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The Impact of Cognitive Reserve on Baseline Neuropsychological Functioning of Older Adults Without Dementia

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by

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DECLARATION OF ORIGINALITY

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ABSTRACT

Background: For decades, a key question that has been posed by the cognitive aging literature is *how do we preserve our cognitive abilities throughout the lifespan?* This thesis examined the influence of cognitive reserve (CR) on different domains of cognitive functioning in a sample of older adults with varying levels of cognitive functioning, ranging from normal cognitive aging to mild cognitive impairment. To date, little research has used latent variable modelling to examine the potential relationships between cognitive reserve and cognition in older adults without dementia. **Objectives:** To examine the (1) cumulative and (2) independent effects of three well-established proxies of CR—educational attainment, mental workplace demands, crystallized intelligence—on performance across several neuropsychological tests assessing verbal and visual memory, executive functioning, visuospatial processing, language, and global cognitive status. **Method**: The current study utilized archival data from 232 older adult patients seen at geriatric specialist hospital in Ontario, Canada. To evaluate hypothesized relationships between CR and late-life cognition, two structural equation models were constructed. Subsequent relative weight and multiple regression analyses were performed to examine the individual relationships between CR proxies and late-life cognition. **Results:** As predicted, CR was associated with better performance on a cognitive screener, however, both hypothesized models demonstrated poor fit. Overall, CR was most important in predicting older adults' higher-order cognitive abilities and crystallized intelligence was the only CR proxy that was a significant predictor of late-life cognition, beyond sociodemographic factors. **Significance**: Findings from this study add to our current understanding of CR by demonstrating that in older age, certain areas of cognitive functioning may be more influenced by CR over others and that dynamic proxies of CR, such as crystallized intelligence may better capture the relationship between CR and late-life cognition.

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LIST OF ABBREVIATIONS/SYMBOLS

AIC	Akaike Information Criterion
CFI	Bentler's Comparative Fit Index
FTLD	Frontal Temporal Lobar Degeneration
KBNA	Kaplan-Baycrest Neuropsychological Assessment
MCI	Mild Cognitive Impairment
MMSE	Mini-Mental Status Exam
TLI	Tucker Lewis Index
PASA	Posterior-Anterior Shift in Aging
RMSEA	Root Mean Square Error of Approximation
sr^2	Semi-Partial Correlation
SEM	Structural Equation Modelling
SES	Socioeconomic Status
SRMR	Standardized Root Mean Square Residual
STAC	Scaffolding Theory of Aging and Cognition
STAC-r	The Revised Scaffolding Theory of Aging and Cognition
WAIS-III	Wechsler Adult Intelligence Scale – Third Edition
WASI	Wechsler Abbreviate Scale of Intelligence

CHAPTER 1

INTRODUCTION

As the population ages, the need for both accurate and reliable methods aimed at predicting the trajectory and onset of age-related cognitive decline is set to increase. According to the 2021 Canadian census, nearly one in five Canadians are aged 65 years or older (Statistics Canada, 2022). Experts predict that this number will continue to grow over the next 30 years, with older adults in the oldest-old age group (i.e., aged 85 years or older) experiencing the largest increase (Statistics Canada, 2022). By 2050, the proportion of adults aged 85 years or older is projected to double from 2.3% of the total Canadian population to 4.6% (Statistics Canada, 2022). Alone, this demographic shift is expected to impact the overall prevalence and incidence of age-related pathologies, such as dementia (Ferri et al., 2005). Recent forecasts suggest that within the next 30 years, the total number of Canadian older adults living with dementia will increase substantially, from 600,000 to 1,300,000 (GBD 2019 Dementia Forecasting Collaborators, 2022). With this in mind, it is evident that there is an increasing need for more research that examines the various factors that predict 'healthy aging' (e.g., Abud et al., 2022) and help to maintain quality of life (e.g., Baernholdt et al., 2012; Samy et al., 2020) of older adults at risk of developing dementia (Livingston et al., 2020).

While it is largely recognized that the adverse effects of aging (e.g., development of chronic health conditions) differ amongst individuals, declines in cognitive functioning, both due to age and disease are commonly associated with a lower quality of life in older age (Borowiak & Kostka, 2004; Hussenoeder et al., 2020). Loss of these critical functions negatively affect individuals' ability to act independently and engage in every-day activities (Hayase et al., 2004; Jekel et al., 2015). Changes in cognition as people reach older age can be attributed to either

normal aging processes or abnormal aging processes (e.g., Alzheimer's disease pathology). In the context of normal aging, the degree to which age-related cognitive changes affect everyday functioning is dependent on a number of factors related to genetic makeup (Reichstadt et al., 2007) and lifestyle (Abud et al., 2022; Daffner, 2010). Since we lack the necessary tools to safely alter our genetic code, research has been primarily focused on identifying which lifestyle factors are associated with healthy aging. Unlike genetics, lifestyle factors are modifiable, and thus, of particular interest among researchers, as changes in lifestyle can be used as a potential target of late-life intervention.

A popular adage used in the discussion of healthy aging, is 'whatever is good for your heart is also good for your brain.' While it is true that this heuristic can be applied to a several different health-related factors, it is most commonly used to demonstrate the neurocognitive benefits of staying active and maintaining a healthy lifestyle. Population studies have shown that keeping physically active is beneficial towards one's cognitive health, as it lower one's risk of future cognitive impairment (e.g., Larson et al., 2006) and is generally associated with greater performance on cognitive testing (e.g., Weuve et al., 2004). Similarly, vascular risk factors, such as hypertension, alcohol consumption, smoking, diabetes, and cardiovascular disease have been associated with risk of late-life cognitive impairment (Duron & Hanon, 2008). Research has shown that individuals with fewer vascular risk factors were more likely to maintain their cognitive abilities in older age, compared to those with a higher number of vascular risk factors (Barnes et al., 2007). As we age, staying physically active and maintaining a healthy diet (e.g., plant-based)—another important factor in maintaining cognitive health (Chen et al., 2019)—are important in not only minimizing risk of cardiovascular disease but also lowering our overall risk of cognitive impairment (Ciumărnean et al., 2021; Rippe, 2018).

Developing research has suggested that keeping mentally active may be just as important as keeping physically active in older age (Livingston et al., 2020). Longitudinal studies have shown that participation in mentally stimulating activities, such as reading and playing intellectually challenging games, like chess and crossword, is associated with lower risk of developing dementia (i.e., Alzheimer's disease; Wilson et al., 2002). Other factors, such as participation in life-long learning, social support, financial security, independence, community involvement, belief in religion and/or spirituality, and outlook (i.e., future-oriented behaviour) have shown to be associated with healthy aging (Abud et al., 2022).

By understanding how these factors specifically impact the cognitive profiles of older adults, we will not only be able to better predict the likely functional impact of age-related cognitive change, but also identify which populations are at highest risk of cognitive impairment. Certain lifestyle factors, such as participation in intellectually stimulating activities and life-long learning have received increased attention in the study of age-related cognitive change, as they are associated with a concept known as cognitive reserve. Cognitive reserve is a hypothetical construct that explains why older adults are differentially affected by aging (Stern, 2002; Stern, 2009; Stern et al., 2020). Individuals with higher levels of cognitive reserve are thought to better maintain their cognitive abilities in older age, compared to individuals with low cognitive reserve (Stern, 2002). Factors such as reading, playing cognitively complex games, and engaging in active learning (e.g., learning a new language, learning to play a new musical instrument) have been shown to promote cognitive reserve (Wilson et al., 2003; Wilson et al., 2007). Specific life experiences accumulated in younger- and middle-age have also shown to be associated with higher levels of cognitive reserve (Stern, 2002). These factors include years of formal education and occupational complexity (Opdebeeck et al., 2016).

Stern's (2002) concept of cognitive reserve answers the very important question of why older adults experience varying degrees of cognitive impairment in older age despite similar age- and disease-related brain changes. A number of studies have shown that older adults with higher levels of cognitive reserve perform better on tests of general cognitive ability and domain-specific skills (e.g., executive functioning) compared to older adults with low levels of cognitive reserve (Opdebeeck et al., 2016). Unfortunately, evidence is limited as the current cognitive reserve literature is plagued with measurement problems (Jones et al., 2011), inconsistent findings (Berezuk et al., 2021; Opdebeeck et al., 2016) and inappropriate statistical techniques (Jones et al., 2011). Emerging research has attempted to address these issues by establishing more consistent definitions of cognitive reserve (Stern et al., 2020) and utilizing more powerful statistical techniques (e.g., multivariate analysis; Delgado-Losada et al., 2019; Feldberg et al., 2021; Lojo-Seoane et al., 2014; Mitchell et al., 2012) however, findings are still limited by outdated coding/measurement tools and investigations that only consider the effect of cognitive reserve on a restricted number of cognitive domains. Few studies (e.g., Mitchell et al., 2012) to date have examined the effects of cognitive reserve on performance across a comprehensive battery of neuropsychological tests.

By examining the differential effects of cognitive reserve on late-life cognition, we can identify which neuropsychological tests are most sensitive to cognitive reserve and which tests are least sensitive. This can be useful when assessing the presence of underlying brain damage or pathology in individuals with higher levels of cognitive reserve, as they typically show clinical symptomology much later than individuals with lower levels of cognitive reserve (Albert et al., 1995; Stern et al., 1999). Diagnoses may be overlooked or entirely missed amongst individuals with higher levels of cognitive reserve (e.g., Gamble et al., 2022), thus, it is important that we

consider its role in the behavioural manifestation of age-related cognitive impairment. In conditions like dementia, early detection is critical in determining responsiveness to intervention (Cosentino & Stern, 2019), therefore, there is need for greater research investigating the effects of cognitive reserve on the neuropsychological functioning of older adults at risk of cognitive decline.

The current thesis sought to elucidate the relationship between cognitive reserve and late-life cognitive functioning by examining the cumulative effects of three cognitive reserve proxies—educational attainment, mental workplace demands, crystallized intelligence—on neuropsychological performance of a clinical sample of older adults without dementia.

In the following sections, I will summarize the research literature which details the impact of cognitive reserve on neuropsychological performance of healthy older adults and older adults with mild cognitive impairment. First, I will introduce the typical neural and cognitive changes associated with normal cognitive aging, then transition into the changes associated with pathological aging. The second section of my literature review will involve the discussion of some of the major theories dominating the cognitive aging literature, with special focus on theories explaining the inter-individual differences in cognitive aging. This will lead into my discussion of the cognitive reserve hypothesis. Through this, I will review the evidence supporting the three main cognitive reserve indicators used in this thesis. In the remaining sections, I will outline two models which were tested, as part of my thesis. The first of which hypothesized that cognitive reserve has a generalized effect on all cognitive domains, and the second hypothesized that there is a hierarchical organization of effects on cognition, with cognitive reserve directly impacting executive functions and indirectly effecting other lower-level cognitive abilities.

Normal Cognitive Aging: Neural and Cognitive Correlates

As we age, our brains undergo a series of anatomical changes, both at the gross anatomic and microstructural level. Normal aging is associated with neuroanatomical (Juraska & Lowry, 2012) and neurofunctional (Cabeza, 2001) changes, characterized most notably by progressive volume loss (i.e., grey matter volume reduction [e.g., Raz et al., 2010], white matter volume reduction [e.g., Meier-Ruge et al., 1992]), decreased functional connectivity (e.g., Sala-Llonch et al., 2015), and maladaptive neuroplasticity (e.g., loss of dendric spines and synapses; Dickstein et al., 2007; Fjell & Walhovd, 2010). Whole-brain and regional analyses have shown that total intracranial volume decreases as we age (Scahill et al., 2003), with regional grey matter volume reductions in the orbitofrontal cortex, lateral prefrontal cortex, hippocampus, primary visual cortex, and cerebellum (Raz et al., 2005; Raz et al., 2010; Fjell et al., 2009; Driscoll et al., 2009). Global and regional white matter volume follows a similar age-related course, with volumetric growth declining in late adulthood (i.e., aged 70+; Gunning-Dixon et al., 2009; Raz et al., 2005).

As one might expect, progressive changes in both the neural architecture (e.g., decreases in white matter tract integrity; Bennett & Madden, 2014; Madden et al., 2009) and structural morphology of the brain (e.g., loss of grey matter, reduced synaptic density) are associated with age-related changes in task-related brain activation and connectivity between brain networks (Andrews-Hanna et al., 2007). For example, when presented with visual stimuli, older adults exhibit reduced activation (Buckner et al., 2000) and neural specialization (Park et al., 2004) within regions of the visual cortex compared to younger adults. Another common finding is that on tasks of working memory (Mattay et al., 2006; Reuter-Lorenz & Cappell, 2008) and episodic memory (Spaniol & Grady, 2012), older adults can exhibit greater activation of certain brain regions (e.g., frontal regions, prefrontal cortex, posterior cingulate cortex) compared to younger

adults. Within the literature, these findings are explained by two distinct age-related neural processes, *dedifferentiation,* and *compensation*. Dedifferentiation refers to age-related loss of functional specialization (i.e., distinctiveness) of posterior and occipitotemporal regions of the brain (e.g., hippocampus, visual cortex; Carp et al., 2011; Grady et al., 2002; Park et al., 2004; Rajah & D'Esposito, 2005), whereas compensation refers to age-related over-recruitment of brain regions, notably the prefrontal cortex (Cabeza, 2002; Cabeza et al., 2002; Cabeza et al., 2004). Research has suggested that age-related decreases in neural activation and differentiation are associated with many of the deficits in cognition seen in older age (Grady et al., 1995; Sala-Llonch et al., 2015). Age-related over-recruitment on the other hand, is thought to represent a compensatory process, as researchers have hypothesized that increased levels of prefrontal activation provide older adults with greater neural resources which can be used to compensate for age-related disruptions in cognitive processing (Grady, 2008).

In recent years, more detailed functional investigations have shown that in addition to age-related differences in task-related activation, older adults exhibit weaker functional connectivity at rest in prefrontal regions compared to younger adults (Hughes et al., 2020; Sala-Llonch et al., 2015). This trend is generally mirrored in terms of network efficiency, as older adults demonstrate poorer global and local network efficiency compared to younger adults (Achard & Bullmore, 2007). Interestingly, network-based analyses have shown that when faced with increased tasks demands, older adults typically exhibit greater within-network functional connectivity in the frontoparietal control and default mode network compared to younger adults (Grady et al., 2016). Furthermore, older adults also have been shown to exhibit greater connectivity between frontal parietal control networks and other large-scale brain networks compared to younger adults, and this increased connectivity is associated with better cognitive

performance (Grady et al., 2016). Mechanistically, these findings are reminiscent of those in support of a functional compensation approach to neural aging (e.g., Cabeza, 2002; Park & Reuter-Lorenz, 2009), where like over-recruitment of the prefrontal cortex, increases in functional connectivity during a task are representative of compensatory mechanisms which help older adults compensate with age-related functional deficits.

