounted for 18.2% of the age-related variance (Model 6). After controlling for Verbal Scale scores, executive function contributed a significant 3.4% to the variance and both these variables accounted for 50% of the age-related variance (Model 7). After controlling for executive function, Verbal Scale scores did not predict recognition (Model 8). The hypothesis that executive function would account for age-related variance in recognition was supported because age no longer predicted recognition after executive function had been entered. However, like the results for free recall, executive function and general ability accounted for a similar amount of the age-related variance. In addition, the hypothesis that executive function would continue to contribute to the age-related variance in recognition after controlling for general cognitive ability seems not to be supported because executive function did not contribute to the variance and marginally contributed to the age-related variance after controlling for Full Scale scores. For recognition, Verbal Scale scores did not predict performance.

For serial recall, Model 1 shows that age contributed a significant 12.7% to the variance in serial recall when entered alone. Executive function predicted 13.8% of the variance in serial recall and accounted for 43.3% of the age-related variance (Model 2). Full Scale scores predicted 10.5% of the variance, and accounted for 39.3% of the age-related variance in serial recall (Model 3). Executive function added 3.8% to the

Table 6. Hierarchical Multiple Regression Analyses Predicting Free Recall, Recognition, and Serial Recall from Age, Full Scale Scores, Verbal Scale Scores, and Executive Function.

Model	Variable	R^2	R^2 change	F change	% ARV
Free recall					
1	Age	.054	.054	6.84**	100
2	Executive	.157	.157	22.33***	
	Age	.175	.018	2.55	66.6
3	Full Scale	.100	.100	13.39***	
	Age	.123	.023	3.09	57.4
4	Full Scale	.100	.100	13.39***	
	Executive	.158	.057	8.10**	
	Age	.175	.017	2.43	68.5
5	Executive	.157	.157	22.33***	
	Full Scale	.158	.001	0.12	
	Age	.175	.017	2.43	68.5
6	Verbal Scale	.079	.079	10.31**	
	Age	.119	.040	5.34*	25.9
7	Verbal Scale	.079	.079	10.31***	
	Executive	.157	.078	11.00**	
	Age	.175	.018	2.59	66.6
8	Executive	.157	.157	22.33***	
	Verbal Scale	.157	.000	0.03	
	Age	.175	.018	2.59	66.6
Recognition					
1	Age	.044	.044	5.50*	100
2	Executive	.061	.061	7.86**	
	Age	.084	.022	2.91	50.0
3	Full Scale	.054	.054	6.80*	
	Age	.077	.023	2.96	47.7
4	Full Scale	.054	.054	6.80*	
	Executive	.066	.013	1.60	
	Age	.087	.020	2.62	54.5
5	Executive	.061	.061	7.86**	
	Full Scale	.066	.005	0.61	
	Age	.087	.020	2.62	54.5
6	Verbal Scale	.028	.028	3.44	
	Age	.064	.036	4.60*	18.2
7	Verbal Scale	.028	.028	3.44	
	Executive	.062	.034	4.26*	
	Age	.084	.022	2.90	50.0
8	Executive	.061	.061	7.86**	
	Verbal Scale	.062	.000	0.00	
	Age	.084	.022	2.90	50.0
Serial recall					
1	Age	.127	.127	17.54***	100
2	Executive	.138	.138	19.33***	
	Age	.210	.072	10.90**	43.3
3	Full Scale	.105	.105	14.19***	
	Age	.182	.077	11.23**	39.3
4	Full Scale	.105	.105	14.19***	
	Executive	.142	.038	5.25*	
	Age	.211	.068	10.29**	46.5
5	Executive	.138	.138	19.33***	
	Full Scale	.142	.005	0.67	
	Age	.211	.068	10.29**	46.5
6	Verbal Scale	.071	.071	9.21**	
	Age	.176	.106	15.38***	16.5
7	Verbal Scale	.071	.071	9.21**	
	Executive	.138	.067	9.36**	
	Age	.211	.073	10.99**	42.5
8	Executive	.138	.138	19.33***	
	Verbal Scale	.138	.000	0.04	
	Age	.211	.073	10.99**	42.5

Note. ARV = age-related variance.
* $p < .05$. ** $p < .01$. *** $p < .001$.

