Note

Bilingualism as a protection against the onset of symptoms of dementia

Ellen Bialystok [a,b,*], Fergus I.M. Craik [b,c], Morris Freedman [b,d,e]

[a] *Department of Psychology, York University, 4700 Keele Street, Toronto, Ontario, Canada M3J 1P3*
[b] *Rotman Research Institute at Baycrest, Canada*
[c] *Department of Psychology, University of Toronto, Canada*
[d] *Division of Neurology, Baycrest, Canada*
[e] *Department of Medicine, Division of Neurology, Mt. Sinai Hospital, University Health Network, and University of Toronto, Canada*

Abstract

This study examined the effect of lifelong bilingualism on maintaining cognitive functioning and delaying the onset of symptoms of dementia in old age. The sample was selected from the records of 228 patients referred to a Memory Clinic with cognitive complaints. The final sample consisted of 184 patients diagnosed with dementia, 51% of whom were bilingual. The bilinguals showed symptoms of dementia 4 years later than monolinguals, all other measures being equivalent. Additionally, the rate of decline in Mini-Mental State Examination (MMSE) scores over the 4 years subsequent to the diagnosis was the same for a subset of patients in the two groups, suggesting a shift in onset age with no change in rate of progression.
© 2006 Elsevier Ltd. All rights reserved.

Keywords: Bilingualism; Cognitive reserve; Dementia

Factors that may delay onset of dementia are of great importance given the social and economic burden of this disorder. According to Brookmeyer, Gray and Kawas (1998), a 2-year delay in onset of Alzheimer's disease (AD) would reduce the prevalence in the United States by 1.94 million after 50 years, and delays as short as 6 months could have substantial public health implications. Many of the factors predisposing a person to dementia are biological (Corder et al., 1993), so the search for methods to delay onset has focused largely on pharmacological and other biologically-based therapies. There is growing evidence, however, that some environmental factors can maintain cognitive functioning in older adults and mitigate the effects of illnesses that produce dementia. Notably, research on "cognitive reserve" has demonstrated that lifestyle factors, such as physical activity, stimulating leisure involvement, and social engagement play a role in postponing the onset of AD and other dementias (Alexander et al., 1997; Scarmeas, Levy, Tang, Manly, & Stern, 2001; Scarmeas & Stern, 2003; Singh-Manoux et al., 2003; Stern, 2002).

The literature on brain reserve is somewhat contentious, but several recent large-scale reviews have provided a context for conflicting results. The overall notion is that some factors allow a person to function within a normal cognitive range, despite the presence of brain pathology that would usually be associated with dementia. For example, Mortimer (1997) found that between 10 and 40% of autopsy cases showing brain pathology exceeding the criteria for AD had shown no signs of cognitive impairment before death. Similarly a population-based study carried out by the UK Medical Research Council (quoted by Valenzuela & Sachdev, 2006a) found that more than 30% of individuals with mild and severe AD pathology at autopsy had shown no previous signs of cognitive impairment. Valenzuela and Sachdev (2006a) distinguish between, 'neurological brain reserve' and 'behavioral brain reserve.' Proponents of neurological brain reserve argue that peak brain volume can ameliorate the effects of brain pathology on cognitive performance and signs of dementia. This type of brain reserve is thus presumably biological and possibly genetic in origin. On the other hand, behavioral brain reserve (also referred to as cognitive reserve, the term used in the present report) suggests that sustained complex mental activity protects against dementia in terms of both incidence (Valenzuela & Sachdev, 2006a) and the rate of cognitive decline in elderly individuals (Valenzuela & Sachdev, 2006b).

