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Lifelong bilingualism contributes to cognitive reserve against white matter integrity declines in aging

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ABSTRACT

Recent evidence suggests that lifelong bilingualism may contribute to cognitive reserve (CR) in normal aging. However, there is currently no neuroimaging evidence to suggest that lifelong bilinguals can retain normal cognitive functioning in the face of age-related neurodegeneration. Here we explored this issue by comparing white matter (WM) integrity and gray matter (GM) volumetric patterns of older adult lifelong bilinguals ($N=20$) and monolinguals ($N=20$). The groups were matched on a range of relevant cognitive test scores and on the established CR variables of education, socioeconomic status and intelligence. Participants underwent high-resolution structural imaging for assessment of GM volume and diffusion tensor imaging (DTI) for assessment of WM integrity. Results indicated significantly lower microstructural integrity in the bilingual group in several WM tracts. In particular, compared to their monolingual peers, the bilingual group showed lower fractional anisotropy and/or higher radial diffusivity in the inferior longitudinal fasciculus/inferior fronto-occipital fasciculus bilaterally, the fornix, and multiple portions of the corpus callosum. There were no group differences in GM volume. Our results suggest that lifelong bilingualism contributes to CR against WM integrity declines in aging.

1. Introduction

Aging is associated with neurodegenerative changes that typically lead to cognitive decline. However, there is a great deal of heterogeneity in the relationship between cerebral declines and cognitive functioning in aging, with variability in task performance tending to increase with age (Christensen et al., 1999). While neurodegenerative changes result in significant cognitive declines in some older adults, others seem to continue to function like young healthy adults (Cabeza, Anderson, Locantore, & McIntosh, 2002; Duarte, Ranganath, Trujillo, & Knight, 2006). Similar heterogeneity between brain burden and cognitive function exists with respect to age-related dementias such as Alzheimer's disease (AD). For example, while the majority of individuals who meet criteria for pathological AD also meet clinical AD criteria, a significant number remain cognitively normal (Mortimer, 1997; Shaw et al., 2009; Valenzuela & Sachdev, 2006).

The theory of cognitive reserve arose as an explanation for such mismatch between brain structure and cognitive functioning (Stern, 2002). Cognitive reserve (CR) theory holds that certain variables improve the brain's ability to cope with damage, effectively mitigating its effects on cognition (Stern, 2002, 2009). Three well established CR variables are education, intelligence, and socioeconomic status (SES) (Albert et al., 1995; Christensen, 2001; Steffener & Stern, 2012). Uncovering other CR variables represents an important step toward maximizing the ability of older adults to live independently. In addition, this line of research has implications for early detection of dementia. Because individuals with high CR present with greater brain burden, typical cognitive screening tests may be insufficient for their early detection. A more complete understanding of the range of effective CR variables may aid early detection.

Recent evidence suggests that lifelong bilinguals may develop clinical AD symptoms at an older age than monolinguals (Bialystok, Craik, & Freedman, 2007; Craik, Bialystok, & Freedman, 2010). Bilingualism carries broad appeal as a potential reserve variable because it is primarily influenced by environmental factors such as country of birth, emigration, or attendance of a second language immersion school (Bialystok & Craik, 2010). In addition, whereas some CR variables like education are typically established as of one's 3rd decade of life, bilingualism can be practiced across one's lifespan. It is the continuous practice/experience of monitoring context for potential language switches and inhibiting the language not under active use

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that have been suggested as a basis for bilingual advantages in executive control (Abutalebi & Green, 2007; Bialystok & Craik, 2010; Green, 1998).

However, bilingual advantages in executive control are not uniformly observed (Hilchey & Klein, 2011; Paap & Greenberg, 2013). In addition, only one neuroimaging study has provided evidence suggesting that lifelong bilinguals can tolerate more neurodegenerative change than monolinguals at similar levels of cognitive functioning (Schweizer, Ware, Fischer, Craik, & Bialystok, 2012). In this previous computed tomography (CT) study, AD patients who were lifelong bilinguals had a larger width of the temporal horn ratio, suggesting more medial temporal lobe (MTL) atrophy, than monolinguals at similar levels of cognitive impairment. While these results are promising, more research is clearly required to determine if lifelong bilingualism contributes to CR.

