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AGE-ASSOCIATED CHANGES IN COGNITIVE FUNCTION IN HIGHLY EDUCATED ADULTS: EMERGING MYTHS AND REALITIES

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ABSTRACT

The effects of education and continued intellectual engagement on age-associated cognitive change were investigated in a sample of 102 members of the professional and college communities in the metro Atlanta Georgia area (ages 30–76). All participants were administered a 60-minute battery that measured different aspects of memory, intelligence and cognitive performance. Age-associated declines in performance were detected on the digit symbol measure of intelligence. Conversely, positive but non-significant trends were detected on the picture completion, arithmetic and similarities subtests. Age effects were also noted on some measures of the Wisconsin Card Sorting Test and both versions of the Trail Making Test. The findings suggest that at least among the highly educated, certain cognitive abilities may receive some degree of amelioration as a consequence of continued intellectual engagement. However, the effects may be associated more with compensation rather than protection against the effects of ageing. Copyright © 2000 John Wiley & Sons, Ltd

KEY WORDS—ageing; intelligence; memory; attention

While a number of theories of psychometric intellectual ability have been put forward, one proposed by Horn and Cattell (1966) has proven to be quite useful for the assessment of age-associated changes in cognitive ability. Horn and Cattell originally characterized intelligence in terms of two factors, crystallized intelligence (G,) and fluid intelligence (G,). Crystallized intellectual abilities include those aspects of intelligence influenced by educational and cultural opportunities. Conversely, fluid intelligence is composed of a set of abilities acquired as a result of genetic factors (Horn, 1991; Horn and Cattell, 1966). Although the conceptualization of these two factors has undergone considerable theoretical evolution, G_c and G_f have remained an essential part of the theory.

Currently, the theory includes consideration of eight cognitive factors that together comprise general intelligence or G. These factors include the evolved G_f and G_c factors (now labelled fluid reasoning and comprehensive knowledge, respectively). processing speed (G,), short-term memory and (G,,), long-term retrieval (G,,), quantitative ability (G,), auditory processing (G,) and visual processing (G_v; Bickley *et al.*, 1995). Germane to the present discussion are the factors of G_f, G_s and G_{sm}, which are considered susceptible to the effects of the ageing process (Bickley et al., 1995; Horn, 1982), with evidence that G_f is particularly vulnerable to the effects of ageing. Conversely, there is no evidence available that suggests that the G_q, G_{lr} and G_c factors are adversely impacted by the ageing process (Horn, 1970; Horn *et al.*, 1981; Horn and Hofer, 1992; Wang and Kaufman, 1993).

Where found, the actual rate of intellectual decline observed in older adults is a source of some controversy (Cornelius and Caspi, 1987; Kaufman *et al.*, 1989; Siegler and Botwinick, 1979). Nonetheless, although many older adults have attained a tremendous pool of knowledge from their life experiences, the available evidence does suggest that at least some aspects of intellectual function decline (eg Horn and Cattell, 1967; Kaufman *et* al., 1989; Salthouse, 1992). One factor that can influence the assessment of normative

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changes in intellectual ability involves the reports of considerable variability in cognitive performance among older adults (Albert *et al.*, 1987; Shimamura, 1990; Siegler and Botwinick, 1979; Sward, 1945; Zelinski *et al.*, 1993). As a result, a representative cross-section of adults may include a broad spectrum of individuals ranging from those with little or no demonstrable change in cognitive performance to others with severe cognitive deficits (Shimamura *et al.*, 1995). The end result may be one of a substantial increase in within-group variability (Siegler and Botwinick, 1979; Sward, 1945).