variance in serial recall after Full Scale scores had been entered (Model 4), but Full Scale scores did not predict serial recall after executive function had been entered (Model 5). Full Scale scores and executive function together accounted for 46.5% of the age-related variance (Models 4 and 5). Model 6 shows that Verbal Scale scores predicted 7.1% of the variance in serial recall and accounted for 16.5% of the age-related variance. Executive function added 6.7% to the variance in serial recall after Verbal Scale scores were entered (Model 7), but Verbal Scale scores did not predict serial recall after executive function had been entered (Model 8). Verbal Scale scores and executive function together accounted for 42.5% of the age-related variance in serial recall (Models 7 and 8). The hypothesis that executive function would account for age-related variance in serial recall was only partially supported. Although executive function accounted for 43.3% of the age-related variance, age continued to predict serial recall after executive function had been entered. However, the hypothesis that executive function would continue to add to the age-related variance in serial recall after controlling for general cognitive ability was supported because executive function added a further 7.2% to the age-related variance compared with the contribution made by Full Scale scores alone. Furthermore, as for free recall, executive function accounted for the variance in serial recall predicted by Full Scale and Verbal scale scores, because these general ability measures did not predict serial recall after executive function had been entered.

The results from the regressions above show that executive function and Full Scale scores accounted for similar amounts of age-related variance in all memory measures (66% compared with 57% for free recall; 50% compared with 48% for recognition; and 43% compared with 39% for serial recall), suggesting that there is a shared contribution to memory from these measures. As a result of this, and on the basis of the suggestion that executive measures may share common variance with fluid intelligence (Burgess, 1997; Duncan, 1995; Rabbitt, 1997), it was decided to examine the relationships between executive function and the individual subtests of the WAIS-R to determine whether this shared contribution was a result of a common construct reflected in both executive function measures and the subtests of the WAIS-R. Table 7 contains Pearson correlations between the executive function index, the subtests of the WAIS-R, age, and memory measures. Pearson correlations between each executive measure and the subtests of the WAIS-R were also computed, but the correlations were similar (around .3 – .4) and thus are not reported here.

The striking thing about the correlations in Table 7 is that executive function correlates

Table 7. Pearson Correlations between Executive Function, Age, Memory Measures, and Wechsler Adult Intelligence Scale-Revised (WAIS-R) Subtests.

WAIS-R subtests	Executive	Age	Recall	Recognition	Serial recall
Performance Scale					
Picture Completion	.50***	–.18*	.26**	.13	.20*
Picture Arrangement	.53***	–.21*	.15*	.26**	.09
Block Design	.57***	–.31***	.20*	.15*	.37***
Object Assembly	.44***	–.27**	.19*	.07	.25**
Digit Symbol	.50***	–.52***	.32***	.35***	.31***
Verbal Scale					
Information	.54***	–.07	.24**	.15*	.14
Digit Span	.46***	–.14	.22**	.13	.26**
Vocabulary	.56***	.03	.19*	.05	.15*
Arithmetic	.50***	–.15	.20*	.20*	.36***
Comprehension	.51***	.00	.17*	.05	.12
Similarities	.58***	–.24**	.27**	.20*	.20*

* $p < .05$. ** $p < .01$. *** $p < .001$.

moderately and similarly with all of the subtests of the WAIS-R, not only with those from the Performance subscale. The highest correlation is between the executive index and Block Design, which is thought to reflect planning aspects of executive function (Lezak, 1995). However, the executive index also correlates highly with Similarities and Vocabulary, tests of verbal comprehension, which would not be expected to be strongly associated with measures of executive function. As expected, age appears to correlate more highly with the Performance subtests, especially with the Digit Symbol Substitution Test (DSST), than with the Verbal subtests. Recall and recognition also correlate more highly with the DSST than with the other subtests. Due to this pattern of correlations between age, recall, recognition, and the DSST, and given the reliable findings that DSST performance has been found to be a mediator of age-related variance in memory (e.g., Bryan & Luszcz, 1996, 1999; Salthouse, 1991), it was decided to investigate the relative contributions of executive function and DSST performance to age-related decline in memory. Once again, hierarchical multiple regressions were employed to examine these predictors of memory and the results appear in Table 8. The amount of variance predictable by age after mediators had been entered was compared with the amount predictable by age alone (presented in Table 6) to produce the percentage of age-related variance explained. This percentage appears in the final column in Table 8.

Table 8 shows that the DSST accounted for 10.4% of the variance in free recall and accounted for 88.9% of the age-related variance

Table 8. Hierarchical Multiple Regression Analyses Predicting Free Recall, Recognition, and Serial Recall from Age, the Digit Symbol Substitution Test (DSST), and Executive Function.