In their review of behavioral brain reserve, Valenzuela and Sachdev (2006a) found strong evidence for protection against

---

dementia provided by education, high occupational status, high levels of premorbid intelligence, and mentally stimulating leisure activities. Importantly, most of the studies included in the review found significant effects of the protective variable in question after co-varying out age and other brain-reserve measures. One surprising conclusion of the review was that "it is evident that mentally stimulating leisure activity is the most robust brain-reserve measure, since all these studies showed a significant protective effect even after controlling for age, education, occupation and other potential confounds" (Valenzuela & Sachdev, 2006a, p. 447). The authors found an overall decrease in incident dementia of 46% after a median follow-up interval of 7.1 years; these figures are based on a total of over 29,000 individuals from 22 studies. It is important to note the authors' caution that higher levels of behavioral brain reserve may simply delay the onset of dementia, rather than reduce incidence in an absolute manner. In a comparison piece, the same authors conducted a review of studies of longitudinal cognitive change and factors ameliorating cognitive decline in the elderly (Valenzuela & Sachdev, 2006b). This second review was based on a new sample of 18 studies involving more that 47,000 individuals; the main finding was that higher levels of behavioral brain reserve were related to decreased rates of cognitive decline. The contributors to behavioral brain reserve were again higher levels of education, occupation, and stimulating leisure and social activities. A review of longitudinal studies by Fratiglioni, Paillard-Borg, and Winblad (2004) also found strong evidence for the role of social, mental, and physical activities in protecting against all types of dementia. Similarly, Staff, Murray, Deary, and Whalley (2004) concluded that "more education and a more cognitively complex occupation predict higher cognitive ability in old age than would be expected for a person's childhood ability and accumulated brain burden" (p. 1196). From these reviews, it seems clear that complex mental activity across the lifespan acts to at least delay the incidence of dementia. Two sets of questions follow from this conclusion; first, what types of mental activity yield this protective function and do they have features in common? Second, what is the mechanism linking mental activity to its neuroprotective function?

The present report contributes to the first question by demonstrating a further type of mental activity that may be associated with a delay in the appearance of the symptoms of dementia. The activity in question is the constant use of two languages over many years. Bilingualism has been shown to enhance attention and cognitive control in both children (Bialystok, 2001) and older adults (Bialystok, Craik, Klein, & Viswanathan, 2004; Bialystok, Craik, & Ryan, 2006). In these studies, lifelong bilinguals who use both languages in their daily lives showed an advantage in a variety of tasks involving attentional control. The suggested interpretation is that the use of two languages requires a mechanism to control attention to the relevant language and ignore or inhibit interference from the competing language (Green, 1998). This experience provides continual practice in attentional control and results in its earlier development in children, improved functioning in adults, and slower decline in older age. Therefore, bilingualism might contribute to cognitive reserve and protect older adults from decline in

the context of dementia. This hypothesis was examined in the present study.

Cognitive reserve is considered to provide a general protective function, possibly due to enhanced neural plasticity, compensatory use of alternative brain regions, or enriched brain vasculature (Fratiglioni et al., 2004). Since cognitive reserve occurs independently of any specific conditions, such as AD, our study sample included all cases of dementia regardless of diagnosis.

1. Method

We examined the records of consecutive 228 patients who were referred to the Memory Clinic at Baycrest in Toronto, Canada, between 2002 and 2005 with cognitive complaints. In addition to a medical history, physical examination, and mental status evaluation, patients were usually assessed with CT, SPECT, and screening blood tests. There were two exclusion criteria that reduced this sample by 44 patients, leaving a final sample of 184. First, 23 patients (12 monolinguals and 11 bilinguals) received a diagnosis that did not include dementia (e.g., depression, mild cognitive impairment), so were not considered further. Second, 21 patients could not be clearly classified as monolingual or bilingual (see below) and were therefore excluded as well. Of the remaining 184 patients, 132 patients met criteria for probable AD by consensus among a group of medically qualified Clinic staff, including at least one neurologist, using NINCDS–ADRDA criteria (McKhann et al., 1984). A further 52 patients were diagnosed with other dementias, including possible AD, dementia due to other neurodegenerative disorders, and cerebrovascular disease.

The age of onset of cognitive impairment was determined by the interviewing neurologist at the first clinic visit who asked patients and their families or caregivers when symptoms were first noticed. Although this approach involves a subjective estimate by patients and their families, it was applied equally to all cases. We see no reason to expect that monolinguals and bilinguals or their families should differ systematically in this judgment, and therefore no reason to expect systematic bias in the clinical information that was recorded. Moreover, the histories were taken prior to any knowledge of the current study.

