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Control beliefs are associated with preserved memory function in the face of low hippocampal volume among diverse older adults

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Abstract

Growing evidence supports a link between locus of control and memory in older adults. Control beliefs may directly predict larger hippocampal volume (i.e., brain maintenance). Alternatively, control beliefs may be associated with smaller hippocampal volume at any given level of memory (i.e., cognitive reserve). Multivariable regression analyses examined associations between verbal episodic memory, locus of control and hippocampal volume among 236 non-demented older adults in the community-based Washington Heights-Inwood Columbia Aging Project. Control beliefs were negatively associated with hippocampal volume when controlling for memory performance, indicating that individuals with stronger control beliefs were able to maintain memory function in the face of lower hippocampal volume. Subsequent exploratory models stratified by race/ethnicity indicated that this association was more prominent among racial/ethnic minorities (particularly Caribbean Hispanic older adults) than among non-Hispanic White older adults. Control beliefs were not associated with hippocampal volume before memory was taken into account. Results are consistent with the view that control beliefs facilitate the maintenance of memory function despite hippocampal volume loss. Results are not consistent with the view that locus of control contributes to brain maintenance. Culturally-appropriate interventions are needed to test whether strengthening control beliefs provides cognitive resistance to neuropathology.

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Compliance with ethical standard

Conflict of Interest: Drs. Zahodne, Schupf, and Brickman declare that they have no conflicts of interest.

Ethical Approval: All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, and the applicable revisions at the time of the investigation.

Informed Consent: Informed consent was obtained from all participants for being included in the study.

Keywords

cognitive reserve; brain maintenance; episodic memory; MRI

Background

Growing evidence suggests that psychosocial factors such as control beliefs protect against cognitive decline in late life independent of negative affect. Cross-sectional studies indicate that higher perceived control is associated with better episodic memory (Hertzog, McGuire, & Lineweaver, 1998; Lachman & Agrigoroaei, 2012). In longitudinal work, higher perceived control and higher baseline self-efficacy, one component of perceived control, were associated with better verbal episodic memory performance months (Neupert & Altaire, 2012) or years later (Seeman et al., 1996). Mechanisms underlying a potential protective effect of stronger control beliefs in memory aging are unclear. One possibility is that control beliefs are directly and positively associated with brain health, which leads to better cognitive health (i.e., brain maintenance; Nyberg et al., 2012). Another possibility is that control beliefs allow older adults to maintain memory function in the face of age-related brain atrophy (i.e., cognitive reserve; Barulli and Stern, 2013). Given that control beliefs can be modified experimentally (Laurin et al., 2008; Kay et al., 2008; Whitson and Galinsky, 2008; Lachman et al., 1992) and via systematic intervention (Searle et al., 1998; Langer and Rodin, 1996; Tennstedt et al., 1998), clarifying mechanisms that link control beliefs and memory among older adults has the potential to inform the design and evaluation of interventions to promote optimal cognitive aging.

Hippocampal volume is a key structural brain predictor of episodic memory performance, particularly among older adults. The hippocampus plays a causal role in episodic memory performance (Squire & Wixted, 2011; Jacobs et al., 2016). Among older adults, hippocampal volume is positively associated with episodic memory cross-sectionally (van Petten, 2004), and longitudinal atrophy of the hippocampus is associated with declines in verbal episodic memory (Gorbach et al., 2016). Hippocampal volume is also an important biomarker for dementia (Apostolova, et al., 2015). Both cross-sectional (den Heijer et al., 2006) and longitudinal (den Heijer et al., 2010) hippocampal volume predict incident dementia. Given its prominent role in memory aging, hippocampal volume represents an ideal measure of structural brain integrity to clarify associations between locus of control, brain health, and episodic memory performance. Indeed, preliminary evidence from a sample of 23 healthy older adults documented a positive association between control beliefs and hippocampal volume, but that study did not incorporate episodic memory (Pruessner et al., 2005).