Model	Variable	R^2	R^2change	*F* change	% ARV
Free recall					
1	DSST	.104	.104	13.86***	
	Age	.109	.006	0.78	88.9
2	DSST	.104	.104	13.86***	
	Executive	.178	.074	10.71**	
	Age	.183	.006	0.81	88.9
3	Executive	.157	.157	22.33***	
	DSST	.178	.021	2.99	
	Age	.183	.006	0.81	88.9
Recognition					
1	DSST	.120	.120	16.38***	
	Age	.121	.001	0.16	97.7
2	DSST	.120	.120	16.38***	
	Executive	.128	.008	1.03	
	Age	.129	.001	0.16	97.7
3	Executive	.061	.061	7.86**	
	DSST	.128	.066	9.03**	
	Age	.129	.001	0.16	97.7
Serial recall					
1	DSST	.097	.097	13.06***	
	Age	.149	.051	7.25**	59.8
2	DSST	.097	.097	13.06***	
	Executive	.159	.062	8.83**	
	Age	.210	.051	7.66**	59.8
3	Executive	.138	.138	19.33***	
	DSST	.159	.022	3.08	
	Age	.210	.051	7.66**	59.8

Note. ARV = age-related variance.
* $p < .05$. ** $p < .01$. *** $p < .001$.

(Model 1). This is more than the amount accounted for by executive function (66.6%) or Full Scale scores (57.4%; see Table 6). Model 2 shows that executive function continued to predict free recall after controlling for the DSST, but Model 3 shows that the DSST did not predict free recall after controlling for executive function. Nonetheless, the addition of executive function to the model after the DSST did not account for any more of the age-related variance in free recall than did the DSST alone.

For recognition, the DSST accounted for 12.0% of the variance in recognition and for 97.7% of the age-related variance. The DSST therefore emerged as the best predictor of recognition and accounted for more of the age-related variance than did executive function and Full Scale scores (see Table 6). Model 2 shows that executive function did not predict recognition after controlling for the DSST, but Model 3 shows that the DSST continued to contribute to the variance after controlling for executive function. As for free recall, the addition of executive function after the DSST had been entered did not account for additional age-related variance over and above that accounted for by the DSST alone.

The results for serial recall show that the DSST accounted for 9.7% of the variance and for 59.8% of the age-related variance (Model 1). As for free recall and recognition, the DSST accounted for more of the age-related variance in serial recall than did executive function and Full Scale scores (see Table 6). Models 2 and 3 show that executive function continued to predict serial recall after controlling for the DSST, but that the DSST no longer contributed to the variance after controlling for executive function. However, the addition of executive function, after the DSST, did not account for more age-related variance than did the DSST alone.

The results of these regressions demonstrate that executive function makes an independent contribution to free recall and serial recall after controlling for the DSST. However, it does not account for additional age-related variance in any memory measure over and above that accounted for by the DSST. Indeed, DSST performance accounted for more of the age-related variance in all three memory measures than did either executive function or general cognitive ability.

DISCUSSION

The executive decline hypothesis of cognitive aging suggests that there is a selective decline in executive function in normal aging (Dempster, 1992; Parkin & Walter, 1992). This hypothesis is particularly influential among those researchers who have addressed cognitive aging from a neuropsychological perspective (e.g., Daigneault et al., 1992; Troyer et al., 1994). Daigneault et al. (1992), for example, note that "The currently dominant neuropsychological model of normal brain aging postulates that cognitive functions dependent on the integrity of the prefrontal brain regions are among the first to deteriorate" (p. 99). Therefore, the first aim of this study was to investigate this purported differential decline in executive function.

The results of Study 1 show that increasing age was associated with significant, but modest, declines on some measures of executive function. Specifically, increasing age was negatively related to performance on the MCST, the Stroop Test, and the Tower of London Test. These results are consistent with the executive decline hypothesis and with the results obtained in previous studies (e.g. Daigneault & Braun, 1993; Daigneault et al., 1992; Mittenberg et al., 1989). However, in the present study, performance on Verbal Fluency, Cognitive Estimates, and Uses for Common Objects was not related to age. Previous research has also produced conflicting results in relation to age differences in verbal fluency, with some studies showing no age differences (Mittenberg et al., 1989; Parkin & Walter, 1992). This finding raises problems for an executive decline hypothesis of cognitive aging because verbal fluency tests are among the most sensitive to, and best validated measures of, frontal lobe dysfunction (Benton, 1968; Lezak, 1995; Parker & Crawford, 1992; Stuss & Benson, 1986) due to their reliance on strategic search processes. The lack of age-related decline in performance on Verbal Fluency, Cognitive

Estimates, and Uses for Common Objects tasks may be because these tasks benefit from a large verbal knowledge base, which has been found to be well maintained with increasing age (Horn, 1982; Salthouse, 1991). Although verbal knowledge has been found to predict initial letter fluency (Bryan, Luszcz, & Crawford 1997), there is little evidence that it compensates for age-related declines in verbal fluency (Bryan et al., 1997; Salthouse, 1993). Further, Phillips (1997) raises concerns regarding the validity of tests of initial letter fluency as tests of executive function because they may not be novel enough. That is, individuals may have had prior experience with similar tasks such as completing crossword puzzles, playing Scrabble, and engaging in other word games, therefore relying on practiced responses.