The case for bilingualism as a CR variable would be strengthened by evidence that bilingual older adults are capable of normal cognitive performance despite neuroimaging profiles typically associated with impaired cognition. Two neuroimaging profiles associated with age-related neurodegeneration involve reduced gray matter (GM) volume and white matter (WM) integrity (Good et al., 2001; Madden et al., 2012; Smith, 2012). Volumetric reduction of GM structures has been linked with poorer cognitive performance (Raz, Briggs, Marks, & Acker, 1999). More recently, age-related WM integrity reductions have been linked with poorer performance on a wide range of motor and cognitive tasks (reviewed in Madden et al., 2012), in part because they reduce the fidelity of signal transmission between GM structures (Bartzokis et al., 2010).

In the present study, we compared imaging measures of cerebral WM integrity and GM volume between groups of cognitively normal monolingual and bilingual older adults. Following the original approach to the study of CR (Stern, Alexander, Prohovnik, & Mayeux, 1992), we matched groups on relevant demographic and neuropsychological scores prior to imaging analyses. Groups were further matched on the previously established CR variables of education, SES and IQ to limit the influence of these variables on group differences. Analyses of the DTI data were conducted on each of the four main indices of the diffusion tensor (fractional anisotropy, mean diffusivity, radial diffusivity, and axial diffusivity) to provide a detailed comparison of potential WM integrity differences between matched bilingual and monolingual groups.

2. Methods

2.1. Participants

A total of 83 right-handed community dwelling older adults were enrolled in the study. Of these participants, 20 were lifelong bilinguals and the remaining 63 were lifelong monolinguals. Informed consent was obtained from each participant under an approved University of Kentucky Institutional Review Board protocol. Exclusionary criteria for the study included the following: a major head injury and/or concussion, stroke, a neurological or psychiatric disorder, high blood pressure, hypercholesterolemia, diabetes, heart disease, the use of psychotropic medications, or the presence of metal fragments and/or metallic implants contraindicated for MRI.

Language status was determined via a detailed questionnaire about language history similar to that used in previous research in this area (Bialystok, Craik, & Ryan, 2006). The questionnaire included items about age and place of language acquisition, and a chart regarding proficiency of each language compared to a native speaker. Lifelong bilinguals had to have been speaking English and another language on a daily basis since the age of 10 years old or younger and had to rate themselves as completely proficient in their two languages (English proficiency was also assessed objectively as described below). Following previous work in this area (Bialystok & Craik, 2010), lifelong bilinguals spoke English and a variety of second languages, whereas lifelong monolinguals spoke only English and had no significant exposure to a second language. The specific non-English languages spoken by lifelong bilinguals in the present study were: African languages (Igbo, Swahili), Filipino, French, German, Indian languages (Gujarati, Hindi, Konkani), Spanish.

Following the original methodological approach to the study of CR (Stern et al., 1992), a sub-group of 20 monolinguals were matched with the group of 20 bilinguals for sex ratio, education level and scores on a range of other cognitive measures described below (Table 1).

Table 1
Group means, standard deviations (in brackets), and *P*-values for demographic and neuropsychological scores.