Generally, where age-associated changes in intellectual function are detected, such changes occur gradually throughout adulthood (Compton *et al.*, 1997; Cornelius and Caspi, 1987). For example, Kaufman et *a/.* (1989) found a gradual reduction in full-scale IQ from ages 20 through 64. After the age of 64, more substantial declines in IQ were found. Nonetheless, in one longitudinal investigation (Siegler and Botwinick, 1979) of older adults 69994 years of age, significant declines were observed only in individuals when they were 85 years old or older. Apparently, intellectual changes include a mixed pattern of both decline and growth. In a series of observations with 50–70-year-old individuals, Cornelius and Caspi (1987) found an increase in measures of G_c but a decrease in measures of G,.

Among other factors, the amount of formal education can have a marked influence on the successful ageing of older adults (Shimamura *et al.*, 1995). Coupled with factors such as general health, genetic predisposition to illness and disease and socioeconomic status, years of formal education and continued cognitive stimulation certainly contribute to the somewhat large within-group variability seen in older adults. Thus, the purpose of the present investigation was to explore further the issue of age-associated changes in intellectual performance using a sample composed of individuals with a high level of education. Additionally, in order to provide further illumination concerning the subset of factors that may contribute to successful ageing (Albert *et al.*, 1987; Baltes and Baltes, 1990; Schaie, 1990, 1994; Shimamura *et al.*, 1995), we examined the effect of continued intellectual stimulation on intellectual and cognitive performance. Thus, the present investigation was conducted in order to provide further support for our previous observations (Compton *et al.*, 1997), as well as those of others (eg Colsher and Wallace, 1991; Evans *et al.*, 1993; Shimamura *et al.*, 1995; Sward, 1945; White *et al.*, 1994), that education and continued intellectual stimulation provide either a protective effect or compensatory strategy mitigating the intellectual (ie fluid and crystallized intelligence), memory and other cognitive changes collectively considered as components of the blanket term ‘cognition’ that often accompany ageing.

METHODS

Participants

In all, the investigation was based on a convenience sample consisting of 102 (53 men and 49 women) highly educated adults with an average age of 47.82 years. An additional 10 individuals were contacted but declined to participate or were excluded because of a current medical condition. Five individuals agreed to participate but terminated participation during the course of the assessment, producing a final sample size of 102 participants. Of the 102 participants, 94 were of Caucasian ancestry. Eighty-six participants were active college professors. The remaining 17 participants were members of the metro Atlanta professional community, with full-time active programmes in some form of community-based or industrial research activity that required a considerable amount of reading and writing. Thus, all participants were currently engaged in at least moderately demanding cognitive activities. Finally, all participants were born in the continental United States and used English as their primary language.

In order to assess possible age-associated changes in cognitive function across the lifespan, the participants were divided into four age groups: (1) a group of young professionals (13 men, 17 women) 30-39 years of age ($M =$ 34.09 years, SD = 3.71 years), with an average level of education of 18.59 years; (2) a group of middle-age professionals (12 men, 15 women) 40-49 years of age (M = 46.19 years, SD = 2.80 years), with an average of 19.18 years of education; (3) a group of late middle-age professionals (13 men, 12 women; M = 54.03 years, SD = 3.20 years), with an average of 19.92 years of education; and (4) a group of older professionals (14 men, six women), at least 60 years of age (A4 = 65.49 years, SD = 5.72 years), with an average of 19.47 years of education. The participants were initially contacted by phone and asked to participate in a study

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entitled 'age-related changes across the lifespan'. All participants were individually tested, with testing occurring at the participant's convenience.

Procedure

All testing occurred in a quiet room. The assessment battery consisted of subtests from a short version of the Wechsler Adult Intelligence Scales-Revised (WAIS-R; Wechsler, 1981) developed by Kaufman and colleagues (cf Kaufman, 1990), the Wechsler Memory Scales-Revised (Wechsler, 1987), a computerized version (Loong, 1990) of the Wisconsin Card Sorting Test (WCST; Heaton, 1981) and forms A and B of the Trail Making Test (Reitan, 1958). The assessment battery was designed to examine age-associated changes in cognitive performance (eg fluid and crystallized intelligence, memory, frontal lobe impairment) in about an hour.