This difference in sensitivity among executive tasks to aging effects demonstrates the breadth of processes subsumed by the term *executive performance* and ascribed to the frontal lobes. It may be the case that increasing age is particularly associated with declines in the planning and control of interference aspects of executive function, which may be evidenced in performance on the MCST, the Tower of London Test, and the Stroop Test, whereas Verbal Fluency, Uses for Common Objects, and Cognitive Estimates tests may reflect and draw upon verbal and knowledge-based ability that may be resistant to aging.

As was noted, the finding of age differences on tests of executive function is consistent with the executive decline hypothesis of cognitive aging. However, because aging is associated with declines in various cognitive domains, such evidence alone is not compelling. Therefore in Study 1, a more stringent test of the executive decline hypothesis was applied by testing whether executive deficits qualified as differential deficits. This did not appear to be the case as none of the deficits on the executive tasks significantly exceeded the deficits on general ability measures (i.e., the Full Scale and Verbal Scale scores from the WAIS-R). This finding clearly complicates, and presents problems for, the executive decline hypothesis of cognitive aging.

However, the finding that executive deficits in aging are no greater than deficits in general intellectual ability does not preclude the possibility that individual differences in executive function may, nevertheless, make a specific contribution to memory performance and its decline with age. The hypotheses tested were that executive function would account for age-related variance in memory, and that it would account for age-related variance after controlling for general cognitive ability. The regression models demonstrated that there were age effects for free recall, recognition, and serial recall and that executive function accounted for moderate amounts of age-related variance in all three memory measures. The hypothesis that executive function would account for this age-related variance was supported in the case of free recall and recognition, because age no longer predicted performance on these memory measures after controlling for executive performance.

In addition, the mediating effect of executive function between age and memory performance was compared with that of general cognitive ability, and the specific contribution of executive function to the age-related variance over and above that contributed by general cognitive ability was also investigated. The results from Study 1 show that executive performance and general cognitive ability (measured by Full Scale scores from the WAIS-R) accounted for similar amounts of age-related variance in all memory measures, suggesting that there is a shared contribution from these measures. However, after controlling for Full Scale and Verbal Scale scores, executive function continued to predict recall and serial recall (but not recognition when Full Scale scores were controlled) and accounted for additional age-related variance in memory over and above that accounted for by Full Scale and Verbal Scale scores alone. Conversely, the general ability measures did not contribute to the variance in memory after controlling for executive function. This suggests that executive function makes a unique contribution to age-related memory decline, having controlled for general cognitive ability.

Nonetheless, this additional contribution from executive function, over and above that contributed by general cognitive ability, was small and, as mentioned earlier, the amount of age-related variance accounted for by executive function and general ability was similar. Therefore, it could be argued that some of the subtests of the WAIS-R, particularly those comprising the Performance subscale, may rely on executive processes such as planning and working memory (e.g., Block Design, Object Assembly, and Digits Backwards), despite the evidence that major frontal lesions (which lead to executive deficits) can leave WAIS-R performance largely unaffected (Lezak, 1995; Shimamura, Janowsky, & Squire, 1991). However, the evidence for this from the current study is not compelling. The correlations presented in Table 7 show that executive function correlated similarly with all of the subtests of the WAIS-R, indicating that executive function measures reflect general cognitive ability to a large extent, even those tapping verbal ability. This supports the suggestions made by Duncan (1995) and Burgess (1997) that executive function shares common variance with Spearman's *g*.

Rabbitt (1997) suggests that the difficulty in differentiating among executive tasks and between executive and nonexecutive tasks may be because executive tasks draw upon a common pool of processing resources. A commonly identified processing resource is speed of information processing and this has been found to mediate age-related declines in the performance of neuropsychological tests which tap executive function (Salthouse, Fristoe, & Rhee, 1996). Speed of processing is also an important component of WAIS-R performance. A number of the subtests of the WAIS-R are timed and therefore draw upon this resource. The DSST, in particular, is commonly used as an index of speed of information processing (Salthouse, 1991, 1992), specifically perceptual speed. However, as pointed out by Parkin and Java (in press), the DSST may tap processes that are more broad than simple perceptual speed and may index more general fluid abilities. Performance on this test has been found to reliably mediate age-related declines in memory performance (Bryan & Luszcz, 1996; Salthouse, 1991).