Age-related changes in both the structure and function of various prefrontal and medial temporal regions of the brain are believed to underly many of the observed late-life changes in cognition reported by older adults (Brickman et al., 2006; Brickman et al., 2007; Park & Reuter-Lorenz, 2009; Zimmerman et al., 2006). While some cognitive abilities appear to improve as we age (e.g., crystallized intelligence, vocabulary), many aspects of our cognition begin to decline in early to middle adulthood (e.g., fluid intelligence; Craik & Bialystok, 2006; Harada et al., 2013; Murman, 2015; Salthouse, 2012). Decades of cross-sectional and longitudinal research has shown that many of our higher-order cognitive abilities, such as complex attention/working memory, problem solving, planning, and reasoning begin to decline in early adulthood (i.e., third decade of life; Ferguson et al., 2021; Salthouse et al., 1995; Salthouse, 2010), becoming progressively worse in older age. Lower-order abilities, such as immediate memory, simple attention span, and visuospatial processing remain relatively stable throughout adulthood and are associated with a milder decline into older adulthood (de Bruin et al., 2016; Lezak et al., 2012). Additional research has shown that our processing speed, or the speed at which we can perform certain cognitive tasks, begins to decline shortly into early adulthood (Salthouse, 2010). Slowed processing speed is one of the most prominent cognitive changes as people reach older age, and researchers have proposed that slowed mental processing affects higher order cognitive functions as well (Salthouse, 1996).

Neuroimaging studies have shown that many of our higher-order cognitive abilities, such as working memory and inhibitory control rely on the recruitment of lateral and medial prefrontal regions (Diamond, 2013; Turken et al., 2008). In normal aging, observed changes in white matter tract integrity and regional activation of the prefrontal cortex have been shown to be associated with age-related declines in executive functioning (Brickman et al., 2006; Madden et al., 2009) and processing speed (Gunning-Dixon & Raz, 2000; Kennedy & Raz, 2009; Papp et al., 2014; Rabbitt et al., 2007).

Problems with memory are among the most common health-related concerns reported by older adult populations (Borglin et al., 2005). Some studies have estimated that up to 50% of older adults report subjective concerns about their memory (Jonker et al., 2000). Performance on tests of episodic memory, otherwise known as our memory for events or distinct episodes in our lives, begins to decline in early to middle adulthood (Murman, 2015; Rönnlund et al., 2005). Episodic memory is often differentiated into verbal episodic memory ability and visual episodic memory ability. Although both types of memory are associated with distinct neurofunctional correlates (Desgranges et al., 1998; Wagner et al., 1998), research has shown that both verbal and visual long-term memory abilities decline with age (Park et al., 2002).

Changes in episodic memory are associated with age-related decreases in hippocampal grey matter volume (Gorbach et al., 2017) and parahippocampal white matter (Rogalski et al., 2012). It is hypothesized that regional decreases in grey and white matter volume disrupt the structural integrity of the medial temporal lobe (e.g., reduced synaptic connections between the hippocampus and parahippocampus, post-synaptic alterations within the hippocampus), which subsequently alters memory functioning (Morrison & Baxter, 2012; Rogalski et al., 2012).

Similar to episodic memory, our ability to remember to perform an intended or planned action, otherwise known as prospective memory, also declines throughout older adulthood (Murman, 2015; Schnitzspahn et al., 2013). However, the degree to which age impacts prospective memory has been widely debated, as some studies have demonstrated little to no changes throughout adulthood (Einstein & McDaniel, 1990; McDaniel et al., 2003), and others have demonstrated distinct age-related effects (Henry et al., 2004; Uttl, 2008). When it comes to our memory for general facts and knowledge, otherwise known as semantic memory, research has consistently shown that our semantic memory is more resistant to age-related changes, compared to episodic and prospective memory (Rönnlund et al., 2005). Like our other crystallized abilities (e.g., vocabulary), our knowledge of general facts and information appears to improve throughout early to middle adulthood with accumulated life experience and learning opportunities (Park et al., 2002; Nyberg et al., 2003). Declines in semantic memory occur much later into older adulthood (i.e., sixth and seventh decade of life) and are typically more gradual compared to other memory abilities (Park et al., 1996). Our implicit memory, on the other hand, appears to remain relatively stable throughout adulthood (Churchill et al., 2003; Nilsson, 2003). This type of memory is commonly associated with priming effects, as well as our ability to perform regular day-to-day tasks.

Pathological Aging: Neural and Cognitive Correlates

While normative aging is associated with mild reductions in particular cognitive domains, some older adults experience cognitive decline that is worse than what would typically be expected due to their age. These older adults may meet clinical criteria for a neurocognitive disorder called mild cognitive impairment (MCI). MCI is considered to represent an intermediate stage between healthy aging and dementia (Harrison et al., 2016; Petersen, 2011; Petersen et al.,

2014), as cognitive decline exceeds the expected range for healthy aging but does not reach the threshold for dementia (i.e., does not interfere significantly with activities of daily living; Harada et al., 2013; Lopez, 2013). When differentiating MCI from normal cognitive aging and other neurocognitive disorders, the Albert et al. (2011) criteria is often used: i.) concern of cognitive change, expressed by the individual, informant, or clinician, ii.) observed impairment in one or more cognitive domains (e.g., >1.5 standard deviation below normative sample), iii.) preservation of independence in performing activities of daily living, iv.) no evidence of significant social or occupational impairment.

Globally, MCI is estimated to have a prevalence rate between 12 and 18% among adults aged 60 years or older (Petersen, 2016). Estimates of incidence suggest that approximately 24.2 per 1,000 persons aged 70–74 to 74.7 per 1,000 persons aged 85 years or older develop MCI in a given year (Gillis et al., 2019). The prognostic outcomes of individuals with MCI are quite heterogenous with some converting to Alzheimer's disease or vascular dementia and others remaining stable or reverting back to cognitively normal status (Hu et al., 2017; Hsiung et al., 2006). According to a recent meta-analysis, approximately 34% of individuals with MCI progress to dementia, 28% progress to Alzheimer's disease, 45% remain stable, and 15% reverted back to cognitively normal (Hu et al., 2017). Studies that have included vascular variants of MCI in their analyses have reported similar findings, with the majority of vascular mild cognitive impairment-no dementia cases remaining stable after two years and smallest portion reverting back to cognitively normal (Hsiung et al., 2006).

Many of the cognitive deficits associated with MCI are believed to be the consequence of several pathologically-mediated changes in the brain that exceed what is seen in normal cognitive aging (Heiss et al., 2016; Nickl-Jockschat et al., 2012). When compared to brains of

individuals experiencing normal cognitive aging, individuals with MCI typically exhibit greater whole brain volume loss (Driscoll et al., 2009) and regional grey matter volume loss in the bilateral medial temporal lobes (e.g., amygdala, hippocampus, thalamus), parietal precuneus, and posterior cingulate gyrus (Nickl-Jockschat et al., 2012). Additionally, the rate of which volume loss occurs is much quicker for those with MCI versus normal cognitive aging (Driscoll et al., 2009). White matter infarcts within the brain and marked changes to white matter around the lateral ventricles (i.e., leukoaraiosis) are more common in MCI associated with cerebrovascular causes (Meyer et al., 2007), however, research has shown that individuals with MCI due to cerebrovascular causes also typically exhibit hippocampal atrophy, in addition to observed white matter abnormalities (Stephan et al., 2009).

MRI investigations have shown that the pattern of volume loss seen in individuals with amnestic MCI—whose primary impairment is memory—generally mirrors that of Alzheimer's disease (Meyer et al., 2007). Individuals typically exhibit pronounced atrophy of the entorhinal cortex and hippocampus and volumetric enlargement of the temporal horns (Meyer et al., 2007). In contrast, the neuroimaging profiles of individuals with MCI due to cerebrovascular disease is similar to those with vascular dementia (Meyer et al., 2007). Individuals with MCI due to cerebrovascular causes typically exhibit greater white matter and basal ganglia infarcts compared to other variants of MCI (e.g., MCI due to neurodegenerative disease; Meyer et al., 2007). Functional imaging has shown that individuals with amnestic MCI often display altered functional connectivity and patterns of activation in certain brain regions compared to healthy controls (Farràs-Permanyer et al., 2015; Lin et al., 2018; Machulda et al., 2009; Sun et al., 2011). For example, when performing a memory tasks, individuals with amnestic MCI typically exhibit increased neural activity in the hippocampus and other memory-dependent structures of the

medial temporal lobe, compared to healthy controls (Dickerson et al., 2005; Mueller et al., 2012). Like in healthy aging, increased activation of the hippocampus and medial temporal regions has been attributed to the presence of compensatory mechanisms, where individuals with MCI overrecruit memory-dependent regions to compensate for deficits in episodic memory (Farràs-Permanyer et al., 2015).

Studies examining the resting-state functional connectivity of several large-scale brain networks in both healthy aging and MCI have found that individuals with MCI often exhibit an abnormal pattern of hypo- and hyper-connectivity within regions of the default mode network (Eyler et al., 2019), a network associated with autobiographical and episodic memory that includes the hippocampus and other medial temporal regions (Andrews-Hanna et al., 2014). One study found that when compared to healthy controls, individuals with MCI displayed decreased inter-regional functional connectivity between the hippocampus and posterior cingulate cortex as well as decreased functional connectivity between the hippocampus, cingulate cortex, and the rest of the brain (Zhou et al., 2008). It is well-understood that both the hippocampus and cingulate cortex are important structures involved in episodic memory (Dickerson & Eichenbaum, 2010), thus, alterations to the functional connectivity between these regions and the whole brain may underlie problems with verbal memory experienced by individuals with amnestic MCI (Zhou et al., 2008).

When an individual is presenting with MCI, the cause of observed cognitive dysfunction may be attributed to i.) an underlying degenerative condition (e.g., Alzheimer's disease, Parkinson's disease), ii.) a vascular condition (e.g., stroke), iii.) a psychiatric condition (e.g., depression), or iv.) a medical condition (Petersen, 2004). Because of its varying etiologies, the clinical presentation of MCI can vary significantly across individuals (Delano-Wood et al.,

2009). Generally speaking, MCI can be classified as amnestic (i.e., characterized by pronounced memory problems) or non-amnestic (i.e., characterized by impairments in domains other than memory), with impairments affecting either a single-domain or multiple domains of cognitive functioning (Petersen, 2004).

Amnestic MCI is most often associated with the earliest clinical signs of Alzheimer's disease (Albert et al., 2011), and commonly reflects accumulation of plaques and tangles and cell death affecting brain regions important for episodic memory function in the medial temporal lobe. Memory problems are common amongst individuals with MCI and are believed to be central to the MCI due to Alzheimer's disease pathology (Yanhong et al., 2013). Deficits in memory mostly manifest as impairments in episodic memory (Irish et al., 2011), however, individuals with MCI due to Alzheimer's disease may also present with impairments in prospective memory (e.g., Costa et al., 2011), and visual memory (e.g., Saunders & Summers, 2010). It is common for individuals with amnestic MCI due to Alzheimer's disease to present with additional impairments other than memory (Albert et al., 2011). Higher-order cognitive abilities, such as working memory, response inhibition, and task-switching have also been found to be affected in individuals with amnestic MCI (Zheng et al., 2012). Other areas of cognitive functioning, such as language, processing speed, visuospatial functioning, and attention have also been shown to be affected alongside memory and executive functioning in individuals with amnestic MCI (Edmonds et al., 2015; Eppig et al., 2012; Libon et al., 2010; Petersen et al., 2001; Petersen & Negash, 2008; Putcha & Tremont, 2016), however, the nature of these impairments are less understood compared to memory, as they are not as common (Busse et al., 2006; Overton et al., 2019) and have been measured inconsistently across the literature (Yanhong et al., 2013).

An individual with MCI who primarily experiences executive function deficits, by contrast, is more likely to be experiencing MCI due to frontotemporal lobar degeneration (FTLD) or cerebrovascular disease. FTLD is clinical syndrome characterized by the progressive loss of neural tissue in the frontal and temporal lobes of the brain (Rabinovici & Miller, 2010). Loss of neural tissue in the frontal and temporal lobes leads to impairments in language, behaviour, and higher-order cognitive processing (Rabinovici & Miller, 2010).

Clinically, individuals with MCI due to FTLD typically experience impairments in several frontal-mediated cognitive functions, including attention, concentration, conceptual thinking, verbal fluency, motor sequencing, and graphomotor skills (de Mendonça et al., 2004). Language impairments are most common among individuals with the progressive non-fluent aphasia variant of FTLD, whereas the understanding of words and concepts is more commonly impaired among individuals with the semantic dementia variant of FTLD (Rabinovici & Miller, 2010). In addition to the discussed neuropsychological impairments, apathy, lack of insight, and behavioural changes are associated with MCI due to behavioural variant FTLD (Petersen, 2016). Unlike other types of the MCI, it has been found that in the earlier stages of the degeneration, visuospatial abilities and episodic memory are preserved in individuals with either the language or behavioural variants of FTLD (Rabinovici & Miller, 2010). Although impairments in language and executive functioning are considered to be hallmarks of MCI due to FTLD, research has shown that impairments in individual with MCI due to cerebrovascular disease (Stephan et al., 2009) or MCI due to Lewy-Body Dementia (Hemminghyth et al., 2020) also exhibit impairments in attention, concentration, and higher-order cognitive functioning.

Cerebral small vessel disease (CSVD) is the most common cause of cognitive impairment seen in individuals with MCI due to cerebrovascular disease (Pantoni, 2010). Age and vascular

risk factors such, as hypertension, smoking, high cholesterol, and diabetes are associated with increased risk of small vessel disease (Wang et al., 2021). CSVD is commonly associated with two pathological changes in the brain, i.) arteriolosclerosis—hardening and loss of flexibility of small arterioles—and ii.) cerebral amyloid angiopathy—accumulation of proteins in small and medium blood vessels in the brain (Li et al., 2018). These changes, along with other vascular-related changes (e.g., breakdown of the blood brain barrier, reduced cerebral blood flow) lead to cerebral white matter lesions, lacunes, and small brain infarcts (Dichgans & Leys, 2017). White matter lesions and small brain infarcts are associated with cognitive impairment (Au et al., 2006; Gorelick et al., 2011; Vermeer et al., 2007) and believed to contribute to the clinical presentation of individuals with MCI due to cerebrovascular causes. Clinically, individuals with MCI due to cerebrovascular causes typically present with impairments in several cognitive domains, including attention, executive functioning, verbal memory, and information processing speed (Loewenstein et al., 2006; Nordlund et al., 2007).

Like in the case of normal aging, research has shown that there is considerable variability in the cognitive and neuroanatomical profiles of individuals with MCI (Delano-Wood et al., 2009; Dong et al., 2017; Gorus et al., 2008; LaPlume et al., 2021; Libon et al., 2010; Moorhouse & Rockwood, 2008; Ramratan et al., 2012). These findings have prompted researchers to uncover the various factors that mediate inter-individual variability in the cognitive profiles of not only healthy older adults but also individuals in the prodromal stages of dementia (e.g., Katzman, 1993; Katzman et al., 1988; Nyberg et al., 2012; Satz, 1993; Stern, 2002).

Theories Explaining Individual Differences in Cognitive Trajectories in Aging

As the previous sections illustrate, healthy aging and the presence of pathology can affect the structure and function of older adults' brains, with consequences for cognitive performance

tied to the location and extent of these neural changes. There is considerable heterogeneity in cognitive outcomes, however, even among individuals with similar brain changes. It has been theorized that the degree to which aging, and neuropathology affects cognition is dependent upon several factors both present at birth and accumulated across the lifespan, including biological sex (e.g., Jockwitz et al., 2021), life experiences (e.g., Salthouse, 2006; Stern, 2002), and environmental influences (e.g., Kramer et al., 2004; Park & Reuter-Lorenz, 2009; Reuter-Lorenz & Park, 2014). This idea has been supported by clinical and empirical investigations that have shown that the cognitive profiles of both healthy and mildly impaired older adults vary considerably across individuals (e.g., Albert et al., 1995; Christensen et al., 1999; Delano-Wood et al., 2009; LaPlume et al., 2021; Rapp & Amaral, 1992; Wilson et al., 2002; Wu et al., 2021).