The files contained the following information about language history: languages spoken, English fluency, place of birth, date of birth, and year of immigration to Canada. This information, without any other details, was given to 11 judges experienced in conducting behavioral research with bilinguals who classified each patient as monolingual or bilingual. The criterion for bilingualism was that patients had spent the majority of their lives, at least from early adulthood, regularly using at least two languages. The judges did not reach a consensus for 21 patients, so these were eliminated from further analyses. Inter-rater reliability was .95 (S.D. = 0.04) for designating an individual as monolingual and .81 (S.D. = 0.08) for designating as bilingual. Immigration occurred predominantly in the 1940s ($n = 14$), 1950s ($n = 25$), and 1960s ($n = 17$). The bilinguals included speakers of 25 different first languages, of which the most common examples were Polish ($n = 20$), Yiddish ($n = 13$), German ($n = 12$), Romanian ($n = 8$), and Hungarian ($n = 7$). Many of these individuals were bilingual prior to arriving in Canada. The data also included scores from Mini-Mental State Examination (MMSE) (Folstein, Folstein, & McHugh, 1975) at the initial appointment, years of education, and occupation.

To summarize, the final sample consisted of 184 patients, of whom 91 were monolingual and 93 were bilingual. There were 66 patients in each language group diagnosed with probable AD, comprising 73% of monolinguals and 71% of the bilinguals. AD was sometimes accompanied by other conditions, such as cerebrovascular disease, depression, psychosis, meningioma, and sleep apnea.

2. Results

The mean values for the relevant variables are reported in Table 1. The difference between monolinguals and bilinguals of 4.1 years in age of onset of symptoms of dementia is significant, $F(1,178) = 9.16$, $p < 0.003$, with no difference between

Table 1
Mean value (and standard deviation) for descriptors for each language group

Language group	N	Age of onset	Age at first appointment	Years of education	MMSE at first appointment	Occupation status
Monolingual	91	**71.4 (9.6)**	**75.4 (9.3)**	**12.4 (3.8)**	**21.3 (6.4)**	**3.3 (1.5)**
Men	43	70.8 (9.5)	76.2 (9.1)	12.9 (4.8)	20.5 (6.8)	3.6 (1.5)
Women	48	71.9 (9.8)	74.7 (9.5)	11.9 (2.8)	22.0 (5.9)	3.0 (1.4)
Bilingual	93	**75.5 (8.5)**	**78.6 (8.4)**	**10.8 (4.2)**	**20.1 (7.1)**	**3.0 (1.6)**
Men	38	76.1 (5.9)	79.4 (6.3)	10.8 (4.8)	20.7 (7.5)	3.0 (1.7)
Women	55	75.1 (9.9)	78.1 (9.6)	10.7 (3.7)	19.6 (6.8)	3.1 (1.4)

men and women, $F < 1$. The power of this effect with $\alpha = 0.05$ is 0.87. In addition, bilinguals were 3.2 years older than monolinguals at the time of the initial clinic appointment, a difference that was also significant, $F(1,180) = 5.93$, $p < 0.02$, with no difference between men and women, $F < 1$. We also analyzed these data separately for diagnoses of AD and other dementias. The delayed onset of symptoms for bilinguals was significant both in the subsample of 132 patients with probable AD, $F(1,128) = 7.07$, $p < 0.009$, with a delay of 4.3 years, and for the other dementias, $F(1,47) = 3.81$, $p < 0.04$, with a delay of 3.5 years.

The scores out of 30 on the MMSE, administered at the initial clinic visit, showed no difference between patients in the two language groups, $F(1,161) = 1.29$, n.s., and no difference between men and women, $F < 1$. We nonetheless carried out an analysis of covariance on the age of onset data, using gender as the covariate. This analysis yielded adjusted scores for age of onset of 71.4 years for monolinguals and 75.5 years for bilinguals; this difference was significant, $F(1,179) = 9.13$, $p < 0.003$.