The results of Study 1 support these claims. Table 7 shows that recall and recognition (but not serial recall) have stronger correlations with DSST scores than with the other subtests of the WAIS-R. In addition, age appears to correlate more highly with DSST performance than with performance on the other subtests. When the DSST was included, along with executive function, as a mediator of age-related variance in memory (Table 8), it was found that DSST performance accounted for more of the age-related variance in all three memory measures than did either executive function or Full Scale scores. Although executive function made independent contributions to the variance in free recall and serial recall (as would be expected due to their purported reliance on strategic encoding and retrieval), over and above that contributed by the DSST, executive function did not make an additional contribution to the age-related variance. This supports a large amount of research which finds that speed of information processing accounts for age-related decline on many types of memory tasks (see Salthouse, 1991 for a review). Therefore a thorough investigation of the executive decline hypothesis of memory and aging requires the relative contributions of executive function and processing resources to age-related memory decline to be determined (Bryan et al., in press).

It should be noted that executive measures accounted for relatively little of the variance in recognition performance. It was expected that free recall and serial recall would be more reliant on executive function than would recognition. Recognition tasks may rely less on planning (which may be tapped by the MCST and the Tower of London Test) or strategic search strategies (possibly reflected in Verbal Fluency, Uses for Objects, and perhaps Cognitive Estimates) than would free recall or serial recall and this is supported by the pattern of correlations in Table 5. It may be expected that recognition of a target word among distracters might be more open to interference effects than would the generation of a word from memory as in recall. However, this was not supported by the small correlation between Stroop performance and recognition ($r = .19$).

Also, it should be noted that although the pattern of results was similar for serial recall when modeling performance on this task, it was found that neither general nor verbal cognitive ability, nor executive task performance, could account for all of the age-related variance. Age continued to predict a significant 7% of the variance in serial recall after controlling for the executive and other cognitive performance measures, and 5.1% after controlling for executive function and the DSST. Thus the mechanism underlying age-related decline on this task remains to be determined. In addition, the amount of age-related variance accounted for by executive performance was lower for serial recall than for free recall and recognition. This was surprising and contrary to expectations; it was expected that aging would be associated with greater declines on this task (which was supported) *because of* age-related declines in executive performance.

It is recognized that the interpretation of the results of the present study may be limited because the sample did not contain participants over the age of 75 years, and relatively few between the ages of 60 and 75 (however, the sample has the advantage of providing a continuum of ages rather than an extreme groups design). Therefore, age-related declines in memory and executive function among very old adults have not been captured in this study and this may account for the small amount of age-related variance in the cognitive performance and memory measures. Study 2 addresses this problem by investigating the executive decline hypothesis of memory and aging among older adults.

STUDY 2

The purpose of this study was to provide a partial replication of Study 1 among a sample of older adults. As it has been suggested that age-related declines in performance on executive tasks may not be evident until older ages (Lezak, 1995; Woodruff-Pak, 1997), the current study investigated the executive decline hypothesis of memory and aging among older adults. The 90 participants in this study were aged between 60 and 89 years, with 15 participants over the age of 80 years. This age profile is virtually identical to that of the sample employed by Troyer et al. (1994), whose study consisted of 51 participants aged between 60 and 91 years with 15 participants over the age of 80 years.

The aims and rationale for Study 2 are the same as for Study 1. As in Study 1, the current study investigated whether aging was associated with a differential decline in executive function. In addition, the extent to which executive task performance could mediate the relationship between age and free recall performance, over and above that mediated by general cognitive ability, was also investigated. A smaller battery of executive tasks, a short form of the WAIS-R, and a test of free recall were employed in Study 2. The predictions for Study 2 were similar to those for Study 1.

METHOD

Participants

The 90 participants were aged between 60 and 89 years (M = 72.80, SD = 6.45). There were 50 females. The participants were volunteers from the Aberdeen (Scotland) community and were recruited to serve as healthy controls for a study of neuropsychological functioning in idiopathic Parkinson's disease. Participants were recruited from a variety of sources including local recreational clubs, community centers, and sheltered housing projects. Participants were screened prior to commencement of the study to exclude individuals currently on centrally active medication and those with a history of central neurological disorders, major psychiatric disorders (including alcoholism), or major systemic disorders (e.g., diabetes). Descriptive statistics for years of education and verbal ability as measured by the number of errors on the National Adult Reading Test (NART; Nelson, 1982) for three age ranges are presented in Table 9. One-way analysis of variance revealed that there were no differences in the number of years of education, or on the NART, between the three age ranges.

Measures

The participants completed a battery of general cognitive ability, executive performance, and memory tests.

Table 9. Means and Standard Deviations for Years of Education and National Adult Reading Test (NART) Scores.