While it is largely accepted that many our cognitive abilities decline as we age (Verhaeghen & Salthouse, 1997), factors other than age are also associated with late-life cognitive ability. Demographic factors, like gender have been shown to contribute to the overall variability in cognitive abilities amongst older adult populations (e.g., Jockwitz et al., 2021). Research has shown the cognitive profiles of older men and women vary significantly, with older women performing better on tasks of verbal fluency, verbal episodic memory, processing speed and interference tasks compared to men, and men performing better on visuospatial tasks (e.g., Jockwitz et al., 2021). This variability is also present amongst older adult with differing medical histories (e.g., Kim et al., 2019). Certain chronic health conditions, such as hypertension and diabetes are associated with poorer cognitive functioning in a number of domains, most notably memory and executive functioning (Elias et al., 2012; Kim et al., 2019; Mayeda et al., 2015). Like our physical health, aspects of our mental health, such as depression are shown to impact our cognitive functioning in late life (Herrmann et al., 2007). In a 2013 study, a group of

researchers found that individuals with late-life depression performed significantly worse on tests of information processing speed and executive functioning, when compared to healthy older adults (Dybedal et al., 2013). Other aspects of cognitive functioning such as episodic and semantic memory have also been shown to be negatively impacted in individuals with late-life depression (Herrmann et al., 2007).

A number of theoretical frameworks have been proposed in the last 20 years to help explain the various mechanism underlying individual differences in late-life cognition (e.g., Park & Reuter-Lorenz, 2009; Reuter-Lorenz & Park, 2015; Salthouse, 2006; Stern et al., 2002). In this section I will be reviewing two major theories that explain individual differences in cognitive aging: i.) The Scaffolding Theory of Aging and Cognition (STAC; Park & Reuter-Lorenz, 2009), and ii.) The Reserve Hypothesis (Stern et al., 2002).

Scaffolding Theory of Aging and Cognition

The STAC model was first proposed in 2009 and sought to explain inter-individual differences in cognitive aging through a concept known as compensatory scaffolding—active recruitment of neurocognitive processes designed to counteract the neurobiological effects of aging (Park & Reuter-Lorenz, 2009). 'Scaffolding' builds off of a common observation reported in the skill acquisition literature—widespread neural recruitment during task learning, followed by focal neural specification during task mastery (Petersen et al., 1998)—and applies it to our understanding of cognitive aging, suggesting that the same neural mechanisms underlying the learning stages of skill acquisition in younger adulthood (i.e., activation of broad set of neural networks to perform the novel task) also help older adults preserve their cognitive ability in the face of age-related neural change. Like other neuroplastic processes, scaffolding is believed to be a dynamic process, meaning that it occurs across the lifespan and can be enhanced through

factors related to one's lifestyle, such as physical exercise and sustained cognitive challenge (i.e., engagement in cognitively stimulating activities; Park & Reuter-Lorenz, 2009).

The STAC model proposes that when people age, the brain actively recruits secondary neural networks in response to increased task demands (Park & Reuter-Lorenz, 2009). According to the model, secondary networks are recruited primarily to help older adults perform familiar versus novel tasks, as the original networks associated with the familiar task are believed to be adversely affected by the aging process (Park & Reuter-Lorenz, 2009).

The idea of secondary recruitment has been seen in context of healthy aging, where older adults on average, demonstrate increased anterior activation in prefrontal cortex and decreased posterior activation in occipitotemporal regions, compared to younger adults (Grady et al., 1994). This pattern of neural activation is described as the posterior-anterior shift in aging (PASA; Grady et al., 1994). Although the function of PASA has been widely debated, the general consensus is that it represents the brain's ability to compensate for changes in structure and function (Davis et al., 2008; Grady et al., 1994). This is further supported by evidence of age-related over-recruitment of the prefrontal cortex (Cabeza, 2002; Cabeza et al., 2002; Cabeza et al., 2004) and greater between and within network connectivity of the frontoparietal control network (Grady et al., 2016). Evidence of age-related reductions in the activation of posterior regions, such as the visual cortex is similarly supported by observations of age-related neural dedifferentiation seen in older adult populations (e.g., Buckner, 2000; Carp et al., 2011; Park et al., 2004). In 2008, Davis et al. conducted a study that examined the purpose of the posterior-anterior shift. Findings from this study revealed that age-related increases in prefrontal activity was positively associated with increased cognitive ability. Additional analyses revealed that decreased activation of occipitotemporal regions was associated with greater prefrontal activity.

These findings support the role of prefrontal recruitment in maintaining late-life cognitive abilities (Davis et al., 2008).

Unlike the behavioural theories that preceded it, the STAC model proposes that differences in late-life cognition may be due to variability in one's genetic susceptibility to aging (i.e., susceptibility to negative neurocognitive consequences of aging) and one's propensity for neurocognitive/compensatory scaffolding; suggesting that late-life cognition is best preserved amongst individuals with both highly efficient scaffolding mechanisms and a low genetic susceptibility for age-related changes in brain (Park & Reuter-Lorenz et al., 2009).

Nearly five years after publishing their original model, Reuter-Lorenz and Park (2014) updated the STAC model to include the influence of cumulative life experiences on mechanisms underlying neurocognitive scaffolding and age-related changes in the brain. In their updated model, Reuter-Lorenz and Park (2014) introduced the effects of positive and adverse life factors on compensatory scaffolding. Positive life experiences, such as education, cognitive stimulation, and physical exercise are believed to promote neural health and drive compensatory scaffolding (Colcombe et al., 2004; Erickson et al., 2014; Plassman et al., 2010; Yaffe et al., 2009), whereas negative life experiences, such are stress, depression, vascular risk factors, and chronic health conditions are believed to promote the opposite, contributing to widespread neural dysfunction (Formánek et al., 2020; Kim et al., 2019; Lavretsky & Newhouse, 2012; Schneider et al., 2015). Accumulation of adverse and compensatory factors are proposed to contribute to two competing age-related neural mechanisms, known as *neural resource depletion* and *neural resource enrichment* (Reuter-Lorenz & Park, 2014). Neural resource enrichment helps ameliorate the effects of aging on the brain whereas neural resource depletion adversely affects neural functioning (Reuter-Lorenz & Park, 2014). Factors, such as physical exercise, educational

attainment, and participation in cognitively stimulating activities are believed to enhance both the structure (e.g., increased cortical thickness, increased synaptic density) and function (e.g., increased functional connectivity) of the brain, promoting higher levels of cognitive functioning in middle and late-adulthood (Reuter-Lorenz & Park, 2014; Singh-Manoux et al., 2003; Stern, 2002). Neural resource enrichment is also hypothesized to enhance neurocognitive scaffolding, which includes increased prefrontal activity (e.g., Cabeza et al., 2004), neurogenesis (e.g., Maguire et al., 2000), and distributed activation (e.g., Cabeza, 2002). Factors that promote neural resource depletion, such as stress, vascular risk factors, and depression are hypothesized to contribute to cognitive dysfunction by counteracting the positive neuroplastic effects of enrichment factors (Reuter-Lorenz & Park, 2014). Neural resource depletion accelerates cognitive aging and increases risk of age-related cognitive disorders (Brickman et al., 2008; Debette et al., 2011; Reuter-Lorenz & Park, 2014). This is hypothesized to occur through several pathologically mediated mechanisms, including disease- and stress-related hippocampal atrophy (Debette et al., 2011; McEwen, 2007) and depression-related white matter lesions (Brickman et al., 2009).

The Reserve Hypothesis

An important question raised by the Reuter-Lorenz and Park (2014) STAC model, is what specific factors make some people more resilient to cognitive effects of aging and disease over others? A concept known as “reserve” is often brought up in the neuropsychological and cognitive neuroscience literature, as a potential mechanism that contributes to the preservation of cognitive abilities in older age (Stern, 2002). Stern’s (2002) concept of reserve is considered by many, as the theoretical basis of population-level differences in cognitive aging trajectories. Within the literature, reserve is primarily discussed in relation of two separate yet related

constructs: brain reserve, a set of compensatory mechanisms associated with the *structure* of the brain, and cognitive reserve, a set of compensatory mechanisms associated with the *function* of the brain.

Brain Reserve Capacity and Threshold Models

Passive models of reserve—brain reserve capacity—propose that *underlying differences in neural resources* contribute to the observed variability in how individuals cope with age- and/or disease-related changes to the brain (Katzman, 1993; Stern, 2002). Brain reserve capacity is defined as one's total "neurobiological capital", which is conceptualized in terms of total brain volume, cortical thickness, white matter tract integrity, and total number of neurons and synapses (Stern et al., 2020, pp 1308). Individuals with higher levels of brain reserve are believed to have a higher threshold for clinical expression (i.e., functional impairment) compared to individuals with lower levels of brain reserve, meaning that they are able to sustain a greater degree of pathology or age-related neural changes before experiencing the same corresponding clinical symptomology. Given that brain reserve is conceptualized as a set of factors related to one's neural architecture and morphology, researchers initially proposed that one's brain reserve capacity and threshold for cognitive impairment is influenced by genetics (e.g., Bartley et al., 1997) and is thus, a static construct. As our understanding of both positive and negative neuroplasticity has improved, the validity of much earlier biologically driven models of brain reserve capacity have been challenged, as research has consistently found that the brain undergoes changes in volume (i.e., neurogenesis) across the adult lifespan (Eriksson et al., 1998) and is influenced by factors related to both one's genetics and lifestyle, such as diet and exercise (Kuipers et al., 2014; Maharjan et al., 2020). While it is important to understand the structural mechanisms that promote cognitive resilience, they do not capture how differences in functional

efficiency (i.e., how the neural resources are utilized) impact the cognitive trajectories of aging and disease-burdened older adults (Stern et al., 2020). Active models of reserve bridge this gap, providing the functional component of reserve (Stern et al., 2020).

Cognitive Reserve

Active models of reserve—cognitive reserve hypothesis—propose that *individual differences in neural adaptability* contribute to the observed variability in how individuals cope with age- and/or disease-related changes to the brain (Pettigrew & Soldan, 2019; Stern, 2002; Stern, 2009). Similar to the brain reserve and threshold hypothesis, it is believed that individuals with higher levels of cognitive reserve are able to delay functional impairment (Albert et al., 1995; Stern et al., 1999) and maintain their cognitive abilities much later into adulthood (Stern, 2002) compared to individuals with low reserve. However, while passive models of reserve suggest that individual differences in clinical presentation (i.e., symptoms and course) of dementia and age-related cognitive decline are a product of underlying differences in neural resources (e.g., synapse count), active models of reserve postulate that differences are not fixed and that the brain instead actively copes with neural change by recruiting compensatory mechanisms at the network level. Research has shown that certain lifestyle factors and demographic variables, such as educational attainment, occupational complexity, intellectual functioning, and participation in cognitively stimulating activities promote the development of cognitive reserve through two neural mechanisms: neural reserve and neural compensation (Stern, 2002; Stern, 2009; Stern & Barulli, 2019).

Neural reserve refers to the naturally occurring variability in network efficiency, capacity, and flexibility (Stern et al., 2005). Differences in these functional processes are present prior to the existence of age-related pathology and therefore, represent inter-individual

differences in cognitive processing (Stern et al., 2005; Stern, 2009). Individuals with higher levels of cognitive reserve are said to have more efficient and resilient neural networks compared to those with lower levels of reserve, such that less activation is required in response to increased task demands (Stern, 2009).

Neural compensation, conversely, refers to differences in one's ability to recruit alternate neural networks and structures (i.e., regions not normally associated with the task) in response to increased task demands (Stern, 2009). Many of the scaffolding processes described in the STAC model, such as increased prefrontal activity, and distributed activation, are direct demonstrations of neural compensation, as they involve the recruitment of alternate neural networks to compensate for deficits in cognitive ability produced by age or disease degraded neural networks. According to Stern et al. (2019), neural compensation is one of the many ways that cognitive reserve is implemented in the brain. Thus, it is said the degree to which scaffolding processes are implemented is dependent on the number and type of positive life experiences accumulated across the lifespan (Reuter-Lorenz & Park, 2014; Stern et al., 2019). Within the framework of reserve, the positive life experiences associated with neurocognitive scaffolding (e.g., educational attainment, cognitive stimulation), represent contributors to cognitive reserve (Stern, 2002).

Growing research has suggested that neurocognitive mechanisms underlying brain reserve and cognitive reserve are in fact distinct from one another, with brain reserve demonstrating fewer associations with late-life cognition compared to cognitive reserve in the earlier stages of cognitive decline (Groot et al., 2018; Vonk et al., 2022; Yang et al., 2020). For example, in one study, a group of researchers examined the differential effects of brain reserve capacity and cognitive reserve in a clinical sample of older adults and found that the effects of

cognitive and brain reserve were independent of each other: cognitive reserve was more strongly associated with executive functioning, attention, and global cognition in older adults with AD in the preclinical and MCI stages, whereas brain reserve had smaller associations with cognition, which did not vary across disease stages (Groot et al., 2018).

Like other theories of cognitive aging, the reserve hypothesis (Stern, 2002), and more specifically, the cognitive reserve hypothesis provides researchers with a neurocognitive framework explaining inter-individual differences in cognition and cognitive decline in older age. Many of the concepts and mechanisms underlying the cognitive reserve hypothesis, such as neural reserve and neural compensation, mirror the theoretical underpinnings of Reuter-Lorenz and Park's (2014) STAC model and earlier use-it-or lose-it hypotheses, like Salthouse's (2006) differential-preservation hypothesis—increased mental activity in older age is associated with greater cognitive functioning. Thus, they can be considered complementary to one another, representing similar age-related processes (Park & Reuter-Lorenz, 2009). Historically, the cognitive reserve hypothesis was proposed prior to the original STAC model and focuses more on the adaptability of the brain in response to aging and age-related pathology, whereas the STAC and STAC-r model are focused more on healthy aging and take more of a life-course approach, suggesting that compensatory mechanisms are present throughout the entire lifespan (Park & Reuter-Lorenz, 2009; Reuter-Lorenz & Park, 2014). Being a more established model, the cognitive reserve hypothesis, has been tested and applied to a number of different populations (e.g., dementia [e.g., Stern, 2012], Parkinson's disease [e.g., Hindle et al., 2014], depression [e.g., Barnett et al., 2006]), generating three consistent findings regarding late-life cognition and onset of cognitive decline (Pettigrew & Soldan, 2019).

The first and arguably most consistent finding reported in the cognitive reserve literature is that individuals with higher levels of cognitive reserve exhibit higher levels of cognitive functioning compared to individuals with lower levels of cognitive reserve (e.g., Berezuk et al., 2021; Opdebeeck et al., 2016). For example, Lavrencic et al. (2018b) examined the influence of cognitive reserve on global and domain-specific cognitive functioning in a sample of adults in the oldest-old age group and found that individuals with higher levels of cognitive reserve exhibited better performance on tests of memory, attention, processing speed, and global cognition. Generally, research supporting the effects of cognitive reserve on global aspects of cognitive functioning is robust (Berezuk et al., 2021; Opdebeeck et al., 2016). However, when it comes to the evaluating the relationship between cognitive reserve and domain-specific aspects of cognitive functioning, evidence is more varied (Berezuk et al., 2021; Opdebeeck et al., 2016). Some studies have demonstrated robust effects of cognitive reserve on multiple areas of cognitive functioning, such as episodic memory, processing speed, and executive functioning (Boyle et al., 2021; Foubert-Samier et al., 2012; Narbutas et al., 2019), whereas others have demonstrated more modest effects on the same domains (Berezuk et al., 2021).