Research on cognitive reserve has pointed to formal education as a protective factor against the onset of dementia (Bennett et al., 2003; Staff et al., 2004). A comparison of the years of schooling for the participants in the two groups (Table 1) indicates that the bilinguals had significantly fewer years of education, $F(1,171) = 7.06$, $p < 0.009$, with no difference by gender, $F < 1$. An analysis of covariance on age of onset data using years of education as the covariate yielded adjusted age of onset scores of 71.7 years for monolinguals and 75.2 years for bilinguals; this difference was significant, $F(1,170) = 6.18$, $p < 0.02$. The lower value for years of schooling for the bilingual group may reflect differences in opportunity more than ability, given that many individuals in that group came from Europe and their lives were disrupted by World War II.

The bilinguals varied widely in their cultural experiences, but we considered whether there might be a general bias in which bilinguals avoided seeking medical attention longer than monolinguals. However, Table 1 shows that the interval between onset of symptoms and the first clinic visit is actually shorter (3.0 years) for the bilinguals than for the monolinguals (3.8 years), a difference that was almost significant, $F(1,178) = 3.69$, $p = 0.06$. There was a main effect of gender, $F(1,178) = 8.84$, $p < 0.003$, in which men postponed clinic visits longer than women, and an interaction of language group and gender, $F(1,178) = 5.35$, $p < 0.02$, because monolingual males were particularly slow in seeking medical attention.

On a related point, most of the bilinguals (81/93) were immigrants to Canada, whereas most of the monolinguals (78/91) were not, and it is possible that immigrants delayed visiting the clinic. We conducted a two-way ANOVA for language group and immigration status on the interval between onset of symptoms and time of appointment and found no effect of either language group, $F(1,177) = 3.33$, $p = 0.07$, or immigration status, $F(1,177) = 1.85$, n.s. A further analysis examined the age of onset of symptoms of dementia for only those individuals in the two language groups who were immigrants (monolinguals = 13, bilinguals = 81). The age of onset for monolinguals was 63.8 years and for bilinguals it was 75.3 years, a difference that was highly significant, $F(1,92) = 17.96$, $p < 0.0001$.

Higher occupation status and more intellectually stimulating work is associated with retained cognitive function in old age (Staff et al., 2004) and reduced effects of dementia (Seidler et al., 2004). We classified the occupations of the patients using the system developed by Human Resources and Skills Development, Canada (2001). Occupations are classified on a five-point scale, with higher numbers associated with higher status. The scale reflects the placement of occupations in terms of the two dimensions of skill level and social class associated with each. Women who did not work outside the home and patients for whom no occupation was listed in the records were not included in this analysis. For this reason, 37 patients (13 monolingual and 24 bilingual) were excluded from the analysis of occupational status. The mean rankings for occupational status for the remaining 147 patients, reported in Table 1, did not differ between the language groups, $F < 1$. An analysis of covariance on age of onset data using occupational status as the covariate yielded adjusted age of onset scores of 71.3 years for monolinguals and 74.2 years for bilinguals. This difference was significant, $F(1,142) = 3.93$, $p < 0.05$, with bilinguals continuing to show a later age of onset of symptoms.

Finally, there is evidence that patients with higher education catch up with their less-educated peers by exhibiting faster rates of cognitive decline in the 5 years after diagnosis (Scarmeas, Albert, Manly & Stern, 2006). Therefore, we examined the progression of the dementia after the initial appointment for the 25 monolinguals and 24 bilinguals who received further MMSE tests over the next 4 years. Fig. 1 indicates no group difference in rate of decline. A regression analysis showed that the year of testing subsequent to diagnosis predicted MMSE score, $t(1) = -3.74$, $p < 0.003$, and that the rate of decline for
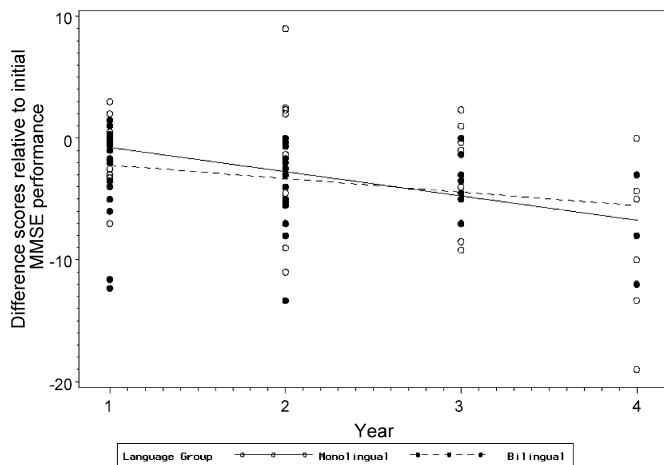
Fig. 1. Slope of decline in MMSE scores for subset of 25 monolinguals and 24 bilinguals across 4 years, indicating equivalent rates of decline for both groups.