Instruments

Wechsler Adult Intelligence Scales— Revised (WAIS-R). A brief version of the WAIS-R comprising the similarities, arithmetic, picture completion and digit symbol subtests was administered. This tetrad of subtests was selected because of its high reliability and validity coefficients (0.93 and 0.95; Kaufman, 1990, p. 135) with the IQ scores derived from the full WAIS-R and its short administration time. Full-scale IQ was derived from the four subtests using the formula proposed by Kaufman *et al.* (1991).

Wechsler Memory Scales—Revised. It has been reported that high verbal ability can offer some protection against age-related deficits tasks designed to assess recall for prose (eg Hartley, 1989; Meyer and Rice, 198 1). The logical memory I and 11 (immediate and delayed recall) and figural memory subtests of the Wechsler Memory Scales-Revised were chosen to assess verbal and pictorial memory. Scores on each subtest were converted to scaled scores for group comparisons. Despite some concern about the Wechsler Memory Scales-Revised (Spreen and Strauss, 1998), factor analytic results suggest that the subscales associated with the Wechsler Memory Scales-Revised and contributing to a General Memory Scale provide a good indicator of group differences in cognitive performance independent of estimates of intelligence (Kaufman, 1990).

Trails A und B. Part of the Halstead–Reitan Neuropsychological Battery (cf Reitan, 1985), trails A and B are considered measured of fluid intellectual ability. In addition, both are considered sensitive to neurological deficits, including those associated with motor and perceptual speed (Spreen and Strauss, 1998).

Wisconsin Curd Sorting Test (WCST). A computerized version of the WCST (Loong, 1990) was employed. The WCST is considered sensitive to frontal lobe impairment (Heaton, 1981). In addition, because the participant is required to acquire a learning strategy throughout the test and the requirements change without notice, abstract reasoning and mental flexibility are required. Thus, the WCST may also be considered a test of fluid intelligence (Compton *et al., 1997).*

Scoring and statistical analyses

Five individuals failed to complete the assessment battery. Of the five, three individuals were from the 40–49-year-old group. The other two were from the 30–39 and 60+ year-old groups, respectively. Available data from these five individuals were not considered in any of the bivariate or multivariate analyses. Lastly, although group sample sizes differed, these differences were non-significant, $\chi^2(3) = 2.07$, NS.

To reiterate, scores from the four WAIS-R subtests were converted to a full-scale IQ score. The WMS-R scores were converted to standard scores. One dependent measure, time to complete the task, was used as an index of performance on trail A and trail B. Finally, several different measures of performance were derived from the WCST (eg time to complete the task, per cent correct and errors, number of categories completed, etc). Computation of Pearson product-moment coefficients constituted a first level of analysis. Specifically, bivariate correlations were calculated between the variable age, the covariate education and the dependent measures. Following the bivariate analyses, the age groups were compared using multivariate analysis of covariance (MANCOVA) with years of education as the covariate. Although the range of educational background was restricted, education was included as a covariate to further refine estimates of experimental error (Keppel, 199 1).

The four age groups did not vary as a function of level of education, $F(3, 98)$ 1.44 NS. Before the

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results of the multivariate analyses were interpreted, the data were examined to determine if the appropriate multivariate assumptions were met (Stevens, 1992).

RESULTS

Bivariute analyses

Bivariate correlations between the variable of interest, age, the covariate, education, and all dependent measures are presented in Table 1. A significant inverse relationship between digit symbol performance and age, $r = -0.209$, $p < 0.05$, was observed. Conversely, a significant positive relationship between age and full-scale IQ, $r = 0.229$, $p < 0.05$, was detected. As expected, a significant relationship between years of education and full-scale IQ, $r = 0.304$, $p < 0.01$, was also observed, as was the crystallized intelligence measure of similarities, $r = 0.320$, $p < 0.01$. As such, this pattern of results is largely consistent with previous research (eg Compton *et al.*, 1997).