A second, well-supported conclusion from the reserve literature is that individuals with higher levels of cognitive reserve typically experience the effects of aging and pathology on cognition later into older adulthood compared to individuals with lower levels of reserve (Albert et al., 1995; Stern et al., 1999). This finding has been demonstrated in more recent research, which has utilized more clinically diverse and larger samples of older adults (van Loenhoud et al., 2019). In 2019, a group of researchers examined the relationship between cognitive reserve and probability of conversion to a new diagnosis associated with greater cognitive decline (i.e., normal aging to MCI, MCI to dementia) in a sample of 839 older adults from the Alzheimer's

Disease Neuroimaging Initiative (ADNI; van Loenhoud et al., 2019). The sample included healthy older adults, individuals diagnosed with mild cognitive impairment, and individuals diagnosed with Alzheimer's disease. Results from this study revealed that higher levels of cognitive reserve were associated with lower risk of diagnostic conversion in both healthy and mildly impaired older adults. In addition to the above findings, the researchers found that higher levels of cognitive reserve were associated with slower decline in executive functioning and memory abilities amongst predementia older adults.

The third, and potentially most paradoxical finding is that individuals with higher levels of cognitive reserve experience more rapid declines in cognition once reserve is depleted (Cosentino & Stern, 2019; Hall et al., 2007; Scarmeas et al., 2006; Stern et al., 1999). This phenomenon is commonly observed amongst individuals with dementia, such as due to Alzheimer's disease (Cosentino & Stern, 2019). For example, in a recent study, van Loenhoud et al. (2022) examined the relationship between education level—a well-established proxy of cognitive reserve—intracranial volume, and cognitive trajectories of older adults with subjective cognitive complaints, mild cognitive impairment, and Alzheimer's disease and found that in older adults with Alzheimer's disease, higher levels of education were associated with faster declines in global cognitive, memory, executive functioning, and language abilities. It is hypothesized that benefits of cognitive reserve become negligible once Alzheimer's disease pathology reaches a certain stage (Cosentino & Stern, 2019; van Loenhoud et al., 2022). Since individuals with higher levels of cognitive reserve are able to ward off cognitive decline much later than individuals with lower reserve, once they do start to experience the effects of Alzheimer's disease, there is no longer a lag between initial symptom onset and functional decline, since their pathology is at a much later stage in the disease process (Stern, 2012).

Together these findings provide ample evidence supporting the integral role of early and mid-life experiences on late-life cognitive functioning.

Proxies of Cognitive Reserve

Being a hypothetical construct, cognitive reserve cannot be measured directly (Stern, 2002) and therefore, must be operationalized indirectly using a combination of variables or single proxy indicators that are believed to represent life experiences that contribute to population-level differences in neural efficiency and adaptability. Epidemiological research has shown that cognitive reserve can be estimated using four proxies: educational attainment, occupational complexity, leisure activities, and verbal/crystallized intelligence (Berezuk et al., 2021; Boyle et al., 2021; Grotz et al., 2017; Opdebeeck et al., 2016; Stern et al., 2020). Of these variables, educational attainment (e.g., Meng & D'Arcy, 2012), verbal intelligence (e.g., Schmand et al., 1997), and occupational complexity (e.g., Kröger et al., 2008) have all demonstrated to be negatively associated with dementia risk.

As previously described, evidence for an association between measures of cognitive reserve and global and domain-specific cognitive function is varied. There is robust evidence in support of an association between cognitive reserve and better global cognition, while effects for specific cognitive domains like episodic memory, processing speed, and executive functioning, are inconsistent. Much of this inconsistency can be attributed to the variable definitions of cognitive reserve in the literature. While early studies focused more on a single-proxy approach to studying cognitive reserve, more recent research has employed an integrative approach, including composite measures that incorporate the influence of multiple cognitive reserve proxies. Some research has suggested that heterogenous findings regarding the cognition-cognitive reserve relationship are likely due to unstandardized methods of estimating cognitive

reserve (Harrison et al., 2015; Jones et al., 2011). Three proxies that have received ample support within the cognitive reserve literature for their unique associations with late-life cognition are educational attainment, occupational complexity (i.e., mental workplace demands), and crystallized intelligence (Boyle et al., 2021; Foubert-Samier et al., 2012). Understanding the evidence associated with each individual proxy can help to clarify the relationship between measures of cognitive reserve and cognition.

Educational Attainment

Educational attainment remains the most widely use proxy of cognitive reserve, as it has consistently been shown to be related to global cognitive functioning in later life (Avila et al., 2021; Opdebeeck et al., 2016). Meta-analytic findings have shown that years of education are positively related to several domains of cognition, including memory, working memory, executive functioning, visuospatial ability, and language (Opdebeeck et al., 2016). These effects are however, varied, with some studies reporting strong effects of education on late-life cognitive functioning (d = 0.96 – 1.28; e.g., Angel et al., 2010; Fletcher et al., 2021) and others reporting modest to weak effects (*path coefficient* = ∼.2 – . ∼.3; e.g., Jefferson et al., 2011). Furthermore, recent findings suggest that the effects of education on normal cognitive aging differ significantly across cognitive domains, with education showing the weakest effect on memory (r = .230) and strongest effect on language ability (r = .314; Opdebeeck et al., 2016).

Cross-sectional research has shown that these effects may extend beyond normal cognitive aging, altering both the cognitive trajectories (Iraniparast et al., 2022; Xue et al., 2019) and profiles (Berezuk et al., 2021) of populations with MCI. A recent meta-analysis found that education had significant, small to moderate effects (r = .10 – .31) on both global cognition and specific areas of cognitive functioning, with education showing the weakest effect on composites

of motor functioning and memory (i.e., weakest effect on delayed verbal recall and delayed nonverbal recall) and strongest effects on language and visuospatial ability (Berezuk et al., 2021).

From a broader perspective, there is robust evidence that educational attainment is associated with cognition across the lifespan. For example, in neuropsychological assessment, it is common to use normative data to compare the performance of an individual to peers that are the same age and possess the same level of education. This is to correct for the association between educational attainment and cognitive performance that is evident in the normative data across many neuropsychological tests (e.g., Heaton et al., 2004). From a developmental perspective, it is hypothesized that receiving formal education provides individuals with the opportunity for cognitive stimulation and training of crystallized abilities, including knowledge for general facts and information and knowledge required to perform certain tasks (Lövdén et al., 2020). Further, formal education is also believed to emphasize one's executive functioning (e.g., working memory, planning) and rote memory abilities, which are precursors of fluid intelligence (Lövdén et al., 2010; Lövdén et al., 2020). With greater opportunities for cognitive stimulation, individuals are able to better hone their cognitive abilities, whilst interacting in a cognitively complex environment (Lövdén et al., 2010). As demonstrated in the environmental enrichment literature, there are numerous cognitive benefits to being reared and exposed to a complex environment (e.g., daycare, school, university) both in childhood and later adulthood (Leon & Woo, 2018).

Within Western culture, educational attainment is also associated with one's socioeconomic status (SES; Lövdén et al., 2020). Research has shown that the total years of formal education one receives is oftentimes reflective of their access to social (e.g., social

network size, social participation, social support) and economic resources (e.g., income) that promote behaviours that reduce the risk of dementia and cognitive decline, such as participation in regular, moderate-intensity physical exercise and adherence to a nutrient-rich diet (Livingston et al., 2020). Individuals with high educational attainment have a higher likelihood of living in a high SES neighborhood (Zimmerman & Woolf., 2014), which on average have greater opportunities for physical exercise (e.g., high number of commercial physical exercise and recreation outlets; Powell et al., 2006) and social participation (e.g., involvement in social groups and organizations; Putnam, 1996). Being of higher socioeconomic status also limits one's exposure to a number of personal (e.g., affordability of high-quality foods, cost of therapy) and environmental barriers (e.g., distance to grocery store, lack of accessible public/personal transport) that are associated with poorer physical (Rawal et al., 2020; Wolfson et al., 2019) and mental health outcomes (Steele et al., 2007)—known risk factors for cognitive impairment.

Higher levels of educational attainment are associated with not only with better health outcomes in older age (Rawal et al., 2020; Wolfson et al., 2019; Zajacova & Lawrence, 2018) but also greater levels of health literacy—one's knowledge of health-related information and ability to make informed decisions regarding one's health (Bennett et al., 2009; Sørensen et al., 2012; Stormacq et al., 2019). Similar to SES, higher levels of health literacy provide older adults with the necessary tools (e.g., access to accurate and reliable health promotion and disease prevention information) to enact positive change in their lifestyle, promoting reserve (Ayotte et al., 2009; Ikanga et al., 2017; Rikard et al., 2016). Together, the indirect effects of higher educational attainment—higher SES and higher health literacy—are believed to protect older adults from late-life cognitive impairment by lowering their likelihood of developing physical (e.g., diabetes, hypertension) and mental health conditions (e.g., depression) that are commonly

associated with increased risk of cognitive decline (Davari et al., 2019; Freeman et al., 2016; Lewis et al., 2015; Suwannaphant et al., 2017).

Occupational Attainment and Complexity of Work Activities

Other socio-behavioural variables, such as occupational attainment and occupational complexity have been used as proxy indicators of cognitive reserve (Berezuk et al., 2021; Opdebeeck et al., 2016). Like educational attainment, complexity of one's primary lifetime occupation is believed to contribute to inter-individual differences in late-life cognitive functioning (e.g., Finkel et al., 2009; Pool et al., 2016; Smart et al., 2014), as complexity of one's work reflects the degree to which they are exposed to cognitively stimulating activities throughout young and middle adulthood (Berezuk et al., 2021). As the educational requirements for a specific occupation increase, so do the overall cognitive demands of the work performed, suggesting that the pursuit of higher education may lead to a more cognitively complex lifetime occupation (Cagney & Lauderdale, 2002).

It is important to note, however, that despite being highly correlated (Boyle et al., 2021), educational attainment and occupational complexity represent entirely different constructs and are believed to individually contribute to reserve (Baldivia et al., 2008; Foubert-Samier et al., 2012). Educational attainment is considered to be reflective of one's early life exposure to complex or cognitively demanding work (i.e., activities that require higher levels of mental processing), as formal education typically ends in young adulthood; whereas occupational complexity is considered to be reflective of one's exposure to cognitively demanding work in mid-life, as retirement does not typically occur until late-middle adulthood or early older-adulthood (Hazel, 2018).

Given that we spend a substantial portion of our lives at work, it is reasonable to hypothesize that the complexity of the activities we perform on a day-to-day basis and the type of environment we work in (i.e., collaborative versus independent) affect cognitive maintenance and resilience in older age. Working in a cognitively demanding occupation provides individuals with the opportunity to practice their higher-order thinking abilities (e.g., problem solving, selective attention, reasoning, planning) on a daily basis, strengthening them, and refining them (Baldivia et al., 2008; Scarmeas & Stern, 2004). Early research has suggested that that complex work environments promote the development of intellectual flexibility—one's ability to cope with increasing cognitive demands while tasked with a complex situation (Kohn & Schooler, 1973)—which in turn, has positive effects on late-life cognitive functioning (Schooler et al., 1999).

Generally speaking, both direct and indirect (e.g., occupational attainment) measures of occupational complexity have shown to be positively associated with global cognitive functioning in both healthy adults (Andel et al., 2007; Kröger et al., 2008; Opdebeeck et al., 2016; Pool et al., 2016) and individuals with MCI (Berezuk et al., 2021). However, much like educational attainment, evidence supporting the individual effects of occupational complexity on specific areas of cognitive functioning is mixed, with some studies finding relatively strong effects of occupational attainment on non-verbal memory (Berezuk et al., 2021) and executive functioning (Foubert-Samier et al., 2012) and others demonstrating weak effects on attention (Berezuk et al., 2021), processing speed (Berezuk et al., 2021; Smart et al., 2014), working memory (Berezuk et al., 2021), language (Berezuk et al., 2021), and visuospatial ability (Berezuk et al., 2021). Researchers have suggested that heterogeneity of these findings may be

due to differences in the definitions used for occupational complexity in the literature (Berezuk et al., 2021; Opdebeeck et al., 2016).

Occupational complexity has been operationalized rather inconsistently in both the aging and cognitive reserve literatures. Some studies have operationalized occupational complexity in terms of the complexity of work with data, people, and things (e.g., Boots et al., 2015; Feldberg et al., 2016; Smart et al., 2014)—a coding scheme derived from the Dictionary of Occupational Title (DOT; United States Department of Labour, 1977); whereas others have chosen to operationalize occupational complexity using other occupational characteristics, such as years in the occupation (Forstmeier & Maercker, 2015), prestige (Sapkota et al., 2018), and highest level of occupational training (Bickel & Kurz, 2009). Given the breadth of workplace demands and occupational characteristics (Stern et al., 1995), a number of researchers have developed their own measures aimed at assessing occupational complexity (e.g., Andel et al., 2007; Facal et al., 2014; Staff et al., 2004). For example, one group of researchers developed their own coding scheme for occupational complexity, where occupational titles were awarded a complexity value from 1 to 5 (e.g., 1 = unemployed, 5 = professors and higher executives; Facal et al., 2014) and categorized into groups based on level of qualification (Garibotto et al., 2008).

Of the available classification schemes, the DOT method of coding complexity with data, people, and things is considered to be among the most popular and accurate methods at capturing the complexity of one's job (Baldivia et al., 2008; Boots et al., 2015; Feldberg et al., 2016; Hussenoeder et al., 2019; Peterson et al., 2001). However, since this method is based on aggregating only three 'complexity' ratings, variability in total complexity scores between jobs is severely limited. Further, as described by Peterson et al. (2001) the occupational information included in the DOT is quite dated (i.e., data collection occurred between 1960s and 1970s) and

therefore, does not include much information regarding the skills and knowledge required to currently perform a job. In order to better capture the complexity of the construct, as well as maximize its total variance, multidimensional approaches to studying occupational complexity have been proposed (e.g., Peterson et al., 2001).

The advent of more detailed occupational libraries has prompted a number of researchers to redefine occupational complexity using a list of occupational variables (e.g., work activities [i.e., mental demands, physical demands, social demands], abilities, skills) scored by analysts (Fisher et al., 2014; Pool et al., 2016; Rodriguez et al., 2017; Sörman et al., 2021; Then et al., 2013; Then et al., 2014; Zülke et al., 2021). A common tool used gather detailed occupational information is the Occupational Information Network (O*NET) online (https://www.onetonline.org/). O*NET is an online database that contains free and accessible occupational information for over 1,000 jobs. O*NET was developed as a replacement for the DOT and was first launched in 1998. Since its release, the project has undergone multiple waves of data collection and is currently in its 26th iteration. Recently, researchers have begun to adopt the use of O*NET descriptors and worker characteristics in their operationalizations of occupational complexity, focusing primarily on inter-occupational differences in cognitively complex work activities/mental workplace demands (Hussenoeder et al., 2019).