the two language groups was equivalent in that there was no interaction between language group and slope, $t(1) = 1.10$, $p = 0.28$.

3. Discussion

The bilingual patients in our sample exhibited a delay of 4.1 years in the onset of symptoms of dementia in comparison to monolinguals. The implications of such a delay are substantial. From the meta-analysis based on 16 European and North American studies presented by Hy and Keller (2000), we calculated that a delay of 4 years at the age of our patients translates into a reduction of prevalence of 47%. Interestingly, in their review, Valenzuela and Sachdev (2006a) report a very similar figure for the reduction in incidence of dementia associated with stimulating mental activities (46%). There are currently no pharmacological interventions that have shown comparable effects.

The interpretation that bilingualism delays the onset of dementia depends on evidence that the monolingual and bilingual groups do not differ apart from their language abilities. The primary data relevant to this point is that the MMSE scores were equivalent for the patients in the two groups at the initial visit to the Memory Clinic, indicating comparable levels of impairment. In addition, we considered cultural differences, immigration, formal education, and employment status. None of these could account for the results. Analyses of covariance on the age of onset data were conducted, using gender, years of education, and employment status as the covariate, with the result that age of onset remained significantly different between the language groups in all cases. Nonetheless, we acknowledge that the present data were gathered retrospectively from clinical records, and that there is necessarily some degree of subjectivity involved in the estimate of age of onset of dementia. There is also some degree of subjectivity on the part of patients and their families in terms of deciding when it is necessary to seek help for the condition, potentially delaying the first visit and increasing the age at which the diagnosis is made. Although we see no reason for a systematic bias between the groups in this respect,

the present report should be treated as suggestive rather than as definitive.

The protective effect of bilingualism found in the present study cannot be generalized to individuals who have some knowledge of another language but are not fully bilingual. All the patients classified as bilingual in the present study were fluent in English as well as another language and have used both languages regularly for most of their lives. A study by LoGiudice, Hassett, Cook, Flicker, and Ames (2001) showed that patients living in Australia who spoke another language and had poor English skills arrived at a memory clinic at a later stage in the disease than did the native English-speaking patients. In contrast, the patients in the present study had fluent English skills and arrived at the memory clinic at the same level of cognitive impairment as the English-speaking monolinguals.

Dementia can be affected by a variety of factors, including genetic, neurobiological, environmental, intellectual, and lifestyle. The finding that bilingualism delays the onset of dementia by 4 years in our sample falls into the last category. These results demonstrate how a psychological factor can affect a biologically-based disease state. Given the findings on behavioral brain reserve reviewed by Valenzuela and Sachdev (2006a, 2006b) the present findings are not entirely surprising. Some caution, however, is needed in interpreting the results. First, the finding is correlational and not the result of an experimental design with random assignment to groups. Such a design is impossible in research of this type; people are monolingual or bilingual for reasons that have nothing to do with our experimental inquiry. However, unlike the correlation between AD and reduced activity levels in midlife (Friedland et al., 2001) where causality could operate in either direction, it is quite unlikely that the early effects of AD predispose a person to be monolingual, especially since most of these patients became bilingual at an early age. Second, the measure of "age of onset" is somewhat subjective, relying on the report of the patient, family members, and caregivers. However, the measure and means of obtaining the data were equivalent for all the cases so we see no reason to expect systematic bias. Having considered and rejected some obvious confounding factors, the data are strongly in line with our hypothesis that bilingualism delays the onset of symptoms of dementia. Third, the evidence on post-diagnosis decline (Fig. 1) is fragmentary, but the evidence suggests that the time between initial appearance of symptoms and the first clinical appointment is the same for the two groups, as is the subsequent rate of cognitive decline. This pattern suggests that bilingualism simply shifts the function relating level of impairment to passage of time by 4.1 years, a pattern also reported by Salthouse (2006) for the beneficial effects of stimulating activities on normal age-related cognitive decline. In contrast to this result, the second review by Valenzuela and Sachdev (2006b) reports results in favor of the notion that behavioral brain reserve slows the rate of cognitive decline in older people. However, another recent report (Scarmeas et al., 2006) found that whereas higher levels of education delay the onset of dementia, the rate of decline is actually faster post-diagnosis in the highly educated group. Further elucidation of this point is obviously needed.