	Monolingual	Bilingual	*P*-Values
Age	64.4 (5.1)	63.9 (4.0)	0.76
Sex (M/F)	10/10	10/10	0.99
Education	17.5 (2.6)	17.4 (2.2)	0.97
ISP	21.6 (7.0)	19.7 (8.7)	0.44
Cattell IQ score	124.6 (20.2)	127.6 (22.5)	0.66
MMSE	28.2 $(1.6)_{17}$	27.8 $(1.2)_{16}$	0.39
Vocabulary (PPVT)	110.1 (13.9)	106.3 (18.5)	0.47
Digits span forward	10.6 (2.0)	9.7 (2.1)	0.23
Digits span backward	6.6 (1.8)	6.6 (2.5)	0.97
Spatial span forward	10.7 $(1.6)_{17}$	10.2 $(1.5)_{16}$	0.36
Spatial span backward	7.6 $(1.4)_{17}$	7.2 $(1.3)_{16}$	0.48
Logical memory I	45.4 $(4.7)_{17}$	44.3 $(3.8)_{16}$	0.44
Logical memory II	28.2 $(5.8)_{17}$	26.8 $(4.3)_{16}$	0.45
Task switching (RT)	179 ms	114 ms	0.04
Task switching (% errors)	3.4 (3.5)	2.6 (2.6)	0.41

Notes. ISP, Index of Social Position; MMSE, Mini-Mental State Exam; PPVT, Peabody Picture Vocabulary Test. If score values were missing, the number of participants used in the comparison is shown as subscript.

2.2. Cognitive and demographic measures

The Mini-Mental State Exam (MMSE) is a 30-point test used to screen for cognitive impairment (Folstein, Folstein, & McHugh, 1975). It assesses orientation to time and place as well as basic memory functions.

The Peabody Picture Vocabulary Test (PPVT-III) is a culture-fair measure used to assess proficiency in English (Dunn & Dunn, 1997). There are a total of 204 test items. Test items are presented on pages containing four black-and-white pictures. Participants were read a word and were asked to choose the picture on that page that best corresponds to the word.

The Hollingshead Two-Factor Index of Social Position (ISP) was used as a measure of socioeconomic states (SES) (Hollingshead, 1958). The ISP is based on an individual's occupation and highest level of formal education. It is calculated by assigning numeric values, from 1 to 7, to an individual's occupation and education. Scores are then weighted by multiplying by 7 (occupation) and 4 (education). Values are then summed to produce a social index. Lower values represent higher earning occupations and more years of education.

The Cattell Culture Fair (CCF) Intelligence Test (Cattell & Cattell, 1960). The CCF is a test of fluid intelligence that is not influenced by cultural background or verbal ability. The CCF (Scale 3) consists of 50 items and assesses inductive reasoning about relationships in shapes and figures.

The Digits Span Subtests of the Wechsler Memory Scale (WMS III) (Wechsler, 1997). The Digit Span tests assess verbal memory. Participants were read digit lists aloud and were instructed to repeat each set of digits verbally in the same order (digit forward; DF) and in reverse order (digit backward; DB). In both conditions participants received two trials. Standard termination procedures were followed and the totals for the DF and DB sets were based on the number of trials that were accurately reported in the correct order.

The Spatial Span Subtests of the WMS III (Wechsler, 1997). The Spatial Span tests assess spatial memory. Participants viewed the examiner touch blocks in a specific order and were instructed to touch the same blocks in the same order (spatial forward; SF) and in reverse order (spatial backward; SB). In both conditions participants received two trials. Standard termination procedures were followed and the totals for the SF and SB sets were based on the number of trials that were accurately completed in the correct order.

The Logical Memory Subtests of the WMS III (Wechsler, 1997). The Logical Memory I test assesses the ability to remember information immediately after oral presentation and the Logical Memory II assesses the ability to remember information after a 25–35 min delay. Standard scoring rules were applied.

Task Switching. The color-shape task switching paradigm assesses the executive functions of attention switching and inhibitory control. This paradigm was administered as part of a previous fMRI experiment described in detail elsewhere (Gold, Kim, Johnson, Kryscio, & Smith, 2013). The stimuli consisted of two possible shapes (circle or square), in one of two possible colors (red or blue), presented in the center of the computer screen. Tasks were indicated via cue words. In shape blocks, participants decided if a stimulus was a circle or square. In color blocks,