Previous studies of control beliefs in cognitive aging have included mostly English-speaking, non-Hispanic White older adults. It is not known whether control beliefs play a similar role in brain and cognitive aging across racial/ethnic groups. Compared to non-Hispanic White adults, African American and Hispanic adults report less perceived control (Ross & Mirowsky, 2013) and score lower on tests of verbal episodic memory (Wilson et al., 2015; Melrose et al., 2015). In addition to these level differences, associations between

control beliefs and episodic memory (Zahodne, Meyer et al., 2015), and between hippocampal volumes and episodic memory (Zahodne, Manly et al., 2015) have been shown to differ across racial/ethnic groups. The importance of examining potential protective factors across racial/ethnic groups is underscored by data indicating that the proportion of older adults in the United States who identify as racial/ethnic minorities is rapidly increasing (U.S. Census Bureau, 2004), and African American and Hispanic older adults are at increased risk of dementia (Tang et al., 2001).

The purpose of the current study was to clarify the role of control beliefs in cognitive aging by testing the brain maintenance and cognitive reserve hypotheses in a large, racially and ethnically diverse sample of older adults without dementia. Evidence that stronger control beliefs are directly and positively related to hippocampal volume would provide support for the brain maintenance hypothesis. Evidence that stronger control beliefs are negatively related to hippocampal volume at any given level of memory ability would indicate that individuals with stronger control beliefs are able to maintain memory function in the face of greater atrophy, thereby providing support for the cognitive reserve hypothesis. It should be noted that these hypotheses are not necessarily mutually exclusive. It is possible that control beliefs are positively associated with hippocampal volume but that the direction of this association reverses after memory ability is taken into consideration.

Methods

Participants and Procedures

The 236 individuals in this study were participants in the Washington Heights-Inwood Columbia Aging Project (WHICAP; Tang et al., 2001; Manly et al., 2005). WHICAP is a prospective, community-based, longitudinal study of aging and dementia in northern Manhattan. In brief, adults aged 65 and older living in the geographic area of northern Manhattan were recruited in three waves: 1992, 1999, and 2009. WHICAP participants are followed up at 18–24 month intervals with a battery of cognitive, functional, and health measures administered in the participant's preferred language (English or Spanish). A subset of participants undergo magnetic resonance imaging (MRI).

The current cross-sectional study included only participants recruited in the newest (2009) wave who (1) received MRI, (2) participated in an ancillary study of psychosocial functioning, (3) did not meet DSM criteria for dementia based on a consensus group consisting of at least one attending physician and neuropsychologist with expertise in cognitive aging and dementia, and (4) did not report another neurological disorder (e.g., Parkinson's disease) or stroke. Structural MRI data were not used to adjudicate dementia diagnoses. Characteristics of the sample are shown in Table 1. This study was approved by the local institutional review board. Informed consent was obtained from all participants.

Magnetic Resonance Imaging

Structural magnetic resonance imaging (MRI) was obtained on a 3.0T Philips Achieva scanner at Columbia University Medical Center. T1-weighted (repetition time = 6.6 ms, echo time = 3.0 ms, field of view 256 cm, 256 × 256 matrix, 1.0 mm slice thickness) images

were acquired in the axial orientation. Total intracranial volume (ICV), and total hippocampal volume (across hemispheres) were derived from T1-weighted images using FreeSurfer version 5.3 (<http://surfer.nmr.mgh.harvard.edu/>). In brief, FreeSurfer processing steps involve Talairach transformation, segmentation of subcortical white matter and gray matter structures, intensity normalization, and tessellation of the gray and white matter boundary. Other procedures consist of surface inflation, registration to a spherical atlas, parcellation of cortex, and generation of surface based data. Steps involving visual inspection or manual correction included Talairach registration and edits to brainmask and white matter volumes. All FreeSurfer outputs were visually inspected by an expert operator and manually corrected if necessary.

Episodic Memory

Episodic memory was assessed with the Selective Reminding Test (Buschke and Fuld, 1974), in which participants are given six trials to learn a list of 12 words. After each trial, participants are only reminded of the words they failed to recall. Following a 15-minute delay, participants are again asked to recall the list. Then, they are given a recognition test that includes all 12 words, along with distractors. The current study used composite scores of immediate recall, delayed recall, and recognition, which significantly correlated with one another (immediate-delayed $r = 0.766$; $p < 0.001$; immediate-recognition $r = 0.479$; $p < 0.001$; delayed-recognition $r = 0.545$; $p < 0.001$). Composites were derived by converting individual memory scores to z-scores based on means and standard deviations from the larger WHICAP cohort at baseline and averaging them.