The present results identifying an experience that may help to maintain cognitive functioning in older age are important because of their implications for research showing that such cognition-enhancing experiences affect both structural volume and functional organization of the central nervous system (Draganski et al., 2004; Karni et al., 1995; Maguire et al., 2000; Steven & Blakemore, 2004). However, unlike most of the studies in which plasticity traced to such experiences is specific to particular skills, the present findings suggest that extensive experience of one kind can have widespread effects on general cognitive functioning. The speculative conclusion (following Fratiglioni et al., 2004; Scarmeas & Stern, 2003; Staff et al., 2004; Valenzuela & Sachdev, 2006a, 2006b) is that bilingualism does not affect the accumulation of pathological factors associated with dementia, but rather enables the brain to better tolerate the accumulated pathologies. The mechanisms underlying such protective effects are not yet clear, and the present results yield no direct evidence on such mechanisms, but plausible candidates listed by Valenzuela and Sachdev (2006a) include increases in resting phosphocreatine levels, increased generation of neurons, synapses and arborized dendrites, and functional reorganization of brain networks. In general, it is increasingly clear that biological factors interact with environmental experiences to determine cognitive outcomes; the present findings suggest that bilingualism is one experiential factor that can provide a positive benefit in this respect.

Acknowledgements

References

Alexander, G. E., Furey, M., Grady, C., Pietrini, P., Brady, D. R., Mentis, M. J., et al. (1997). Association of premorbid intellectual function with cerebral metabolism in Alzheimer's disease: Implications for the cognitive reserve hypothesis. *American Journal of Psychiatry*, *154*, 165–172.

Bennett, D. A., Wilson, R. S., Schneider, J. A., Evans, D. A., Mendes de Leon, C. F., Arnold, S. E., et al. (2003). Education modifies the relation of AD pathology to level of cognitive function in older persons. *Neurology*, *60*, 1909–1915.

Bialystok, E. (2001). *Bilingualism in development: Language, literacy, and cognition*. New York: Cambridge University Press.

Bialystok, E., Craik, F. I. M., Klein, R., & Viswanathan, M. (2004). Bilingualism, aging, and cognitive control: Evidence from the Simon task. *Psychology and Aging*, *19*, 290–303.

Bialystok, E., Craik, F. I. M., & Ryan, J. (2006). Executive control in a modified anti-saccade task: Effects of aging and bilingualism. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *32*, 1341–1354.

Brookmeyer, R., Gray, S., & Kawas, C. (1998). Projections of Alzheimer's disease in the United States and the public health impact of delaying disease onset. *American Journal of Public Health*, *88*, 1337–1342.

Corder, E. H., Saunders, A. M., Strittmatter, W. J., Schmechel, D. E., Gaskell, P. C., Small, G. W., et al. (1993). Gene dose of apolipoprotein E type 4 allele and the risk of Alzheimer's disease in late onset families. *Science*, *261*, 921–923.

Draganski, B., Gaser, C., Busch, V., Schuierer, G., Bogdahn, U., & May, A. (2004). Changes in grey matter induced by training. *Nature*, *427*, 311–312.

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research*, *12*, 189–198.

Fratiglioni, L., Paillard-Borg, S., & Winblad, B. (2004). An active and socially integrated lifestyle in late life might protect against dementia. *Lancet Neurology*, *3*, 343–353.