	Age group					
	60-69 years $n = 32$		70-79 years $n = 43$		80-89 years $n = 15$	
	M	(*SD*)	*M*	(*SD*)	*M*	(*SD*)
Years of education	9.50	(1.30)	9.34	(1.02)	9.80	(2.14)
NART[a] errors	23.69	(9.12)	26.67	(7.79)	26.67	(8.32)

General Cognitive Ability
Participants completed a short form of the Verbal Scale of the WAIS-R comprising the Vocabulary, Arithmetic, Digit Span, and Similarities subtests. As in Study 1, scaled scores from these subtests were summed to produce a measure of general cognitive ability.

Tests of Executive Function

The Modified Card Sorting Test (MCST; Nelson, 1976). The MCST was administered and scored according to standard procedures as in Study 1. The number of categories achieved was used as the MCST variable in the present study.

The Controlled Oral Word Association Test (Benton, 1968; Benton & Hamsher, 1976). As in Study 1, participants were required to produce as many words as possible beginning with the letters *F*, *A,* and *S*, but were allowed 90 s per trial. The total number of words produced for the three trials was used as the measure of verbal fluency. The alternate-form reliability of this test was good ($\alpha = .91$).

Semantic fluency. Semantic fluency tasks require individuals to produce as many items from a semantic category (e.g., animals) as possible in a set time limit. The task therefore provides a structure which can guide the retrieval of items from memory. Even so, performance on this task benefits from a strategic approach, such as the development of subcategories within a semantic category (e.g., farm animals). Whereas it has been found that individuals produce more items on semantic fluency compared with initial letter fluency tasks (Rosen, 1980), age differences on this task are more consistently found than on initial letter fluency tasks (Kozora & Cullum, 1995; Tomer & Levin, 1993; Troyer, Moscovitch, & Winocur, 1997; Whelian & Lesher, 1985). This may be because older adults have more difficulty searching for semantic sub-categories (Troyer et al., 1997). In the current study, participants were required to produce as many instances of *animals*, *birds,* and *vegetables* in 90 s per trial. The total number of items produced for the three trials was the measure of semantic fluency. The alternate form reliability was moderate to good ($\alpha = .86$).

Memory Measure
Verbal memory was examined by testing free recall of word lists. Four separate trials were administered with a different word list on each occasion. All four lists contained 12 concrete, high frequency words; words were presented aurally at a rate of 2 s per word. In the current study, the sum of items recalled over the four lists was used as a measure of verbal memory.

Procedure
Participants were tested in the neuropsychology laboratory of the University of Aberdeen. Tests were administered in the following order: the WAIS-R subtests, Recall Trial 1, the MCST, Recall Trial 2, Initial Letter Fluency, Recall Trial 3, Semantic Fluency, Recall Trial 4, NART.

RESULTS

Prior to hypothesis testing, distributions of data were examined for normality and linearity. The number of categories achieved on the MCST was, once again, the only instance of departure from normality. Reflect and logarithmic transformation of the data made little difference to results of analyses; therefore original scores on the MCST were used in all analyses.

Hierarchical regression analyses were performed to determine if there were nonlinear components in the relationship between age and any of the cognitive measures. The cognitive measures were regressed on age and the addition of quadratic and cubic functions of age to the regression models did not produce a significant increase in R^2. As in Study 1, there was no evidence that the relationships between age and the cognitive measures deviated from linearity.

Means and standard deviations for the number of correct categories on the MCST, Verbal and Semantic Fluency scores, WAIS-R (Short Form), and free recall performance appear in Table 10. Pearson correlations between age, WAIS-R, executive function, and recall measures appear in Table 11. Age correlated negatively and significantly with the executive and recall measures and with WAIS-R scores. Semantic fluency performance appeared to be more strongly negatively correlated with age than was initial letter fluency, but the difference between the correlations was not significant, $t(87) = 1.43, p = 0.08$. The strongest correlations were between age and MCST categories and between age and recall performance. There were moderate, positive correlations between executive measures and the WAIS-R measures with the exception of Digit Span, which did not correlate as reliably with the executive measures as did the other WAIS-R subtests.

Table 12 contains the *t* values which are the results of the Williams (1959) test for the comparison of dependent correlations between age and the executive function measures, and age and WAIS-R scores. The table shows that the correlation between age and MCST categories was significantly higher than the correlation between age and WAIS-R scores. Correlations between age and the fluency measures did not differ from the correlations between age and WAIS-R scores.