Mental Workplace Demands. Mental workplace demands have been operationalized as either i.) the cognitive abilities performed during work-related activities, ii.) work activities that stimulate mental process, or iii.) a combination of both (Hussenoeder et al., 2019). Often, researchers have used O*NET descriptors as of way of quantifying differences in mental demands across jobs. Of the nearly 300 O*NET descriptors available, 10 O*NET work activity variables have been consistently selected in the measurement of mental workplace demands

(Fisher et al., 2014; Pool et al., 2016). Together, these variables reflect inter-occupational differences in work activities that require higher-order thinking skills, such as problem solving, decision making, planning, and information processing.

In general, evidence supporting the relationship between mental workplace demands and late-life cognitive functioning is promising yet limited. Like other proxies of cognitive reserve, research supporting the relationship between cognitive occupational complexity and late-life cognition is favoured in terms of global cognitive functioning, rather than individual cognitive domains. Being a relatively new concept, most investigations have only examined the role of mentally demanding work activities on global aspects of cognitive functioning (Fisher et al., 2014; Pool et al., 2016; Zülke et al., 2021). Few studies have examined the relationship between mental workplace demands and specific aspects of late-life functioning (e.g., Sörman et al., 2021). Of the available research, most studies have examined cognition using measures of episodic memory (Sörman et al., 2021) or screening tools for global cognitive status, such as the Montreal Cognitive Assessment (Nasreddine et al., 2005; e.g., Zülke et al., 2021) or the Mini-Mental Status exam (Folstein et al., 1975; e.g., Pool et al., 2016). While these tools are useful for screening cognitive impairment, they do not provide a great deal of information with respect to areas of cognitive strength and weakness. Due to these methodological constraints, little is known about how mental workplace demands impact other important areas of late-life cognition, such as visual memory, attention and concentration, executive functioning, language, and working memory.

While both operationalizations (i.e., cognitive abilities, work activities) have shown to be significantly associated with late-life cognition (Fisher et al., 2014; Pool et al., 2016; Rodriguez et al., 2017; Then et al., 2014), work activities are believed to better capture occupational

complexity, as the cognitive abilities associated with a job may reflect occupational requirements, rather than regular engagement in cognitively complex activities. Mental workplace demands are an important factor to consider when estimating cognitive reserve, as it is a major contributor to cognitive stimulation in middle adulthood, next to formal educational experience. The workplace is arguably one of the most important environments a young and middle-aged adult spends time in, therefore, more research is needed to understand how factors in the work environment, both positive, and negative (e.g., stress, burnout) impact future cognitive status and likelihood of future cognitive decline.

Crystallized Intelligence/Verbal Intelligence

A third and perhaps more informative proxy of cognitive reserve is crystallized intelligence (Boyle et al., 2021; Pettigrew et al., 2013). Measures of crystallized intelligence, such as word reading ability and tests of general knowledge have become popular in the cognitive reserve literature as performance on both these tests have demonstrated to be relatively stable in older age and are more resistant to neurodegeneration-related cognitive decline (Okada de Oliveira et al., 2014; Serrao et al., 2015). In a recent study, Boyle et al. (2021) proposed that verbal intelligence—a component of crystallized intelligence—may be the most robust measure of cognitive reserve, as it demonstrates the strongest associations with global cognitive functioning, verbal fluency, episodic memory, executive functioning, attention, and processing speed, compared to other proxies (see Narbutas et al., 2021 for additional evidence). In neuropsychological assessment, measures of word reading ability and verbal intelligence are commonly used to estimate premorbid intelligence, that is, abilities before a brain injury or onset of a neurological disease. Premorbid intelligence is commonly measured using tests of the ability to pronounce written words, like the National Adult Reading Test (NART; Nelson, 1982), North

American Adult Reading Test (Blair & Spreen, 1989), or Test of Premorbid Function (TOPF; Pearson, 2009). However, research has shown that tasks involving vocabulary may be a more stable measure of crystallized or premorbid intelligence (Barnes et al., 2004; Okada de Oliveira et al., 2014). The Vocabulary subtest from versions of the Weschler Adult Intelligence Scale (e.g., WAIS-IV) and Wechsler Abbreviated Scale of Intelligence (e.g., WASI, WASI-II; Wechsler, 1999; Wechsler, 2011) has been shown to be reliable test of crystallized intelligence in a variety of populations (e.g., Sattler & Ryan, 2009; Strauss et al., 2006).

Crystallized intelligence increases steadily throughout adulthood and is believed to only start declining in the later stages of life (e.g., late sixties; McArdle et al., 2002; Salthouse, 2009). Research has suggested that population-level differences in crystallized intelligence may reflect individual differences in life experiences and academic achievement, where lifelong learning (Williams et al., 2008) and other related factors such as curiosity (Hartung et al., 2022) facilitate the acquisition of knowledge, building one's crystallized intelligence. Like occupational complexity, individuals who choose to participate in lifelong learning activities (i.e., repeated cognitive stimulation) are expected to experience gains in cognitive efficiency and flexibility, promoting the development of reserve. From a theoretical perspective, the neurocognitive mechanisms underlying differences in cognition amongst those with high and low levels of crystallized intelligence are similar to those discussed in Salthouse's (2006) differential-preservation hypothesis. Salthouse's (2006) hypothesis proposes that in older adults, baseline cognition is preserved primarily through the repeat engagement in cognitively stimulating activities. According to this theory, individuals who engage in higher levels of mental activity in later life would be expected to possess higher levels of crystallized intelligence and as a result exhibit higher levels of cognitive functioning, as Salthouse's (2006) idea of continual mental

engagement is synonymous with more colloquial definitions of life-long learning. Furthermore, researchers have found that individuals with higher crystallized cognitive abilities, on average had better physical health and mental health and engaged in more social and intellectually challenging activities, compared to individuals with lower crystallized cognitive abilities (Borgeest et al., 2020). While the directionality of this relationship is unclear, the results from Borgeest et al. (2020) study nonetheless suggest that individuals with higher crystallized intelligence lead healthier lives and engage in behaviours (e.g., social participation) that promote the development of reserve.

Generally speaking, crystallized intelligence is believed to be a better representation of intellectual achievement compared to educational attainment (years of formal education), as it sensitive to both *formal* and *informal* educational experiences (Boyle et al., 2021). For this reason, educational attainment has undergone criticism as a proxy of cognitive reserve, since formal educational experiences are known to differ across cultures (i.e., countries) and institutions (Opdebeeck et al., 2016). Crystallized intelligence is influenced by one's educational experiences and cultural experiences (Cattell, 1971), whereas educational attainment simply reflects the number of years an individual spent in an educational institution. Neither complexity of the learning environment nor the quality of instruction are captured in one's educational attainment or 'years of formal education'. Additionally, research has suggested that the synergistic effects of educational attainment and occupational complexity on late-life cognition may vary according to one's racial identity, and therefore, these effects are highly susceptible to various sociocultural factors and racial inequities (Fujishiro et al., 2019; Tomaskovic-Devey et al., 2005). Beyond addressing the various limitations of educational attainment as a proxy of reserve, crystallized intelligence provides a unique perspective on cognitive reserve, as it is not

reliant on same compensatory mechanisms as occupational complexity and education, rather it is reflective of one's lifetime intellectual achievement not their exposure to repeated cognitive stimulation.

Cumulative Life Experiences

For the sake of parsimony, it may be tempting to conceptualize reserve in terms of a sole demographic or lifestyle factor; however, it is important to understand that this oversimplified approach of measuring reserve is inconsistent with Stern (2002) original definition. By themselves, specific life experiences, such as education and occupation have been shown to individually contribute to reserve (Foubert-Samier et al., 2012), as well as demonstrate unique association with late-life cognition (e.g., Berezuk et al., 2021; Grotz et al., 2017; Narbutas et al., 2019; Opdebeeck et al., 2016). However, as our understanding of reserve has improved, so has our ways of measuring it. Rather than emphasizing the importance of a single variable, more recent research has proposed that one must adopt an integrative approach to studying cognitive reserve (e.g., Grotz et al., 2017; Jones et al., 2011; Richards & Deary, 2005). This conceptualization suggests that one must consider the *combined* role of life experiences that have been (e.g., educational attainment, occupational attainment, and complexity) and currently being collected across the lifespan (e.g., crystallized intelligence).

When combined, several proxies of cognitive reserve, such as education, occupational complexity, and verbal intelligence have been shown to be positively associated with performance on tests of verbal episodic memory, language, and semantic memory, attention, executive functioning, and processing speed (Boyle et al., 2021; Turcotte et al., 2022). Similarly, in a recent study, Narbutas et al. (2019) examined the combined effects of educational attainment, occupational demands, crystallized intelligence, physical activity, and leisure

activities on late-life cognition and found that their global measure of cognitive reserve was positively associated with performance on a battery of tests assessing verbal memory, processing speed, and verbal fluency. Collectively, these findings suggest that composite measures of cognitive reserve may be effective in predicting baseline cognitive functioning in older adults at risk of cognitive decline (e.g., Chan et al., 2018; Lee et al., 2020; León et al., 2014; Narbutas et al., 2019).

Composite measures often assume equal weight of cognitive reserve proxies in calculating a total score. This conceptualization is however, limited because it is not consistent with our current understanding of cognitive reserve. Research has demonstrated that different proxies exhibit variable relationships with late-life cognition, both in terms of strength of association, and domains impacted (Berezuk et al., 2021; Opdebeeck et al., 2016). To address these limitations, a growing number of researchers have begun to reconceptualize the way they estimate cognitive reserve (Grotz et al., 2017; Jones et al., 2011).

Models of Cognitive Reserve

A practical way researchers can overcome the discussed limitations of both composite and single-proxy models of reserve is to use latent variable modelling methods when estimating an individual's level of cognitive reserve. Use of multi-indicator models are believed to be more accurate and reliable than single indicator models, as they better reflect the inherent complexity and proposed multidimensionality of reserve (Grotz et al., 2017; Jones et al., 2011; Stern, 2002). Furthermore, multi-indicator models consider the unique influences of several proxy measures and are thus, less reliant on measurement of individual pathways that may not be generalizable across other proxies of cognitive reserve (Jones et al., 2011).

Interestingly, even though cognitive reserve is defined as a hypothetical variable, a surprisingly low number of studies have used latent variable modelling techniques, such as structural equation modelling (SEM) or confirmatory factor analysis to examine the effects of cognitive reserve on neuropsychological functioning (e.g., Delgado-Losada et al., 2019; Feldberg et al., 2021; Lojo-Seoane et al., 2014; Mitchell et al., 2012). Of the available research, a limited number of studies have successful modelled the structural relationships between cognitive reserve, memory, executive functioning, language, and global cognition (Delgado-Losada et al., 2019; Giogkaraki et al., 2013; Lojo-Seoane et al., 2014). None to date have modelled the structural relationship between cognitive reserve and a comprehensive battery of neuropsychological tests assessing critical cognitive functions, such as verbal memory, visual memory, and attention/concentration. I sought to fill this gap in the literature by examining the impact of cognitive reserve on older adults' performance across a comprehensive battery of neuropsychological tests (total of 19 tests) that assess aspects of visual memory, verbal memory, attention control and working memory, executive functioning, language, global cognitive status, and visuospatial processing. Findings from my thesis will help elucidate the impact of cognitive reserve on the full neuropsychological profiles of older adults without dementia.

Relationship Between Cognitive Reserve and Executive Functioning

To date, little research has examined the mechanism in how cognitive reserve exerts its influence on cognitive functioning. Early structural models have suggested that cognitive reserve has direct effects on both global and domain-specific aspects of cognitive functioning (Lojo-Seoane et al., 2014; Mitchell et al., 2012). These findings, however, do not explain a growing portion of the literature, which has found that cognitive reserve may benefit only some areas of cognitive functioning (e.g., verbal fluency, executive attention) over others (Lavrencic et al.,

2016; Lavrencic et al., 2018a; Zamarian et al., 2021). Since these findings do not fit within the existing framework proposed by Stern et al. (2020), opposing research has suggested that the effects of cognitive reserve are not generalized to every cognitive domain, rather, cognitive reserve may only have a direct influence on higher-order executive functions (Lavrencic et al., 2016; Lavrencic et al., 2018a; Zamarian et al., 2021).

There are several lines of evidence in support of the idea that increased cognitive reserve may impact other cognitive domains through improved executive functioning. Executive functions are involved in coordinating other cognitive abilities, therefore, improvements in executive functioning may benefit performance in other cognitive domains. In addition, executive functioning is a common target for training programs for older adults (Mowszowski et al., 2016). Of the cognitive domains impacted by cognitive reserve, executive functioning has consistently shown to be influenced by certain lifestyle factors, such as exercise (e.g., Engeroff et al., 2018) and participation in physical and social activities (e.g., Opdebeeck et al., 2016). Exercise training programs have been shown to improve executive functioning in healthy older adult populations (Chen et al., 2020; Colcombe & Kramer, 2003), supporting the strong relationship between higher-order cognitive processing and reserve-promoting factors. Other research has shown that certain executive skills, such as working memory and set shifting, may be involved in mediating the effects of non-executive training interventions (e.g., prospective memory), as these skills have been linked to one's ability in learning and applying the new strategies taught in the program (Burkard et al., 2014; Kinsella et al., 2020). On a similar note, some studies have found that executive functioning training produces near and far-transfer effects in older adults, meaning that training one's executive functions is successful in improving both one's executive functioning, as well as their performance in other areas of cognitive

functioning, such as processing speed and episodic memory (Au et al., 2015; Karbach & Verhaeghen, 2014; for evidence against far transfer effects see Melby-Lervåg & Hulme, 2013; Melby-Lervåg et al., 2016; Schwaighofer et al., 2015).

Working in a complex work environment, pursuing higher education, and lifelong learning opportunities, may also be seen as a real-world form of executive functioning training, as individuals are tasked with solving problems, planning, and exercising cognitive flexibility—a higher-order cognitive function—on a daily basis (Kohn & Schooler, 1973). Therefore, mechanisms underlying the effects of executive function training on late-life cognition may mirror those for the development of cognitive reserve, as proxies represent life experiences that promote the training of one's executive functions. Neuroimaging research has supported these findings, further emphasizing importance of executive functioning in the maintenance of cognitive abilities (Davis et al., 2008; Grady et al., 1994; Park & Reuter-Lorenz, 2009). In the aging brain, compensatory processes, such as increased activation of the prefrontal cortex and recruitment of alternate brain networks, are associated with improved performance (Davis et al., 2008; Grady et al., 2014). This compensatory activity is observed in the prefrontal cortex and frontoparietal control network regions that are involved in higher-order cognitive processing (Diamond, 2013); thus, it is likely that this pattern of compensatory neural activation seen in older adults is reflective of the brain's propensity of deploying executive control processes to help compensate for deficits in other areas of cognitive functioning (Davis et al., 2008). Furthermore, research has shown that performance on tests of executive functioning is significantly associated with performance on tests of memory (e.g., Duff et al., 2005), visuospatial processing (e.g., Libon et al., 1994), language skills (e.g., Higby et al., 2019), and attention/concentration (e.g., Ferguson et al., 2021), supporting the notion that the cognitive

domains are closely related and organized in a hierarchical fashion, where changes in executive functioning innervate more general changes in lower-level processes, such as motor functioning, and attention (Harvey, 2019).

When one considers the role of executive functioning, and more broadly the prefrontal cortex, in neural compensation it is unlikely that cognitive reserve benefits all areas of cognitive functioning equally (Lavrencic et al., 2016; Lavrencic et al., 2018a; Zamarian et al., 2021). A more accurate explanation may be that the effects of cognitive reserve are mediated through its influence on executive functioning. In other words, this would mean that cognitive reserve has a direct impact on executive functioning and indirect impact on areas of cognition associated with executive functioning, such as memory, language, visuospatial skills, attention, and concentration.