Age was associated with performance on trails A and B as well as the figural memory component of the Wechsler Memory Scales-Revised (see Table 1). However, unlike previous investigations in our laboratory, a significant association between age and logical memory II performance, $r = -0.193$, $p > 0.05$, was not detected. Interestingly, as can be seen in Table 1, significant relationships between all measured components of the Wechsler Memory Scales—Revised and education were found.

While WCST performance was not associated with education, age appeared to have an adverse impact on a number of measures of WCST performance. Significant associations between the age of the participant and WCST performance were found on time to complete the test, ı' = 0.30 1, $p < 0.01$. As expected, a positive relationship between the age of the respondents and reaction time was observed, $r = 0.494$, $p < 0.01$. This relationship is consistent with previous reports (Cerella, 1985; Compton *et al.*, 1997; Myerson *et al.*, 1992; Shimamura *et al.*, 1995) and is considered indicative of age-associated declines in cognitive functioning (Shimamura *et al.*, 1995). Given these relationships, the observed inverse relationship between the number of categories completed or the percentage of conceptual level responses and age, $rs = -0.353$ and -0.356, ps < 0.01, was not surprising. Finally, significant

Table 1. Pearson product-moment correlation coefficients

Test	Age	Education
WA IS-R		
Picture completion	0.097	0.215
Arithmetic	0.081	0.192
Digit symbol	-0.209”	0.203
Similarities	0.139	$0.304^{a,b}$
Full-scale IQ	$0.290^{a,b}$	$0.320^{a,b}$
Trails A & B		
Trails A	$0.362^{a,b}$	0.090
Trails B	$0.412^{a,b}$	0.121
Wechsler Memory Scales Revised		
Logical memory I	-0.128	$0.388^{a,b}$
Logical memory II	-0.193	$0.345^{a,b}$
Figural memory	-0.241”	$-0.336^{a,b}$
WCST		
Test duration	$0.301^{a,b}$	-0.155
Response time	$0.494^{a,b}$	-0.170
No. of categories completed	$-0.356^{a,b}$	0.156
Total trials	$0.320^{a,b}$	-0.098
No. of trials to complete I st category	0.130	0.078
Total no. correct	$-0.362^{a,b}$	0.117
Per cent correct	$0.351^{a,b}$	-0.126
Per cent perseverative errors	0.261”	-0.070
Per cent conceptual level responses	$-0.353^{a,b}$	0.121
Total no. failure-to-maintain sets	0.073	-0.059
Learning-to-learn	0.067	0.06 1

$^{a}p < 0.05$; $^{b}p < 0.01$, two-tailed test.

associations between age and the WCST measures of per cent correct, $r = -0.361$, $p < 0.01$, per cent errors, $r = 0.361$, $p < 0.01$ and per cent perseverative errors, $r = 0.261$, $p < 0.05$, were found. No relationship was detected between the remaining measures, number of trails to complete category one, failure-to-maintain response set and learning-to-learn, and age (ie ps > 0.05).

Multivariate analyses

Brief WAIS-R. Mean scaled scores for the four groups on the subscales of the Brief WAIS-R as well as the mean calculated full-scale IQ scores are provided in Table 2. A one-way multivariate analysis of covariance (MANCOVA) with education as the covariate revealed a significant effect of age, Wilks' $\lambda = 0.758$, approximate $F(15, 251) = 1.77$, $p < 0.05$. Closer examination of each dependent measure revealed an age effect on only digit symbol performance, $F(3, 95) = 3.61$, $p < 0.02$, $\omega^2 = 0.073$. As can be seen in Table 2, pairwise

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Table 2. Summary statistics for the cognitive measures