As in Study 1, the mediating effect of executive function and general cognitive ability on the relationship between age and recall was assessed using a series of hierarchical multiple regression analyses. Scores for the executive tasks were converted to *z* scores and summed, resulting in a composite measure of executive function which was used in the regressions. The results from the regression analyses appear in Table 13. Model 1 shows that age predicted 24.7% of the variance in recall when entered alone. Executive function accounted for 32.7% of the variance in recall and accounted for 74.1% of the age-related variance (Model 2). Model 3 shows that WAIS-R scores account for 22.5% of the variance and accounted for 40.5% of the age-related variance in recall. After WAIS-R scores were entered, executive function continued to contribute 11.4% to the variance (Model 4). WAIS-R scores and executive function together accounted for 71.3% of the age-related variance in recall. Model 5 shows that after controlling for executive function, WAIS-R scores no longer predicted recall performance.

The hypothesis that executive function would account for the age-related variance in recall was partially supported. Executive function accounted for 74.1% of the age-related variance, but age continued to predict recall after controlling for executive function. The regressions

Table 10. Means and Standard Deviations for Tests of Executive Function, Wechsler Adult Intelligence Scale-Revised (WAIS-R; Short Form), and Recall Performance.

Tasks	*M*	(*SD*)
WAIS-R (Short Form)	39.01	(7.62)
MCST categories correct	4.60	(1.67)
Verbal fluency	41.60	(16.52)
Semantic fluency	42.69	(12.39
Recall performance	18.21	(4.32)

Note. MCST = Modified Card Sorting Test.

Table 11. Pearson Correlations between Age, Executive Function, Wechsler Adult Intelligence Scale-Revised (WAIS-R), and Recall Measures.

Tasks	Age	WAIS-R (Short Form)	Vocabulary	Arithmetic	Digit Span	Similarities
MCST categories correct	–.51***	.50***	.37***	.35***	.14	.43***
Initial letter fluency	–.24*	.55***	.48***	.38***	.38***	.40***
Semantic fluency	–.37***	.57***	.57***	.44***	.20*	.48***
Recall performance	–.50***	.47***	.32**	.39***	.35***	.34***
WAIS-R (Short Form)	–.27**					

Note. MCST = Modified Card Sorting Test.
* $p < .05$. ** $p < .01$. *** $p < .001$.

show that executive function accounted for more of the age-related variance in recall (74%) than did WAIS-R scores (41%). Indeed, executive function alone accounted for more of the age-related variance in recall than did WAIS-R scores and executive function combined (71%). As predicted, executive function continued to predict recall over and above the contribution of WAIS-R scores, and the addition of executive function to the contribution of WAIS-R scores to recall accounted for more of the age-related variance than that accounted for by WAIS-R scores alone. WAIS-R scores no longer predicted recall after executive function had been entered.

DISCUSSION

The results of Study 2, which employed a sample of older adults aged between 60 and 89 years, support and enhance the findings from Study 1 and provide some support for the executive decline hypothesis of memory and aging. The results showed that increasing age was associated with significant declines on the performance of executive tasks: the MCST, initial letter fluency, and semantic fluency. A negative relationship between increasing age and MCST performance was also found in Study 1 but the correlation was stronger among the older sample of Study 2. Age was not associated with initial letter fluency in Study 1 and in the current study age was only weakly (although significantly) associated with declines in initial letter fluency. Semantic fluency performance appeared to be more strongly negatively associated with increasing age than was initial letter fluency, but the difference between the correlations was not significant.

The finding of a slightly greater age-related decline on semantic fluency compared with ini-

Table 12. *t* Values and Significance Levels for the Differences between Dependent Correlations between Age and Executive Measures, and Age and Wechsler Adult Intelligence Scale-Revised (WAIS-R; Short Form) Scores.

Tasks	*t* value
	$r_{\cdot \text{age}}/r_{\cdot \text{WAIS-R}}$
MCST categories correct	2.56*
Verbal fluency	0.31
Semantic fluency	1.08

Note. MCST = Modified Card Sorting Test.
* $p < .01$.

Table 13. Hierarchical Multiple Regression Analyses Predicting Free Recall from Age, Wechsler Adult Intelligence Scale-Revised (WAIS-R; Short Form) Scores, and Executive Function.