No studies to date have examined this *executive function hypothesis* using structural equation modelling. To test this hypothesis, the current thesis evaluated model fit for two structural equation models, one (Model 1) depicting more generalized effects of cognitive reserve on cognitive functioning (i.e., direct effect of cognitive reserve on each aspect of cognitive functioning), and the other (Model 2) depicting the novel hierarchically organized, higher-order effects of cognitive reserve (i.e., direct effect of cognitive reserve on executive functioning and indirect effect on all other aspects of cognitive functioning).

Objectives

Using structural equation modelling and multiple regression analyses, I examined the direct effects of cognitive reserve on the baseline neuropsychological functioning in a clinical sample of older adults without dementia. To accurately estimate cognitive reserve in this sample, I developed an empirically driven measurement model, which included a total of three well-

established proxies: educational attainment, mental workplace demands, and crystallized intelligence. Age, gender, number of vascular risk factor, and depression diagnosis were included in the models as potential covariates, to better isolate the effects of cognitive reserve on late-life cognitive functioning.

The goal of the current thesis was to address three main research questions:

1. Does cognitive reserve produce differential effects across the neuropsychological profiles of older adults in our sample?
2. Are the effects of cognitive reserve generalized across cognitive domains or hierarchically organized (i.e., influenced by executive functioning)?
3. Are certain domains of cognitive functioning differentially affected by the three proxies of cognitive reserve—educational attainment, occupational complexity (i.e., mental workplace demands), crystallized intelligence?

To address the first research question, I developed and tested a total of two structural models depicting the hypothesized relationships between cognitive reserve and various domains of cognitive functioning (i.e., verbal memory, visual memory, attention and concentration, executive functioning, visuospatial processing, language). Parameter estimates (beta-weight coefficients), standard errors, and correlation coefficients were used to evaluate structural relationships in each model. Based on previous research, I hypothesized that a.) individuals with higher levels of cognitive reserve will perform better on measures of global cognitive functioning (Berezuk et al., 2021; Opdebeeck et al., 2016), and b.) cognitive reserve will have different effects across cognitive domains (Lavrencic et al., 2016; Lavrencic et al., 2018a; Zamarian et al., 2021).

To address the second research question, I compared the overall fit of both structural models. Chi-square, absolute fit, and comparative fit indices were used to evaluate differences in model fit. Based on previous research, I hypothesized that Model 2 (Hierarchical Effects of Cognitive Reserve) will provide greater overall fit for our data compared to Model 1 (Generalized Effects of Cognitive Reserve).

To address the third research question, a series of multiple regression analyses with relative weight analyses were performed to model independent effects of education, occupational complexity, and crystallized intelligence on each cognitive domain. Given that little research has examined the relative importance of different cognitive reserve proxies in predicting late-life cognitive functioning (e.g., Boyle et al., 2021; Malek-Ahmadi et al., 2017; Pettigrew et al., 2013), no specific hypotheses were tested, making these analyses strictly exploratory in nature.

CHAPTER 2

GENERAL METHODOLOGY AND DESIGN

Participants

The data used to conduct the current analyses were obtained from a large clinical database containing neuropsychological test scores (i.e., raw and standardized) and basic demographic information for 687 adults who were seen at a clinical neuropsychology program at a geriatric specialist hospital in Ontario, Canada between 2001 and 2017. The archival dataset contains de-identified clinical data from patients with a wide variety (i.e., 23 different diagnoses) of major and mild neurocognitive disorders (e.g., dementia due to Alzheimer's disease, MCI, normal cognitive aging, vascular dementia).

Our analyses used data from a subset of this sample (n = 497) without dementia based on diagnoses listed in their neuropsychological report. That is, patients with dementia diagnosed based on evidence of cognitive decline severe enough to interfere with functional independence in daily living were excluded. Included participants were aged 50 years or older at the time of the assessment and had diagnoses of either i.) amnestic MCI, ii.) non-amnestic MCI, iii.) MCI (multidomain), iv.) MCI due to presumed cerebrovascular causes, or v.) normal cognitive aging.

Individual cases were removed if they were missing data required to estimate cognitive reserve, including i.) missing occupational information (n = 92), ii.) missing scores on the WASI vocabulary subtest (n = 133), or iii.) missing years of education (n = 2). Cases were also removed if i.) there was an apparent data entry error (e.g., score above the maximum or below the minimum possible score) for any one of the 19 included variables (n = 2), ii.) their data were associated with a second, repeated assessment (n = 6) or iii.) if the occupation reported was too

vague to code for complexity (e.g., “consultant”, “student”; $n = 4$). This resulted in a sample of 258 participants.

Procedure

Archival data were extracted from patient’s physical files housed in a geriatric specialist hospital in Ontario, Canada. A research assistant extracted raw/standardized neuropsychological test scores and demographic information (i.e., age, gender, occupation, education, lifestyle habits [i.e., smoking, alcohol use], comorbid diagnoses, subjective memory complaints) from the physical tests, summary sheets, and neuropsychological reports included in each patient file and inputted the data into a password-protected database.

All patients had been referred to the outpatient neuropsychology service for a comprehensive neuropsychological evaluation. Referrals were made by a physician working in the behavioural neurology or geriatric psychiatry units of the hospital. Leading up to their assessment, patients presented with either a subjective or informant-based cognitive complaint (e.g., memory, attention, problem solving). All neuropsychological testing was performed by a trained psychometrist or licensed clinical neuropsychologist who followed standardized protocols for test administration and scoring (i.e., test scoring rules set by the test publisher). Test batteries were tailored to the needs of the patient (i.e., all patients in the sample were not administered the same test battery). Informed consent was obtained for each patient prior to neuropsychological testing. Diagnoses were made by the clinical neuropsychologist using data from the evaluation (e.g., background information, clinical interview, collateral reports, social and psychological history, medical history, neuroimaging, neuropsychological testing).

Measures

Cognitive Reserve

Educational Attainment. The total number of years of formal education reported by the patients was used as an indicator of cognitive reserve in the present analyses. Within the context of neuropsychological assessment, formal education typically refers primary school, secondary school, and post-secondary training (e.g., college, university). Years of formal education is common method used to operationalize educational attainment in the cognitive reserve literature (Berezuk et al., 2021; Opdebeeck et al., 2016). The patient's reported years of education based on self-report during the neuropsychological interview were extracted directly from their respective neuropsychological reports during data entry.

Mental Workplace Demands. Self-reported patient occupation based on the neuropsychological interview was used to estimate mental workplace demands. Each listed occupation was cross-referenced in O*NET and mental workplace demands were measured using the mean analyst ratings for 10 O*NET (O*NET 26.2) variables assessing cognitively complex work activities (Tsacoumis & Willison, 2010).

The 10 selected O*NET variables are categorized in the O*NET library based on, i.) *information and data processing* (i.e., analyzing data or information; evaluating information to determine compliance with standards; judging the qualities of objects, services, or people; processing information), and ii.) *reasoning and decision making* (i.e., developing objectives and strategies; making decisions and solving problems; organizing, planning, and prioritizing work; scheduling work and activities; thinking creatively; updating and using relevant knowledge; Tsacoumis & Willison, 2010). In the O*NET database, the analyst ratings for all 10 variables are scored using an anchored scale assessing the skill level required to perform the activity. For this

investigation, a total score representing mental workplace demands was calculated by averaging the skill level ratings for the 10 variables. The range of scores achievable for average mental workplace demands is between 0 and 7. Higher scores on this measure indicate greater complexity.

Complexity scores for ambiguous occupation titles, such as "teacher," "professor," "doctor," "engineer," "businessperson," "finance," "insurance," "marketing," "real estate," "social worker," "administrative assistant," and "tradesperson" was calculated by averaging the complexity scores for all relevant O*NET occupations in the same job family/category. For example, complexity scores for "teacher" were calculated by averaging the complexity score for elementary school teachers, middle school teachers, and high school teachers. Complexity scores for occupation titles not listed in the current O*NET library, such as "homemaker" were calculated by converting the occupation's total occupational complexity score derived from the DOT to the same units as the O*NET coding scheme[1] (n = 5 participants in the sample). A scale conversion was performed for all occupations not listed in the O*NET library, so that DOT occupational complexity was reflective of the O*NET coding scheme. Further, to ensure complexity scores were accurate for occupations (e.g., homemaker) not listed in the O*NET library, total occupational complexity scores for a similar occupation that was listed in the O*NET library (e.g., support worker) were compared with the converted total complexity score—based on scores from the DOT—of unavailable occupations (e.g., homemaker). Similar occupations were chosen based on overlap in qualifications and work activities.

[1] Total complexity scores for the DOT complexity range from 0 to 21. This score is derived by summing the complexity scores for data, people, and things. Lower scores on this scale is representative of higher work complexity.

Crystallized Intelligence. Raw scores on the Vocabulary subtest on the Wechsler Abbreviated Intelligence Scale (WASI; Wechsler, 1999) were used as the primary measure of crystallized intelligence in this study. The Vocabulary subtest is a well-established measure of verbal and crystallized intelligence (e.g., Sattler & Ryan, 2009; Strauss et al., 2006). During administration of this subtest, patients were asked to orally define a series of images (4) and words (38) that were presented to them either verbally (words) and visually (images). The maximum score on this test is 80. The minimum score is 0. Items are scored as either a 0, 1, or 2. Picture items are scored out of 1. Higher scores reflect better performance. Data from the Vocabulary subtest on the WASI demonstrates good reliability, demonstrating very high levels of internal consistency (>.90; Strauss et al., 2006).

Measures of Neuropsychological Functioning

As part of their assessment, patients were administered a battery of neuropsychological tests assessing aspects of verbal memory, visual memory, attention, concentration and working memory, visuospatial processing, executive functioning, language, and global cognitive status. Individual tests were selected from the Kaplan-Baycrest Neurocognitive Assessment (KBNA; Leach et al., 2000), Wechsler Abbreviated Intelligence Scale (WASI; Wechsler, 1999), Wechsler Adult Intelligence Scale–III (WAIS–III; Wechsler, 1997), and Halstead-Reitan Battery (Reitan, 1956). For the current analysis, I used data from a total of 19 different neuropsychological tests. In general, these tests are well-validated and demonstrate marginal (.60–.69) to very high levels (>.90) of internal consistency (Strauss et al., 2006).

Verbal Memory

Word List 1 (KBNA). In this list-learning task, patients were asked to recall as many words as they could after being read a list of 12 words (Leach et al., 2000). This task was

completed over four successive learning and recall trials and primarily used to assess patient's learning and ability to encode information into memory. The total number of words correctly recalled across four trails were summed as a Word List 1 total score. The maximum raw score on this test is 48. The minimum score is 0. Higher scores on this test indicate better performance.

Word List 2 (KBNA). In this delayed-recall task, patients were asked to recall the same list of words learned during the Word List 1 task (Leach et al., 2000). This test is administered 20 minutes after the completion of Word List 1. Patients were asked to recall words under a free-recall condition and a cued-recall condition (i.e., patients were presented with the category names for each of the words). The maximum raw score on this test is 24 (12 for each trial). The minimum score is 0. Higher scores on this test indicate better performance. Performance on this task is reflective of patients' verbal episodic memory abilities (Leach et al., 2000).

Word List 2 Recognition (KBNA). This delayed-recognition task asked patients a total of 36 yes/no questions to identify which words were presented in Word List 1 (Leach et al., 2000). The 36 questions include the 12 words listed in Word List 1, 12 distractor words from similar categories as the target words, and 12 unrelated distractor words. The maximum raw score on this test is 36. The minimum score is 0. Higher scores on this test indicate greater performance. Like Word List 2, this task assesses verbal episodic memory, but it is less impacted by possible retrieval problems, as patients are asked to identify which words were previously presented to them, not recall them from long-term memory (Leach et al., 2000).

Visual Memory

Complex Figure 1 (KBNA). In this free-recall task, patients were asked to draw a complex figure from memory, immediately after copying a version in front of them (scored as part of the Complex Figure 1 Copy/Clock task; Leach et al., 2000). Patients' drawings are scored

using a standardized method developed by the test developers, whereby patients' drawings are rated on accuracy and placement of figure's components. Generally speaking, this task is used to assess patient's ability to encode visual information into their visuo-perceptual memory (Leach et al., 2000). Poor performance may indicate problems with memory encoding of nonverbal information. The maximum raw score on this test is 20. The minimum score is 0. Higher scores on this test indicate better performance.

Complex Figure 2 (KBNA). In this delayed-recall task patients were asked to draw the same complex figure 20 to 30 minutes after completing Complex Figure 1 (Leach et al., 2000). Patients' drawings were scored using the same criteria as Complex Figure 1. Performance on this task is reflective of patients' ability to retrieve previously encoded information from visuo-perceptual memory (Leach et al., 2000). The maximum score on this test is 20. The minimum raw score is 0. Higher scores on this test indicate better performance.

Complex Figure 2 Recognition (KBNA). This delayed-recognition task asked patients to identify specific details from the complex figure presented in the above tasks immediately following completion of the Complex Figure 2 recall task (Leach et al., 2000). Patients were presented with a sheet that contained five rows with four details across each row (i.e., three were foils, one was correct) and asked to identify which detail belonged to the original complex figure, then place the detail on an outline of the figure. Correctly identified details and location of the detail were scored and summed as a total Complex Figure 2 Recognition score. The maximum raw score on this test is 10 (5 for correct identification and 5 for correct location). The minimum score is 0. Higher scores on this test indicate better performance. Performance on this task measures delayed visual memory when retrieval demands are reduced because the patient chooses which item seems familiar rather than drawing it without any cues (Leach et al., 2000).

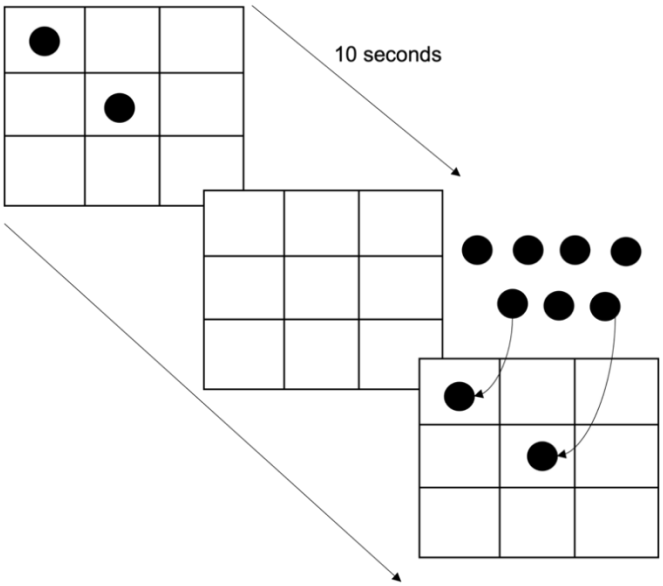
Attentional Control and Working Memory

Sequences (KBNA). In this selective-attention and working memory task, patients were asked to produce a sequence of stimuli and mentally rearrange information based on a specific prompt (e.g., recite the months of the year in order, recite the months of year in reverse order; Leach et al., 2000). The maximum raw score on this test is 57. The minimum score is 0. Higher scores on this test indicate greater performance. Performance on this task is reflective of how well patients are able to sustain their attention and manipulate information in working memory.