Locus of Control

Locus of control was assessed with the Perceived Control scale (Lachman and Weaver, 1998). The scale comprises 12 items rated on a 7-point Likert-type scale. A total score on this measure was computed as the mean response on all 12 items (Cronbach's $\alpha = 0.75$). Items from the Mastery subscale reflect internal locus of control (e.g., "When I really want to do something, I usually find a way to succeed at it"), and items from the Constraints subscale reflect external locus of control (e.g., "What happens in my life is often beyond my control;" "I sometimes feel I am being pushed around in my life").

Covariates

Models controlled for age, sex, African American race, Hispanic ethnicity, education, income, depressive symptoms, chronic conditions, and total ICV. Sex, race, and ethnicity were determined via self-report using the format of the 2000 U.S. Census. Education (0–20 years) was also measured via self-report. Monthly household income (1–12) was self-reported using the following 12 categories: \$450 or less, \$451–\$550, \$551–\$650, \$651–\$750, \$751–\$1,000, \$1,001–\$1,250, \$1,251–\$1,500, \$1,501–\$1,750, \$1,751–\$2,000, \$2,001–\$3,000, \$3,001–\$4,000, and more than \$4,000. Depressive symptoms were quantified with a 10-item version of the Center for Epidemiological Studies Depression Scale (CES-D; Irwin et al., 1999). Number of chronic conditions was quantified as the sum of the self-reported presence of hypertension, diabetes, and heart disease. Total ICV was quantified using FreeSurfer as described above.

Statistical Analysis

Analyses were conducted in SPSS version 24 (IBM Corp., Armonk, NY). Multivariable regression analyses were used to test relationships among hippocampal volume, memory, and locus of control. The brain maintenance hypothesis was tested by regressing hippocampal volume onto locus of control and all covariates, which were neither centered nor standardized prior to model entry. This model allowed us to determine whether locus of control was positively associated with hippocampal volume independent of the covariates but without taking memory ability into consideration. Based on previous studies in our group (Stern et al., 1992; Brickman et al., 2011), the cognitive reserve hypothesis was tested by regressing hippocampal volume onto memory, locus of control, and all covariates. This model allowed us to determine whether, at any given level of episodic memory ability, locus of control was negatively associated with hippocampal volume independent of the covariates. Individuals with high cognitive reserve show more advanced brain pathology than individuals with low cognitive reserve who are matched on cognitive level (Stern et al., 1992). This pattern of results indicates that individuals with high reserve are able to maintain cognitive performance in the face of a higher level of brain pathology. Because cognitive reserve may not become evident until an individual has started to develop neuropathology (Serra et al., 2015), this model also included a multiplicative interaction term for locus of control and memory to allow for the possibility that the reserve relationship is stronger in individuals with more memory difficulties. To explore whether patterns of associations were being driven by internal or external locus of control, initial models were also run separately for Mastery and Constraints subscales of the Perceived Control Scale. As a final exploratory step, we also stratified initial models by racial/ethnic group (i.e., African American, Hispanic, white) to see whether similar patterns of association were evident across these groups.

Results

Independent of the covariates, locus of control was not significantly associated with hippocampal volume ($r = 0.001$; $p = 0.990$) or episodic memory ($r = 0.071$; $p = 0.278$). Hippocampal volume was significantly associated with episodic memory ($r = 0.219$; $p = 0.001$). This association was the same upon controlling for total ICV.

Brain Maintenance

Table 2 displays the results from a regression examining the association between locus of control and hippocampal volume (brain maintenance). As shown, locus of control was not significantly associated with hippocampal volume independent of the covariates.