Cognitive measure	Age group			
	30–39[b] M (SD)	40–49[c] M (SD)	50–59[d] M (SD)	60 + [e] M (SD)
WAIS-R[a]				
Digital symbol	II.84 (1.97)	12.03 (2.29)	10.75 (1.97)	10.77 (2.32)
Arithmetic	II.53 (3.09)	11.85 (2.18)	12.62 (2.06)	11.77 (2.18)
Similarities	II.58 (2.17)	11.63 (2.33)	12.70 (1.92)	12.50 (2.53)
Picture completion	10.29 (1.90)	10.18 (3.00)	II.00 (2.21)	II.05 (1.92)
Full-scale IQ	109.46 (9.05)	112.55 (8.53)	113.90 (15.27)	116.74 (7.58)
Trails A'	21.42 (6.97)	30.73 (8.99)	30. I3 (7.06)	36.86 (9.19)
Trails B	55.61 (20.85)	57.80 (14.47)	61.98 (15.10)	82.63 (20.49)
Wechsler Memory Scales—Revised				
Figural memory	9.97 (2.99)	8.85 (2.58)	8.92 (2.10)	8.00 (2.35)
Logical memory I	20.59 (12.69)	18.82 (10.00)	19.79 (12.04)	18.28 (9.34)
Logical memory II	18.88 (10.61)	16.22 (8.28)	17.29 (10.15)	15.61 (8.61)
WCST				
Average response time	2.49 (1.04)	2.87 (1.10)	3.44 (0.99)	3.82 (1.07)
Mean categories completed	5.00 (1.59)	4.93 (1.75)	4.04 (2.44)	3.25 (2.57)
Mean perseverative errors	8.05 (8.71)	8.41 (12.22)	II.22 (11.01)	16.43 (14.06)
Mean % conceptual level responses	77.67 (15.62)	77.46 (1 5.48)	69.55 (21.68)	60.16 (24.26)

[a]Mean standard scores and estimated full-scale IQ from the brief version (see text) of the WAIS-R
[b]$n = 30$; [c]$n = 27$; [d]$n = 25$; [e]$n = 20$.
[f]Mean completion time in seconds.

comparisons using Tukey_A ($p < 0.05$) indicated that digit symbol in the 30-39 and 40–49-year-old groups was superior to that of the 50–59-year-old and 60+ year-old groups. Digit symbol performance in the latter two groups was comparable.

Trails A and B. Following a significant MANCOVA, Wilks' $\lambda = 0.747$, approximate $F(6, 192) = 5.03$, $p < 0.001$, both univariate F-tests generated by the MANCOVA indicated the presence of an age effect in both trail A and trail B performance (Fs(3, 97) = 5.06 and 9.04, $ps < 0.005$, ω^2s = 0.108 and 0.193, trail A and trail B, respectively). As can be seen in Table 2, individuals in the 60 + year-old group took significantly more time to complete both versions of the Trail Making Test. The performance of the other three groups was similar.

Wechsler Memory Scales- Revised. Group performances on all dependent measures of the Wechsler Memory Scales were similar. Therefore, no further analyses of Wechsler Memory Scales—Revised performance were conducted.

WCST. Following a significant MANCOVA, Wilks' $\lambda = 0.522$, approximate $F(33, 259) = 1.95$, $p < 0.005$, the univariate analyses revealed significant differences in reaction time (see Table 2), $F(3, 98) = 9.93$, $p < 0.001$, $\omega^2 = 0.208$, number of categories completed (see Table 2), $F(3, 98) = 4.63$, $p < 0.01$, $\omega^2 = 0.096$, and related to this, the total number of trials, $F(3, 98) = 4.63$, $p < 0.01$, $\omega^2 = 0.074$.

Tukey_A tests used to explore the detected age effect further suggested a rather profound age-associated impairment. First, individuals in the 50-59 and 60 + year-old groups took significantly more time to respond then either of the younger two groups. However, reaction times in the latter two groups were not significantly different. Second, the younger three groups completed significantly more categories than the members of the 60 + year-old group. Interestingly, no differences were detected in the number of trials necessary to complete the first category, $F(3, 97) = 0.19$, NS (range: A4 = 16.96, 30–39-year-olds vs A4 = 20.50, 50–59-year-olds). Finally, the 60+ year-olds required significantly more trials than

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the other three age groups, where performances were similar.