Model	Variable	R^2	R^2 change	*F* change	% ARV
1	Age	.247	.247	28.88**	100
2	Executive	.327	.327	42.76**	
	Age	.391	.064	9.21*	74.1
3	WAIS-R	.225	.225	25.53**	
	Age	.372	.147	20.32**	40.5
4	WAIS-R	.225	.225	25.53**	
	Executive	.339	.114	14.95**	
	Age	.409	.071	10.28*	71.3
5	Executive	.327	.327	42.76**	
	WAIS-R	.339	.012	1.52	
	Age	.409	.071	10.28*	71.3

Note. ARV = age-related variance.
*$p < .01$. **$p < .001$.

tial letter fluency supports previous findings (Kozora & Cullum, 1995; Tomer & Levin, 1993; Troyer et al., 1997; Whelian & Lesher, 1985). Troyer et al. (1997) investigated the strategies that younger and older participants used when performing initial letter and semantic fluency tasks. They found age differences in the type of strategies used, with older adults switching to a new semantic subcategory less often than did younger adults when performing the semantic fluency task. In addition, switching was associated with the production of more words on the task. This indicates that older adults may have more difficulty searching for new semantic subcategories, thus limiting the number of words produced on this task. For the initial letter fluency task, Troyer et al. found no age differences in performance, and older adults were able to produce more words within a category on this task. The authors interpreted this finding as indicating that older adults' possibly larger vocabularies aid performance on this task. Thus, the semantic fluency task may be more sensitive to age effects than is initial letter fluency (Bryan & Luszcz, in press).

Even though increasing age was associated with declines in the performance of executive tasks, there was only limited support for a differential age-related decline in executive function compared with declines in general cognitive ability. When the correlations between age and the executive measures were compared with the correlations between age and WAIS-R scores, it was found that only the correlation between age and MCST performance was greater than the correlation between age and WAIS-R scores. Thus MCST performance declines more with age than does general cognitive ability. In addition, this study provides a conservative test of the differential executive decline hypothesis, because age-related declines in executive function were compared with age-related declines on subtests from the Verbal subscale of the WAIS-R, which often shows only small age-related declines. The findings from this study, together with those from Study 1, which provided no evidence for a differential age-related decline in executive function, suggest that a differential age-related deficit in executive function, if it exists at all, may appear only for some aspects of executive function and only at older ages.

The strengthening of the negative correlation between age and executive performance and the emergence of a differential decline in executive function among the older sample of the current study suggests a decline in executive function which emerges at older ages. This is at odds with the claim made by Daigneault et al. (1992) that executive function may be the first of the cognitive functions to decline with increasing age. It also suggests that age-related declines in executive function may not be linear across the life span. In both Studies 1 and 2, the relationships between age and the executive measures were linear, but this finding may be due to the restriction of the range of age in both Studies 1 and 2. In Study 1, the age range of participants was between 18 and 75 years and these participants may have not yet displayed any decline in executive function, which may not be evident until after 70 years of age (Lezak, 1995; Woodruff-Pak, 1997). In Study 2, participants were aged between 60 and 89 and the function between age and executive performance may have displayed the accelerated decline which may be evident later in life. Thus for both studies the relationship between age and executive performance may appear linear. In order to assess the nature of the developmental trajectory of executive performance, investigation of the performance of participants across the whole adult age range (i.e., from 18 to 85 + years), or longitudinal studies, are required.

The results from the regression analyses examining the mediating effects of executive function and general cognitive ability on the relationship between age and memory performance support the findings from Study 1. As in Study 1, executive function accounted for more of the age-related variance in memory than did general cognitive ability as measured by four subtests of the WAIS-R. Further, and as predicted, executive function continued to predict recall, and further age-related variance in it, after controlling for WAIS-R scores. However, WAIS-R scores did not predict recall, or account for any more of the age-related variance in recall after controlling for executive function. As mentioned earlier, the measure of general cognitive ability used in Study 2 was a reflection of verbal ability, as the subtests used came from the Verbal subscale of the WAIS-R. If Full Scale scores had been available for the present study, and used in the regression analyses, there may have been more of an overlap in the contribution of executive function and general cognitive ability as was found in Study 1.

Even so, these results support the findings from Study 1 and from Troyer et al. (1994). It is useful to closely compare the current study with that of Troyer et al. because the age range of the participants is virtually identical. Likewise, the findings from the current study and those from Troyer et al. are strikingly similar. The correlation between age and memory in the current study ($r = -.50$) compares well with the correlation found by Troyer et al. ($r = -.47$). Similarly, the correlation between executive performance and memory in the current study ($r = .57$) is similar to that found by Troyer et al. ($r = .60$). However, Troyer et al. found that the relationship between age and memory performance was completely mediated by executive function.

In summary, the results of Study 2 indicate that there are age-related declines in executive function, and provide some evidence of a differential age-related decline on the MCST compared with general cognitive ability among older adults. In addition, the findings indicate that executive function mediates much of the age-related variance in memory over and above that contributed by general cognitive ability. The results from both Studies 1 and 2 are consistent with the hypothesis that age-related declines in memory performance are associated with declines in executive function but Study 1 indicates that the relative contribution of executive function and processing resources to age-related memory decline needs to be investigated.

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