Friedland, R. P., Fritsch, T., Smyth, K. A., Koss, E., Lerner, A. J., Chen, C. H., et al. (2001). Patients with Alzheimer's disease have reduced activities in midlife compared with healthy control-group members. *Proceedings of the National Academy of Sciences of the United States of America*, *98*, 3440–3445.

Green, D. W. (1998). Mental control of the bilingual lexico-semantic system. *Bilingualism: Language and Cognition*, *1*, 67–81.

Human Resources and Skills Development, Canada (2001). National Occupational Classification. Retrieved May 13, 2006. from http://www23.hrdc-drhc.gc.ca/2001/e/groups/index.shtml.

Hy, L. Y., & Keller, D. M. (2000). Prevalence of AD among whites: A summary by levels of severity. *Neurology*, *55*, 198–204.

Karni, A., Meyer, G., Jezzard, P., Adams, M. M., Turner, R., & Ungerleider, L. G. (1995). Functional MRI evidence for adult motor cortex plasticity during motor skill learning. *Nature*, *377*, 155–158.

LoGiudice, D., Hassett, A., Cook, R., Flicker, L., & Ames, D. (2001). Equity of access to a memory clinic in Melbourne? Non-English speaking background attenders are more severely demented and have increased rates of psychiatric disorders. *International Journal of Geriatric Psychiatry*, *16*, 327–334.

Maguire, E. A., Gadian, D. G., Johnsrude, I. S., Good, C. D., Ashburner, J., Frackowiak, R. S. J., et al. (2000). Navigation-related structural changes in the hippocampi of taxi drivers. *Proceedings of the National Academy of Sciences of the United States of America*, *97*, 4398–4403.

McKhann, G., Drachman, D. A., Folstein, M., Katzman, R., Price, D., & Stadlan, E. M. (1984). Clinical diagnosis of Alzheimer's disease: Report of the NINCDS-ADRDA work group under the auspices of Department of Health and Human Services Task Force on Alzheimer's disease. *Neurology*, *34*, 939–944.

Mortimer, J. A. (1997). Brain reserve and the clinical expression of Alzheimer's disease. *Geriatrics*, *52*, S50–S53.

Salthouse, T. A. (2006). Mental exercise and mental aging: Evaluating the validity of the "use it or lose it" hypothesis. *Perspectives on Psychological Science*, *1*, 68–87.

Scarmeas, N., Albert, S. M., Manly, J. J., & Stern, Y. J. (2006). Education and rates of cognitive decline in incident Alzheimer's disease. *Journal of Neurology, Neurosurgery and Psychiatry*, *77*, 308–316.

Scarmeas, N., Levy, G., Tang, M., Manly, J., & Stern, Y. (2001). Influence of leisure activity on the incidence of Alzheimer's disease. *Neurology*, *57*, 2236–2242.

Scarmeas, N., & Stern, Y. (2003). Cognitive reserve and lifestyle. *Journal of Clinical and Experimental Neuropsychology*, *25*, 625–633.

Seidler, A., Nienhaus, A., Bernhardt, T., Kauppinen, T., Elo, A.-L., & Frölich, L. (2004). Psychosocial work factors and dementia. *Occupational and Environmental Medicine*, *61*, 962–971.

Singh-Manoux, A., Richards, M., & Marmot, M. (2003). Leisure activities and cognitive function in middle age: Evidence from the Whitehall II study. *Journal of Epidemiology and Community Health*, *57*, 907–913.

Staff, R. T., Murray, A. D., Deary, I. J., & Whalley, L. J. (2004). What provides cerebral reserve? *Brain*, *27*, 1191–1199.

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

Steven, M. S., & Blakemore, C. (2004). Cortical plasticity in the adult human brain. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences III* (pp. 1243–1254). Cambridge: MIT Press.

Valenzuela, M. J., & Sachdev, P. (2006a). Brain reserve and dementia: A systematic review. *Psychological Medicine*, *36*, 441–454.

Valenzuela, M. J., & Sachdev, P. (2006b). Brain reserve and cognitive decline: A non-parametric systematic review. *Psychological Medicine*, *36*, 1065–1073.