Spatial Location (KBNA). In this spatial working memory task, patients were asked to recreate a pattern of dots using tokens and a blank 3 x 3 or 4 x 4 matrix, after being presented with a card that contained a box with dots (i.e., between three and seven) in various locations (see Figure 1 for a visual representation of the test; Leach et al., 2000). The maximum raw score on this test is 46. The minimum score is 0. Higher scores on this test indicate greater performance. Number and type of errors made on this test (i.e., omission errors, commission errors, and misplacement errors) are considered to be reflective of different aspects of the patients' spatial working memory (Leach et al., 2000). Omission errors (i.e., failing to place tokens) are often reflective of problems with working memory capacity; whereas misplacement errors are reflective of problems with memory for location.

Figure 1

Visual Depiction of Spatial Location Subtest from the Kaplan-Baycrest Neurocognitive Battery



Note. The first card (top left) represents the stimulus card. The second card represents the blank matrix provided to the examinee after being presented the stimulus card for 10 seconds. The dots beside the second card represent the tokens the examinee is provided with to use for the purposes of recreating the same pattern presented on the stimulus card. The third card represents the examinee's response. During the real test, examinees are presented with a stimulus card that will have *three* to *seven* tokens randomly placed on either a 3 x 3 or 4 x 4 matrix. Two tokens are used in this example solely for demonstrative purposes.

Digit Span (WAIS-III). In this verbal working memory task, patients were asked to repeat a string of numbers, forwards and backwards (Weschler, 1997). Patients were first presented with a string of two digits, then asked to repeat them back either in the same sequence or in reverse order. If the patient fails to correctly repeat two consecutive trials with the same number of digits, then the test is discontinued. Conversely, if the patient is successful in not meeting discontinue criteria, then they were presented with a string of digits that progressively increased in length over several trials. The maximum number of digits patients were asked to recall in the same and backwards sequence was 8 and 7, respectively. The maximum raw score

on this test is 30 (16 on forward trials, 14 on backwards trials). The minimum scores is 0. Higher scores on this test indicate greater performance. Performance on this task reflects patients' attentional ability and auditory working memory capacity.

Visuospatial Processing

Complex Figure 1 Copy/Clocks (KBNA). This composite measure of visuospatial skills includes performance on tasks in which patients were asked to i.) draw a copy of a novel complex figure presented to them (i.e., the same complex figure for which memory is tested in the Complex Figure 1 and 2 tasks), ii.) draw a clock with hands at 10 after 11, iii.) place hands at 20 after 8 on a pre-drawn clock, and iv.) copy a picture of a clock (Leach et al., 2000). Generally speaking, this task is used to assess patients' visuo-constructional ability, graphomotor skills, and visual-motor integration. The maximum score on the figure copy component is 20, and the maximum score is 37 across all three clock drawing trials (13 in the free draw condition, 11 in the pre-drawn condition, and 13 in the copy condition). The maximum score for the combined Copy/Clocks test is 57. The minimum score is 0. Higher scores on this test indicate greater performance. Poor performance may be indicative of problems with visuospatial processing, attention, planning, and/or organization (Lezak et al., 2012).

Trail-Making Test: Part A. In this visual scanning and psychomotor speed task, patients were asked to draw lines with a pencil to connect 25 circles numbered 1 to 25 as fast as they can (Reitan, 1956). This test is timed and scored as the total time to completion. Performance on this task is dependent on several cognitive functions, including visual attention, visuospatial processing speed, working memory, and psychomotor speed. Lower scores on this test indicate greater performance. Scores on this test were reverse coded so they were keyed in the same

direction as the other tests. The Trail Making Test (Part A and B) is among one of the most sensitive tests to brain damage (Reitan & Wolfson, 1994).

Matrix Reasoning (WASI). In this visuospatial reasoning task, patients were presented with an incomplete matrix and asked to select one out of four options to complete the matrix (Weschler, 1999). The maximum raw score on this test is 32 for patients aged 45-79 and 28 for patients aged 80 and older. The minimum score is 0. Higher scores on this test indicate greater performance. Performance on this task requires the use of several visuospatial processes, including spatial perception and spatial reasoning. Unlike the other included tests of visuospatial processing, performance on the Matrix Reasoning subtest of the WASI is not influenced by the patients' ability to solve problems quickly, as this subtest is not timed, meaning patients are not penalized for taking a slow and deliberate approach to responding.

Executive Functioning

Phonemic Fluency (KBNA). In this verbal fluency task, patients were asked to come up with as many words as possible starting with the letter C in 60 seconds (Leach et al., 2000). Performance on this task is often reflective of one's language ability, however, it also measures several higher order/executive abilities including, cognitive flexibility, set-shifting, self-regulation, and self-monitoring (Lezak et al., 2012). The total raw score on this test is equal to the number of words correctly generated. Higher scores on this test indicate greater performance.

Practical Problem Solving and Conceptual Shifting (KBNA). This score represents the combination of two problem solving tasks. In the practical problem-solving task, patients were presented with five hypothetical scenarios (e.g., what would you did if you smelled smoke in your house?) and asked to give two distinct and effective solutions (Leach et al., 2000). In the conceptual shifting task, patients were asked to identify which three of four designs on a card are

the most similar based on shared attributes including shape, shading, size, orientation (Leach et al., 2000). As part of this task, patients are also asked to explain the similarity between the three designs. They then are asked to identify a second set of similar designs based on a different attribute. Difficulty generating a second response and shifting attention away from the first response is often indicative of brain dysfunction affecting the frontal lobes. The maximum raw score for these combined tests is 30. The minimum score is 0. Higher scores indicate greater performance.

Similarities (WASI). In this verbal comprehension and reasoning task, patients are presented with two words and asked how the two words are similar (Wechsler, 1999). Performance on this task is dependent on patients' level of abstract reasoning and verbal concept formation. The maximum raw score on this test is 48 (maximum of 2 points for all 24 items). The minimum scores is 0. Higher scores on this test indicate greater performance. Patients who score low on this task typically provide more concrete responses, whereas patients who do well provide more abstract responses, reflective of higher degrees of verbal abstraction.

Trail-Making Test: Part B. In this alternating attention task, patients were asked to connect 13 circles numbered 1 to 13 and 12 circles labelled A to L in alternating numeric and alphabetic order (Reitan, 1956). This test is timed and scored as the total time to completion. Lower scores on this test indicate greater performance. Scores on this test were reverse coded so they were keyed in the same direction as the other tests. Performance on this task requires the use of several higher order/executive processes, including cognitive flexibility, set-shifting, and complex attention. Unlike the other included tests of executive functioning, performance on the Trail Making Test: Part B is not influenced by one's expressive language output, as it is purely a visual-motor task.

Language

Boston Naming Test. In this visual confrontation naming task, patients were asked to verbally identify 60 different line drawings of objects, presented from most common object to least common object (Kaplan et al., 1983). Correct responses are awarded one point. During this test, patients were provided with a semantic cue (e.g., category of the drawing) if they misperceive the drawing or a phonemic cue (e.g., first sound of the word) if they say, "I don't know." The maximum raw score on this test is 60. The minimum score is 0. Higher scores on this test indicate greater performance. The BNT is a test sensitive to problems with retrieving semantic information and naming objects. Performance on this task varies amongst older adult populations (Mitrushina et al., 2005), with lower scores often seen in patients with semantic dementia and Alzheimer's disease (Diehl et al., 2005).

Semantic Fluency (KBNA). In this verbal fluency task, patients were first asked to come up with as many names of animals as possible in 60 seconds, then asked to come up with as many first names in 60 seconds (Leach et al., 2000). The total raw score on this test is equal to the number of words correctly generated across both the animals and first names conditions. Higher scores on this test indicate greater performance. Performance on this task is reflective of one's verbal functioning and ability to retrieve semantic knowledge from long-term memory. Performance on this task is believed to be more representative of one's linguistic ability compared to other verbal fluency tasks like phonemic fluency, as performance on phonemic fluency tasks have been shown to be more reliant on the use of executive control processes (Luo et al., 2010).

Global Cognitive Status

Mini-Mental State Exam (MMSE). Global cognition was screened in patients using the Mini-Mental State Exam (MMSE; Folstein et al., 1975). The MMSE is an 11-item test that measures individuals' orientation to time and place, attention, calculation, language, immediate and delayed-recall. The maximum raw score on the MMSE test is 30. The minimum score is 0. Higher scores (>24) suggest normal cognition, whereas lower scores (<24) indicate mild and moderate impairment.

Covariates

Age, number of vascular risk factors (i.e., diagnosis of hypertension, high cholesterol, stroke, cardiovascular disease, diabetes, cardiovascular surgery, arrythmia, peripheral vascular disease, or aneurysm), diagnosis of depression (i.e., dichotomized as either [1] diagnosis of depression noted in neuropsychological report, [0] no diagnosis of depression noted in neuropsychological report), and gender were included as potential covariates in present analyses, as they have been proven to be significant factors related to inter-individual differences in cognition (Beaudreau & O'Hara, 2009; Jockwitz et al., 2021; Kim et al., 2019; Pinter et al., 2015; Subramaniapillai et al., 2021). For a detailed discussion of how these variables impact cognitive functioning in older adulthood, please refer to paragraph two in Chapter 1: Theories Explaining Individual Differences in Cognitive Trajectories In Aging.

Data Analysis

Descriptive Analysis

A descriptive analysis was performed prior to the main analyses to characterize differences in cognitive reserve (i.e., mean mental workplace demands score, mean years of

education, mean raw scores on the Vocabulary subtest), demographics (e.g., age, gender, proportion with vascular risk factors, proportion of sample with depression diagnosis), and neuropsychological test performance across groups (i.e., normal cognitive aging, MCI). Data from a total of 232 participants were included in these analyses[2]. A reliability analysis was also performed on the same dataset to evaluate the internal consistency of the 10 O*NET mental workplace demand variables.

Structural Equation Modelling: Research Questions #1 and #2

Data Cleaning and Outlier Removal

Prior to assumption testing, a descriptive analysis was performed on the $N = 258$ dataset, to identify patterns of missing data. Results from this analysis revealed the presence of several multivariate outliers and missing data. Outliers were identified and removed following imputation. A missing value analysis (MVA) performed on the same dataset revealed that out of 258 cases, 26 had 10% or more missing data. After deletion of these cases, the sample size was reduced from 258 to 232. Using this updated sample size, a second MVA was performed. Results from the MVA revealed a nonsignificant Little MCAR test (χ^2 (167, $N = 232$) = 193.30, p = .080), suggesting that the pattern of missing data is ignorable.

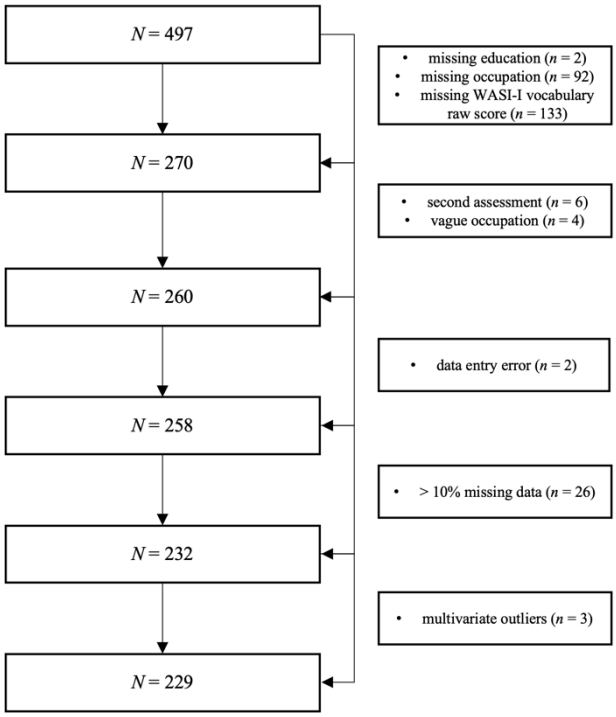
A frequency analysis revealed that Spatial Location and Similarities had the largest amount of missing data. Variables with the largest amount of missing data did not share any specific qualities, therefore missing data can be treated as ignorable as there is insufficient evidence supporting the existence of data missing not at random (i.e., systematic pattern of missing data). Missing data were imputed using an expectation maximization procedure in IBM

[2] Multivariate outliers identified prior to the SEM analysis were included in these analyses to ensure consistency between the data used for the SEM analysis and the multiple regression analyses. Said multivariate outliers were not identified as influential observations for the regression analyses.

SPSS (v.28.0). Following imputation, a total of three multivariate outliers were identified using Mahalanobis squared Distance ($p < .001$; Tabachnik & Fidell, 2013). A visual inspection of the distributions post-outlier deletion revealed marginally improved symmetry and skewness/kurtosis statistics. After deletion of missing data and outliers, the sample size of the dataset was adjusted to $N = 229$. This adjusted sample size is deemed minimally acceptable based on MacCallum et al. (1996) power analysis guidelines for structural equation modelling. With an adjusted sample of $N = 229$ and chi-squared degrees of freedom over 100, we can expect a power of close to 1.0 for test of close fit ($RMSEA = .05$) and exact fit ($RMSEA < .01$; MacCallum et al., 1996). A flow diagram depicting the data cleaning procedures can be found below:

Figure 2

Data Cleaning Procedures



Assumption Testing

A series of univariate and multivariate tests were performed in IBM SPSS (v.28.0) to evaluate the data's suitability for structural equation modelling. Multivariate normality was assessed using i.) Mardia's coefficient of skewness and kurtosis (Mardia, 1970) ii.) univariate skewness and kurtosis statistics (+3 > skewness < -3; Tabachnik & Fidell, 2013), and iii.) visual inspection of the generated distributions. Using the MVN package in R (Korkmaz et al., 2014), Mardia's coefficient for multivariate skewness and kurtosis were computed for the cleaned dataset. Mardia's coefficient for multivariate skewness (Mardia's coefficient = 2911.18, $p <$ .001) and kurtosis (Mardia's coefficient = 2.5, $p < .009$) were both significant, indicating that the assumption of multivariate normality is violated.

With the exception of a few variables, skewness and kurtosis values for the neuropsychological test performance variables, cognitive reserve proxies, and covariates were outside the recommend interval, indicating significant violations to univariate normality. Evidence of non-normality was further demonstrated by Anderson-Darling test of normality, which indicated that based on a $p < .05$ significance level, only i.) age, ii.) Word List 1, and iii.) Semantic Fluency were normally distributed within the sample. A visual inspection of the generated histograms revealed that most neuropsychological test variables were negatively skewed and platykurtic. Violations to univariate normality imply violations to multivariate normality (Tabachnik & Fidell, 2013), therefore, combined evidence from univariate tests and multivariate tests (i.e., Mardia's test) support violations to multivariate normality.

Thirty-eight univariate outliers were identified across all included endogenous and exogenous variables. It was decided that including these cases in the final analysis was the more appropriate choice than removing them, as i.) removing 38 cases would be representative of

over-cleaning the dataset and ii.) removal did not impact multivariate normality. Mardia's coefficient for skewness was still significant after removal (Mardia's coefficient = 2630.99 $p <$ .001), whereas Mardia's coefficient for kurtosis was not significant (Mardia's coefficient = - 0.1, $p = .90$). Removal of all 38 univariate outliers resulted in normal distributions for only two additional variables: Phonemic Fluency and Complex Figure 2. Follow-up testing using Royston's test of multivariate normality (Royston, 1992) confirmed that multivariate normality was still violated after removal of univariate outliers (Royston H = 568.36, $p < .001$).