Cognitive Reserve

Table 2 also displays the results from a regression analysis that examines the association between locus of control and hippocampal volume, controlling for episodic memory performance (cognitive reserve). As shown, locus of control was significantly negatively associated with hippocampal volume, independent of the covariates. At any given level of memory performance, stronger control beliefs were associated with smaller hippocampal volume, suggesting that individuals with stronger control beliefs are able to maintain

memory function in the face of greater brain atrophy. The locus of control by memory interaction was at trend, providing limited evidence that locus of control may be more strongly associated with hippocampal volume in individuals with poorer memory. Figure 1 provides a graphical depiction of this interaction described in the last row of Table 2. Among individuals with memory composite scores below the sample median of 0.599, there was a significant, negative association between locus of control and hippocampal volume, independent of covariates and memory score ($B = -0.193$; $SE = 0.073$; $p = 0.010$). This association was not significant among individuals with memory composite scores above the sample median ($B = 0.289$; $SE = 0.249$; $p = 0.250$).

Internal versus external locus of control

Brain maintenance and cognitive reserve models were repeated to examine internal (Mastery subscale) and external (Constraints subscale) locus of control separately. In brain maintenance models that did not control for memory, neither internal ($B = -0.001$; $SE = 0.066$; $p = 0.987$) nor external locus of control ($B = 0.061$; $SE = 0.040$; $p = 0.123$) was associated with hippocampal volume. In cognitive reserve models that controlled for memory, higher external locus of control was associated with greater hippocampal volume ($B = 0.100$; $SE = 0.046$; $p = 0.031$), but internal locus of control was not associated with hippocampal volume ($B = 0.017$; $SE = 0.101$; $p = 0.869$).

Stratification by Race/Ethnicity

Exploratory analyses stratified the cognitive reserve model by race/ethnicity, resulting in separate regression for white ($N=71$), African American ($N=80$), and Hispanic ($N=85$) participants. In these models, which included all covariates along with memory score, locus of control was only significantly associated with hippocampal volume in Hispanic participants ($B = -0.212$; $SE = 0.099$; $p = .036$). This association did not reach significance in African American participants ($B = -0.157$; $SE = 0.128$; $p = .223$) or white participants ($B = 0.103$; $SE = 0.140$; $p = .462$). Locus of control by memory interactions were not significant in any racial groups (all p 's $< .119$). Figure 2 provides a graphical depiction of these stratified results, contrasting the independent locus of control – hippocampal volume association across the three racial/ethnic groups. Visual inspection of these associations reveals preliminary evidence for stronger associations among racial/ethnic minority groups.

Alternate Cognitive Reserve Model

Because an alternative approach to evaluating cognitive reserve is to examine the association between hippocampal volume and episodic memory performance as a function of locus of control, we ran an additional model to test whether stronger control beliefs systematically attenuated the association between hippocampal volume and memory. Specifically, episodic memory performance was regressed onto hippocampal volume, control beliefs and their interaction, controlling for all covariates. The interaction term in this model was not significant ($B = 0.044$; $SE = 0.036$; $p = 0.218$).

Discussion

The results of this study provide evidence that control beliefs allow older adults to maintain episodic memory function in the face of low hippocampal volume, over and above factors that have previously been shown to provide cognitive reserve, such as education and socioeconomic status. Because results were also independent of depressive symptoms and chronic conditions, they are not likely to reflect the general effects of control beliefs on mental or physical health. Rather, control beliefs may serve as a motivational resource that promotes the implementation of effortful strategies to compensate for cognitive limitations such as those resulting from brain pathology (de Frias et al., 2003; Miller and Gagne, 2005). Forstmeier and Maercker (2008) developed the concept of “motivational reserve” to explain positive associations between motivational abilities and late-life outcomes. They propose that exercising motivational abilities contributes to neural network efficiency and compensation. The current study provides critical support for this model by demonstrating the expected relationships among locus of control, hippocampal volume, and episodic memory.

The results of this study do not support a direct association between control beliefs and hippocampal volume. This null finding is in contrast to the significant, positive association between internal locus of control and hippocampal volume found in a sample of 23 healthy, highly educated older adults recruited via community advertisements (Pruessner et al., 2005). Because of a similarly-sized association between internal locus of control and hippocampal volume in young adults, these authors suggested that normal variation in hippocampal volume may causally influence one’s level of internal locus of control (as opposed to locus of control causally influencing hippocampal volume). It is possible that a direct association between locus of control (internal or external) and hippocampal volume was not found in the current study because hippocampal volume was more likely to reflect neurodegeneration, in addition to normal variation. This is because participants in the current study were older, were less educated, and had multiple chronic conditions, on average.