In addition to the effects reported above, as a result of the univariate analyses, a significant effect of age was detected on the per cent correct, $F(3, 98) = 5.29$, $p < 0.005$, $\omega^2 = 0.112$, per cent errors, $F(3, 98) = 5.29$, $p < 0.005$, $\omega = 0.112$, per cent perseverative errors, $F(3, 98) = 2.86$, $p < 0.05$, $\omega^2 = 0.052$ and the per cent conceptual level responses, $F(3, 98) = 5.03$, $p < 0.005$, $\omega^2 = 0.106$, measures of the WCST (see Table 2). Closer examination of the significant age effects with Tukey_A tests revealed the following. First, although the per cent of correct responses shows a general decline with age, only the 60+ year-old group was significantly different. A similar trend was observed in an analysis of the percentage of perseverative errors. In fact, as can be seen in Table 2, once middle age is reached, it appears that perseverative responses are significantly more likely with advancing age. Finally, the 50-59 and 60+ year-old groups made significantly fewer conceptual level responses than either of the two younger groups, which did not differ. It is noteworthy that the 60 + year-old participants made significantly fewer conceptual responses than even the 50–59-year-old group.

DISCUSSION

The present investigation of different aspects of human cognition in a highly educated sample has highlighted several neuropsychological features associated with ageing. Age differences in performance were observed on a number of tasks, including some generally associated with the assessment of psychomotor speed. Further, these age differences in performance were observed even after controlling for differences in education.

Nonetheless, the results are consistent with the idea that certain cognitive experiences can provide some protection, maintaining or perhaps even enhancing cognitive performance at least into late adulthood (eg Charness, 1989; Salthouse, 1987). The present results are generally in accord with previous reports suggesting that above-average intelligence and the effects of education may provide some moderating influence on the changes in cognitive performance associated with ageing (eg Avolio and Waldman, 1994; Christensen and Henderson, 1991; Osterweil *et al.*, 1994; Shimamura *et al.*, 1995; Sward, 1945). A low level of education is associated with an increased level of deterioration in cognitive performance (Colsher and Wallace, 1991; Farmer *et al.*, 1995). Thus, coupled with the effects of good health (Perlmutter and Nyquist, 1990), appropriate occupation (Avolio and Waldman,1994) and active engagement in the surrounding environment (Schooler, 1984, 1990), continued intellectual stimulation may offset at least some of the normative changes that accompany ageing (Christensen *et al.*, 1997a). Nonetheless, as pointed out by Christensen *et al.* (1997a,b) and others (eg Gold *et al.*, 1995; Hultsch and Dixon, 1990; Hultsch *et al.*, 1990; Shimamura *et al.*,1995), while intellectual ability and continued intellectual or educational experiences may provide an ameliorative effect, such protection appears to extend primarily to verbal abilities.

Even so, the results are not unequivocal. For example, in a recent report of a 5-year longitudinal investigation, Christensen *et al.* (1997a) noted a decline in the verbal intellectual abilities of academics, as measured by the similarities subtest of the WAIS-R and the National Adult Reading Test (NART; Nelson, 1982). Similarities is considered a test of crystallized (G,) intellectual ability. The decline was comparable to that of a sample of blue-collar workers and apparently not attributable to ceiling effects among the academic sample. Further, longitudinal assessment of blue-collar and academics performance suggested similar levels of decline on tests of fluid intellectual ability (Symbol Digit Modalities Test, Smith, 1973; Raven's Progressive Matrices, Raven, 1984). In an investigation of old elderly who were nonetheless health and free of neurological impairment, significant age differences were observed on the logical memory component of the Wechsler Memory Scales—Revised and picture completion and block design components of the WAIS-R (Howieson *et al.*, 1993).