Evidence that individuals with stronger control beliefs were able to maintain memory performance in the face of lower hippocampal volume appeared strongest among participants with low memory performance. Thus, it may be easier to detect individual differences in resilience once people experience a challenge (e.g., early cognitive decline) (Serra et al., 2015). This may be because hippocampal volume is a stronger predictor of memory scores among individuals with neurodegenerative disease (Van Petten, 2004). Among healthier individuals, variance in hippocampal volume is more likely to reflect normative individual differences rather than neuropathology.

In exploratory race/ethnicity-stratified analyses, support also appeared strongest for racial/ethnic minorities, which is consistent with work showing that control beliefs are more relevant for mental and physical health outcomes among lower social class groups. This pattern of results suggests that control beliefs may provide a buffer against the negative impact of low social class (Lachman and Weaver, 1998). Indeed, self-efficacy, one aspect of perceived control, can buffer against the negative cognitive impact of educational

disadvantage (Zahodne et al., 2015). African American and Hispanic adults often report having less control over their life outcomes than non-Hispanic whites (Shaw and Krause, 2001; Skaff et al., 2003), which may stem from experiences of weaker contingency between action and outcomes due to environmental constraints such as structural racism and discrimination (Bruce and Thornton, 2004). The current study suggests that reducing these disadvantageous experiences or developing stronger control beliefs in the face of these experiences may be particularly beneficial for racial/ethnic minorities. It should be noted that these race/ethnicity-stratified analyses had reduced statistical power, and the absence of significant associations within African American and white participants may therefore reflect Type II error.

In analyses examining internal and external locus of control separately, results indicated that the inverse association between locus of control and hippocampal volume controlling for memory was driven by external locus of control, or the perception of outside constraints. Specifically, individuals reporting fewer perceived constraints were able to achieve equivalent memory performance despite having lower hippocampal volume, compared to individuals with reporting more perceived constraints. This finding suggests that interventions targeting control beliefs to optimize cognitive aging may be most effective when they target real or perceived barriers, as opposed to beliefs about personal mastery or self-efficacy. Given that previous studies have also found positive associations between self-efficacy, a component of internal locus of control, and late-life cognition (Seeman et al., 1996; Zahodne et al., 2014), additional research is needed to clarify different mechanisms underlying associations involving internal locus of control (e.g., self-efficacy) versus external locus of control.

A potential implication of this study is that increasing control beliefs, particularly by reducing real or perceived constraints, may delay the clinical onset of dementia in the face of advancing brain pathology. Interventional studies with comprehensive dementia assessments, neuroimaging, and longitudinal follow-up are needed to fully evaluate this possibility. In the current study, an additional analyses using an alternative approach to examining cognitive reserve did not indicate that control beliefs systematically attenuate the relationship between hippocampal volume and memory. However, the current study may have been underpowered to detect interaction effects, particularly in models controlling for well-known contributors to cognitive reserve (e.g., education, income), as well as physical and mental health. Thus, larger samples are needed, and future studies should investigate whether control beliefs systematically attenuate the relationship between more direct markers of neuropathology (e.g., amyloid) and episodic memory.

While locus of control is often viewed as a fixed personality trait, it is more accurately characterized as a learned view of the self and the environment (Lachman et al., 2011). As such, it is amenable to change (Hooker and McAdams, 2003). Several interventions have already been shown to increase control beliefs in various life domains, as well as mental and functional outcomes (Searle et al., 1998; Langer and Rodin, 1996; Tennstedt et al., 1998). Future studies should test whether targeting general versus cognitive control beliefs is more effective at optimizing cognitive aging.

A primary limitation of this study is its cross-sectional design, which precludes further exploration of the direction of effects involving locus of control, hippocampal volume, and episodic memory. Of note, previous studies have found that control beliefs directly predicts subsequent cognitive changes rather than vice versa (Agrigoroaei et al., 2013; Neupert & Allaire, 2010). However, this previous study measured domain-specific control beliefs (i.e., beliefs about control over performance on a cognitive task) rather than more general control beliefs (i.e., beliefs about control over life outcomes in general), which were measured in the current study. While the current study focused on episodic memory because the majority of previous literature has linked control beliefs to this cognitive domain, future studies should explore potential mechanisms linking locus of control to other cognitive domains. A primary strength of this study over previous work was its inclusion of neuroimaging data, which allowed us to begin to explore mechanisms underlying the association between control beliefs and cognition. Additional longitudinal neuroimaging work is needed to further explicate these mechanisms. Other strengths of this study include its racial/ethnic diversity, which allowed us to explore patterns of associations across African American, Hispanic, and white older adults living in the same geographic region, though larger studies specifically designed and powered to systematically test for racial/ethnic differences in these patterns of association are needed.