No age-associated differences in performance on any of the Wechsler Memory Scales-Revised scales were detected, a result that is in accord with our previous report (Compton *et al.*, 1997). While this finding is incongruent with some theories of the effects of ageing on memory function (eg Verhaegen *et al.*, 1993), it is possible that the Wechsler Memory Scales-Revised measures were not sufficiently sensitive to detect the differences among a highly educated sample (Kaufman, 1990; Waldmann *et al.*, 1991).

Although some of the results are congruent with those reported by other investigators, some

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important differences were detected. For example, while Kaufman *et al.* (1989) reported an age-associated decline in full-scale IQ, consistent with a previous report from our laboratory (Compton *et al.*, 1997), in the present study a positive but non-significant linear trend was detected (see Table 2). In Compton *et al.*, age accounted for approximately 31% of the variance in full-scale IQ. Bivariate correlations in the present study suggested that age accounted for about 29% of the variance.

On the basis of neuropsychological assessments of older adults, it can be argued that there is an age-associated decline in at least some higher-order cognitive abilities such as problem-solving, planning and organization (Denney and Pearce, 1989; Shimamura *et al.*, 1995). While still open to debate, much of the available evidence suggests that the observed intellectual changes are due to processes such as neural atrophy of regions of the frontal cortex (Haug et al., 1983; see Coleman and Flood, 1987 and Ivy *et al.*, 1992, for a review). Nonetheless, a greater loss of neurons actually occurs during the perinatal period, at least in normal adults (Scheibel, 1996). Further, according to Scheibel, neuronal plasticity is observed through the lifespan, allowing for the opportunity for continued cognitive growth.

Attempts have been made to determine the nature of intellectual changes that occur at the neural level (see Moscovitch and Winocur, 1992, for a review). Using a number of approaches such as the assessment of release from proactive inhibition (Moscovitch and Winocur, 1983), changes to source memory (Craik *et al.*, 1990; Parkin and Walter, 1992) and assessment of short-term memory (Parkin and Walter, 199 1), investigators have focused on frontal lobe dysfunction in an attempt to examine a possible linkage between frontal lobe deterioration and age-associated changes in fluid intelligence (eg Isingrini and Vazou, 1997). Further, requiring conceptual reasoning for successful performance, the WAIS-R similarities subtest may be especially sensitive to frontal lobe pathology (Lezak, 1995). Thus, on the basis of the present results on the similarities subtest as well as elements of the WCST and other investigations (Isingrini and Vazou, 1997; Lezak, 1995; Pillon and Dubois, 1992; see also Salthouse, 1991), it could be argued that the observed age-associated differences in fluid intellectual functioning are due to changes in the efficiency of function in areas of the frontal lobe (Isingrini and Vazou, 1997).

It has been suggested that high verbal ability attenuates the age-associated memory deficits typically reported (Zelinski and Gilewski, 1988). In one study of older adults with high verbal ability (Meyer and Rice, 1989, cited in Hultsch and Dixon, 1990), recall was comparable to that of young adults, at least on some measures of cognitive ability. Further, while highly verbal older adults may not remember prose passages as well as young adults, they do perform equally well in identifying the main ideas (Dixon *et al.*, 1984).

In the present study, age appeared to be relevant on some of the neuropsychological measures that include a perceptual or psychomotor speed component. Consistent with prior research, an effect of age was detected on both trails A and B performance. While the argument has been raised that such inferior performance on these tasks can be attributed to psychomotor speed (eg LaRue and D'Elia, 1985), other research contradicts this position (Horn and Cattell, 1967; Kaufman *et al.*, 199 1; Kennedy, 198 1; Salthouse, 1994; Storandt, 1976). For example, Storandt (1976) compared two forms of the WAIS digit symbol subtest. The standard version required the coding of symbols oas a way to monitor cognitive speed. To measure motor speed, a modified version was used where the participant was only required to copy the symbols. The results suggested that some of the age-associated differences in performance may be attributable to changes in cognition as well. Thus, according to the above research and Salthouse (1994), the inferior performance on the Trail Making Test and components of the WCST observed in our older participants could be attributed to age-related declines in cognitive processing.