This study demonstrated that control beliefs are associated with the maintenance of episodic memory ability in the face of lower hippocampal volume, above and beyond age, educational attainment, income, depressive symptoms, and general physical health. The identification of modifiable sources of cognitive resilience is of critical importance due to the non-availability of disease-modifying agents and the projected increase in dementia cases in the coming years. Positive psychosocial factors are a worthwhile target of future research given their modifiability and growing evidence for their unique role in brain and cognitive aging.

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Fig. 1.

Associations between locus of control and hippocampal volume by memory performance, controlling for age, sex, race/ethnicity, education, income, depressive symptoms, number of chronic conditions, and total intracranial volume. Individuals with low memory performance (i.e., memory composite scores below the sample median of 0.599) showed a significant negative association between locus of control and hippocampal volume, but individuals with high memory performance (i.e., memory composite scores at or above the sample median of 0.599) did not. Therefore, evidence that locus of control reflects cognitive reserve was stronger among individuals with worse memory. Higher scores on locus control correspond to stronger control beliefs.

Fig. 2.

Associations between locus of control and hippocampal volume by race/ethnicity, controlling for age, sex, education, income, depressive symptoms, number of chronic conditions, and total intracranial volume. African American and Hispanic participants exhibited a negative association between locus of control and hippocampal volume, but this negative association was only significant among Hispanic participants. Therefore, evidence that locus of control reflects cognitive reserve was stronger among racial/ethnic minorities. Higher scores on locus control correspond to stronger control beliefs

Table 1

Sample characteristics

	Mean	SD
Age (years)	73.1	5.3
Female (N; %)	142; 60.2	-
Race/ethnicity		
African American (N; %)	80; 33.9	-
Hispanic (N; %)	85; 36.0	-
White (N; %)	71; 30.1	-
Education (years)	12.8	4.6
Income (1–12)	7.9	3.1
Number of chronic conditions (0–3)	1.0	0.9
CESD (0–10)	1.3	1.8
Memory (z-score composite)	0.6	0.7
Immediate recall (0–72)	43.6	9.5
Delayed recall (0–12)	6.3	2.7
Recognition (0–12)	11.3	1.2
Locus of control (1–7)	5.3	1.1
Mastery (1–7)	6.1	0.9
Constraints (1–7)	3.1	1.5
Hippocampal volume (cm ³)	7.3	9.7
Intracranial volume (cm ³)	1362.9	162.2

Note. SD=standard deviation; CESD=Center for Epidemiologic Studies Depression Scale

Unstandardized regression results from brain maintenance and cognitive reserve models in which hippocampal volume was the dependent variable

Table 2

	Brain maintenance			Cognitive reserve		
	B	SE	p	B	SE	p
Age	−0.057	0.011	<0.001	−0.055	0.011	<0.001
Female	−0.082	0.136	0.548	−0.096	0.136	0.481
African American	−0.173	0.149	0.246	−0.140	0.150	0.354
Hispanic	0.214	0.185	0.247	0.231	0.184	0.210
Education	0.002	0.017	0.920	−0.003	0.017	0.873
Income	0.029	0.024	0.217	0.023	0.024	0.346
Chronic illnesses	−0.062	0.064	0.337	−0.042	0.065	0.521
Depressive symptoms	−0.079	0.032	0.014	−0.073	0.032	0.023
Intracranial volume	0.002	0.000	<0.001	0.002	0.000	<0.001
Locus of control	−0.074	0.053	0.166	−0.138	0.066	0.039
Memory	-	-	-	−0.602	0.436	0.169
Memory × locus of control	-	-	-	0.134	0.078	0.087

Note. B=unstandardized regression coefficient; SD=standard deviation