On the basis of the preservation of at least some aspects of cognitive function observed here as well as reported by others (eg Compton *et al.*, 1997; Dixon *et al.*, 1984; Shimamura *et al.*, 1995; Sward, 1945; Zelinski and Gilewski, 1988), at least two compatible processes are suggested. First, given the intellectual demands associated with their occupation, college professors may develop compensatory strategies and adapt to changes in cognitive ability. Certainly, possessing a certain basal level of intellectual ability and having their respective disciplines developed during such protracted and advanced education, an enhanced ability to compensate for changing performance is realistic. Second, the level of mental activity incumbent

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with the demands of the academic world may minimize the reported age changes or differences that normally accompany ageing (Shimamura *et al.*, 1995).

Thus, it may be that there is a 'slowing' of the biological ageing process among the highly educated and presumably intellectually engaged (cf Orrell and Sahakian, 1995). On the other hand, the observed protective effects of a high level of education may be more a result of compensation, mostly as a direct result of the concomitantly higher levels of expertise, verbal knowledge and ability. If this is so, these crystallized intellectual advantages would serve as a means for compensatory strategies in a number of cognitive domains, perhaps masking otherwise similar rates of biological ageing (Christensen *et al.*, 1997b). This latter explanation has, in fact, received some indirect or direct support (eg Christensen and Henderson, 1991; Christensen *et al.*,1997a,b; Foulds and Raven, 1948).

As has been noted elsewhere (Verhaegen *et al.*, 1993), it is questionable whether conventional measures of intelligence are relevant to the daily intellectual demands experienced by the elderly. Further, the question remains as to whether age-associated declines in cognitive ability, where found, are indicative of actual impairment. At any rate, the present data suggest that the effects of education, coupled with continued intellectual experiences, may offset some of the cognitive declines associated with the ageing process. However, as Christensen *et al.* (1997b) point out, such effects may provide the individual with greater compensatory resources rather than protection against the consequences of biological ageing.

Limitations of the present investigation

One limitation of the present investigation and shared by cross-sectional research in general is the problem of potential cohort effects. Generational shifts in performance on measures of mental abilities are well documented (Schaie, 1989, 1995; Willis, 1989), with advantages typically observed among later born cohorts. Such advantages have been explained in terms of greater educational opportunities and improved nutritional, medical and other lifestyle variables (Schaie. 1996). Thus, the present results are suggestive of patterns of age 'differences' rather than age 'change' or decline. Nonetheless, our results provide additional support for the proposal that the effects of higher levels of education, coupled with continued intellectual challenges, may at the very least provide a compensatory strategy or perhaps even to some extent offset some of the cognitive declines associated with the ageing process.

Another limitation of the present investigation suggested by a reviewer was the lack of a control group consisting of adults with more normative educational experiences. Because of the available data on the intellectual performance of older adults with a high school education or less (eg Blum and Jarvik, 1974; Granick and Friedman, 1973), such a control group was not included. However, the younger members of the sample (ie the 30–39-year-old group) may be considered an appropriate comparison group.

An additional area of concern, and one noted previously, was the issue of psychomotor speed. Although we did not make any formal attempt to determine the specific level of motoric ability among the participants, all participants were queried about medical conditions and/or medications that could have influence the test results. Individuals with such conditions were excluded from the study.

Several personality factors have been suggested as an important component in understanding age changes in intellectual performance. Among these is a flexible attitude on entering midlife. In one research report (Schaie, 1995), individuals with more flexible attitudes experience less intellectual decline than individuals with more rigid attitudes. In addition, motor-cognitive flexibility in older adults is associated with verbal and numerical abilities (O'Hanlon, 1993). While personality variables were not examined in the present study, owing to their possible moderating influence on intellectual ability (Schaie, 1995), this could be considered an important limitation of the study.

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