An analysis of several scatterplots between variables included in the SEM analysis revealed that the assumption of linearity was preserved in the included dataset. Values within the item-item correlation matrix were generally below .90, indicating no significant evidence of singularity or multicollinearity (Tabachnik & Fidell, 2013). Correlations were generally low-to-moderate in strength, with the exception of one correlation above .90 ($r_{\text{Complex Figure 1 <-> Complex Figure 2}} = .92$), one correlation above .80 ($r_{\text{Complex Figure 2 <-> Complex Figure Recognition}} = .83$), and several correlations below .10. Correlations below .10 were generally between i.) cognitive reserve proxies and neuropsychological test performance, ii.) between covariates and neuropsychological test performance, and iii.) between covariates and cognitive reserve proxies. With the exception of one set of variables ($r_{\text{Digit Span <-> Practical Problem Solving and Conceptual Shifting}} = .003$), most correlations between neuropsychological test performance were above .10. Computation of the normalized residuals revealed the presence of several large residual covariances (i.e., greater than +3, less than -3) for both models, indicating a large degree of unexplained error between the observed and hypothesized models. Large residual covariance is symptomatic of poor model fit. A frequency analysis of the residual covariances revealed that they were relatively symmetrical.

Model Specification

Prior to conducting the SEM analyses, a confirmatory factor analysis (CFA) was performed on the measurement components of both structural models to detect possible misspecification problems prior to model estimation. Fitting both the imputed and non-imputed data onto the original models (see Figures 1A and 2A in Appendix A) resulted in negative variance estimates and standardized values greater than one, indicating possible empirical under-identification. Evidence of empirical under-identification was further supported by several warning messages in R indicating the presence of negative eigenvalues and warnings that both the variance-covariance matrix and latent variable covariance matrix were not positive definite. Post-hoc modification were performed on the original structural models to ensure the covariance matrices used were positive definite[3]. Raw covariance matrices for the indicator variables and latent variables were examined to diagnose the cause of each warning message and negative variance estimate.

Collinearity diagnostics revealed the presence of a high correlation between the executive functioning latent variable and the attentional control and working memory latent variable ($r >$ .90). To correct for this problem, all the indicator variables from the attentional control/working memory latent variable were combined with the executive functioning latent variable. Theoretical and empirical justification for this decision comes from that fact that many of the measures of complex attention, including Sequences (KBNA) and Digit Span (WAIS-III) assess working memory, which has traditionally been conceptualized as a component of executive functioning, and attentional control incorporates interference control, selective attention, and

[3] The decision to make post-hoc modifications to the a priori models was made in consultation with Dr. Renee Biss (research supervisor) and Dr. Dennis Jackson (quantitative statistics consultant). Presence of negative variance estimates, and non-positive definite matrices can lead to inaccurate parameter estimates and biased model estimates.

cognitive inhibition components of executive function (e.g., Diamond, 2013; Lehto et al., 2003; Miyake et al., 2000). Combining both latent variables (i.e., attentional control/working memory and executive functioning) corrected for negative variance estimates, however, several warning messages were still present in the dataset after this modification, indicating the need for greater investigation and possible re-structuring of the measurement models and/or removal of certain variables.

Further modifications to the measurement model included i.) changing Matrix Reasoning from a measure of visuospatial processing to a measure of executive functioning, ii.) changing Phonemic Fluency from a measure of executive functioning to a measure of language skills, and iii.) removing Spatial Location (KBNA), Similarities (WASI-I), and Trail Making Test: Part A from both models. The decision to change the latent variables associated with Matrix Reasoning and Phonemic Fluency was based on evidence of negative latent variable residual variance for the latent variables they were originally associated with (e.g., Matrix Reasoning loading onto visuospatial processing factor and Phonemic Fluency loading onto executive functioning factor) and warning of misidentification. Changes to the measurement model were driven by prior theory and suggestions from post-hoc modification indices.

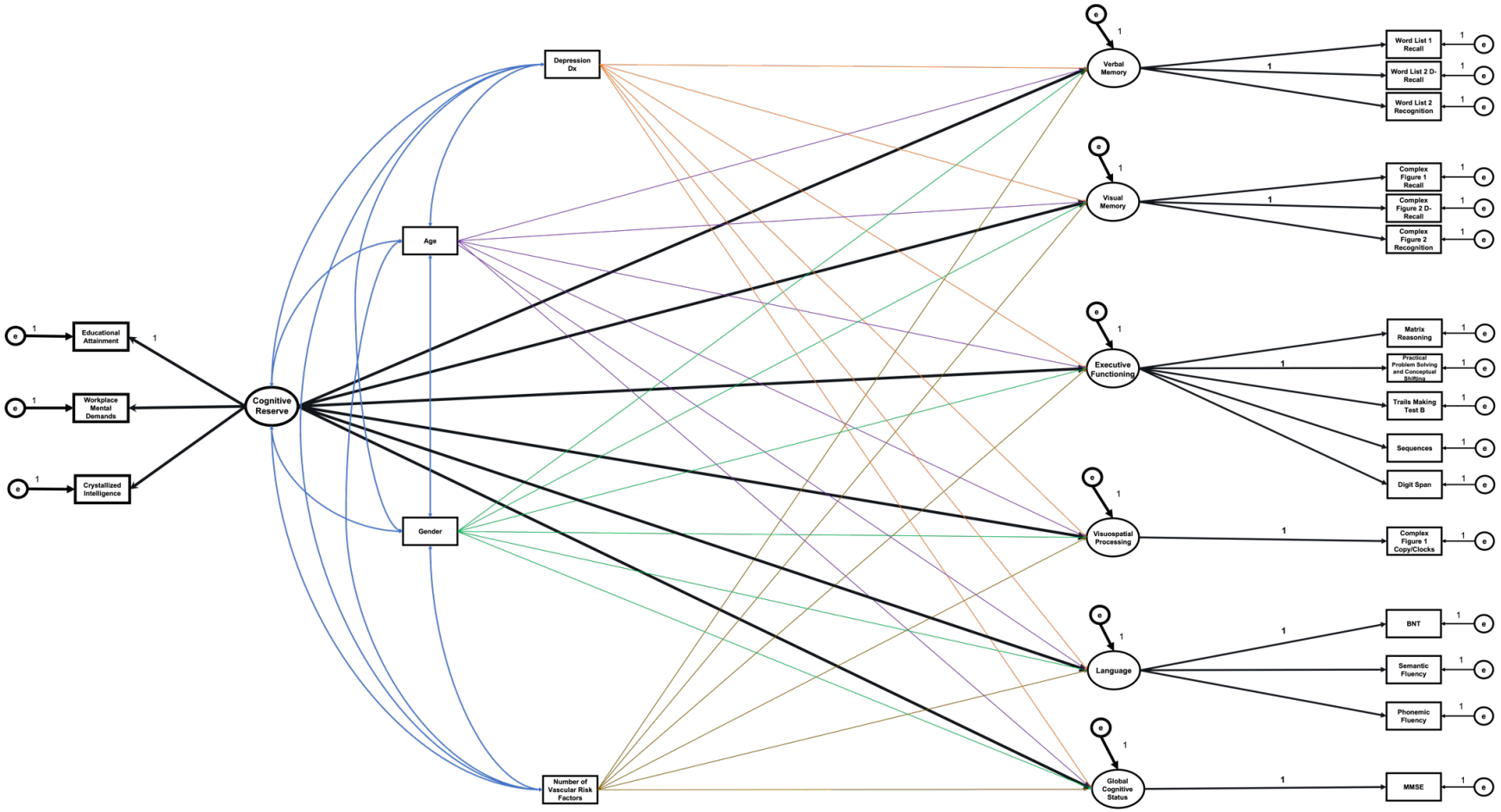
Trail Making Test: Part A was removed from both models due to evidence of poor factor loadings with its respective latent variable (i.e., visuospatial processing) and other latent variables included in the model. Similarities and Spatial Location were removed from both models due to the high amount of missing data in our sample. A frequency analysis revealed that approximately 37% of the sample did not have data for the Spatial Location subtest and 17% of the sample did not have data for the Similarities subtest. With that said, I decided to remove both these variables from the model as interpretation of parameter estimates and fit statistics would

likely be biased, given that data for most of the sample would be artificially derived from imputation procedures. Moreover, inclusion of these variables led to several warning messages related to the variance-covariance matrix and latent variable covariance matrix being non-positive definite, further supporting their removal for the analysis. Removal of said variables eliminated all warning messages and negative variance estimates. The original structural models developed for this thesis can be found in Appendix A.

The revised structural models can be found in Figures 3 and 4, below. In both models, circles represent latent variables (i.e., shared variance among measurement variables), single-headed arrows represent direct effects, rectangles represent measured/observed variables, and double-headed arrows represent shared variance. All endogenous and exogenous latent variables were scaled using a unit-loading identification constraint. The decision as of which indicator variable was constrained to a factor loading of one was made through consultation with my research supervisor, Dr. Renée Biss, a trained clinical neuropsychologist. In both models, educational attainment, mental workplace demands, and crystallized intelligence are defined as reflexive indicators of cognitive reserve and age, gender, depression, and vascular risk factors were hypothesized to covary with cognitive reserve and exhibit direct effects on all six domains of cognitive functioning. Both of the hypothesized models are over-identified and were tested with 196 degrees of freedom (80 parameters estimated out of 276 possible datapoints)

Figure 3

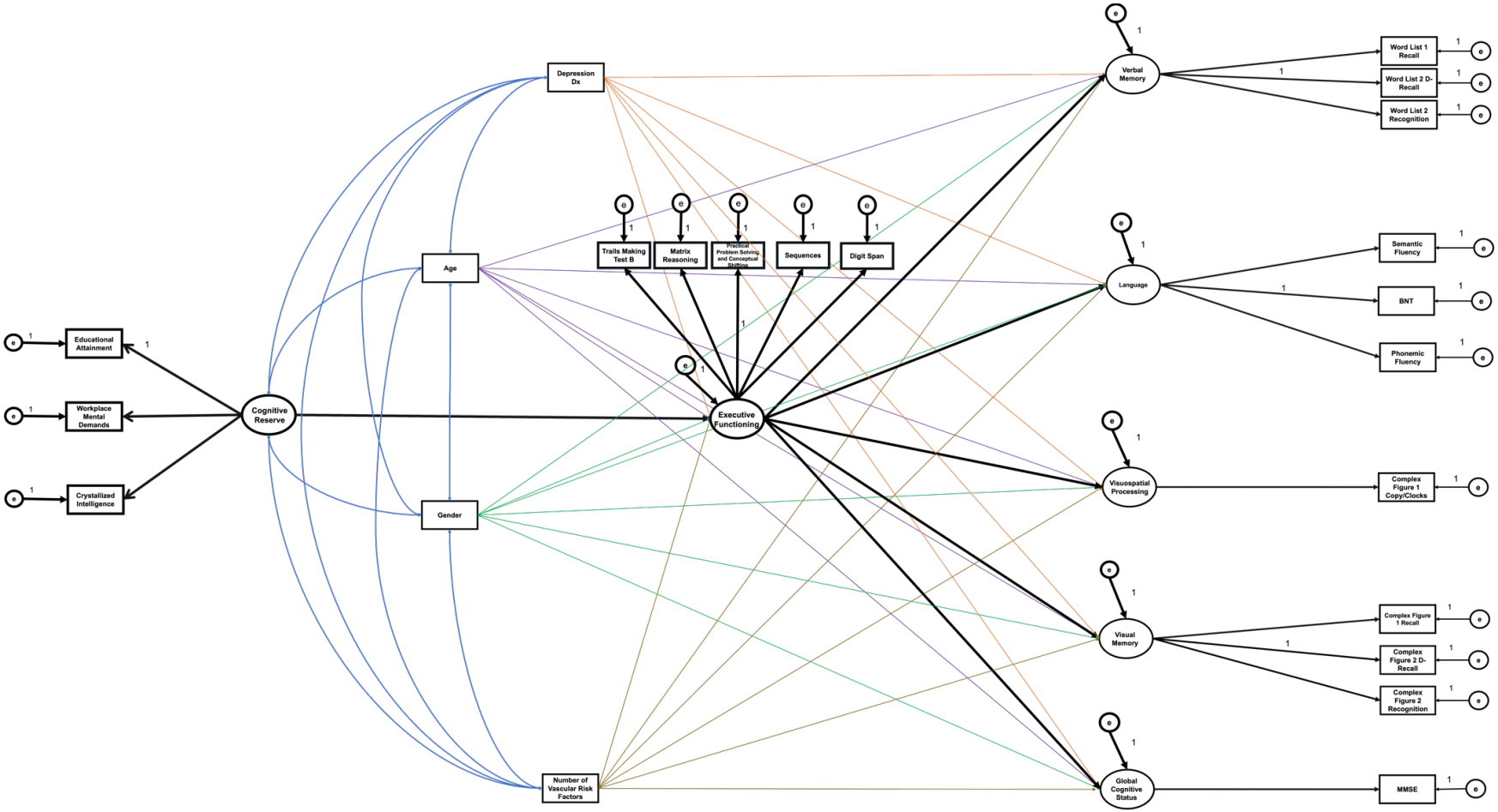
Model 1: Generalized Effects of Cognitive Reserve on Cognitive Functioning



Note. MMSE = Mini-Mental Status Exam, BNT = Boston Naming Test.

Figure 4

Model 2: Hierarchical Effects of Cognitive Reserve on Cognitive Functioning



Note. MMSE = Mini-Mental Status Exam, BNT = Boston Naming Test.

Model 1: Generalized Effects of Cognitive Reserve on Cognitive Functioning. Model 1 depicts the hypothesized *direct* effects of *cognitive reserve* on *six latent variables* representing different aspects of neuropsychological functioning: i.) verbal memory, ii.) visual memory, iii.) iii.) executive functioning, iv.) visuospatial processing, v.) language, and vi.) global cognitive status (see Figure 3).

The verbal memory factor included patients' raw scores on three list-learning tests of verbal memory from the KBNA battery: Word List 1, Word List 2, and Word List 2 Recognition. The visual memory factor included patients' raw scores on three tests of visual memory from the KBNA battery: Complex Figure 1, Complex Figure 2, and Complex Figure Recognition. The executive functioning factor included patients' raw scores on: Digit Span from the WAIS-III, Sequences from the KBNA, Matrix Reasoning from the WASI-I, Practical Problem Solving and Conceptual Shifting from the KBNA battery, and Trail Making Test B. The visuospatial processing factor included patients' raw scores on the Complex Figure Copy/Clocks test from the KBNA battery. For identification purposes, error variance for the visuospatial processing factor was constrained to (1-reliability * [sample variance]). Reliability of the Complex Figure Copy/Clocks test from the KBNA ($\propto$ = .78) was extracted from the sample data reported in the KBNA manual (Leach et al., 2000). The language skills factor included patients' raw score on three tests of confrontational naming and verbal fluency: BNT, Phonemic Fluency test from the KBNA battery, and Semantic Fluency from the KBNA battery. The global cognitive status factor included patient's raw score on the MMSE. Like the visuospatial processing factor, error variance for the global cognitive status factor was constrained to (1-reliability * [sample variance]). The reliability coefficient ($\propto$ = .78) used for the MMSE was extracted from a study

by Kabátová et al. (2016), which examined the psychometric properties of the MMSE in a sample of 84 older adults.

Model 2: Hierarchical Effects of Cognitive Reserve on Cognitive Functioning. Model 2 depicts an alternate model of cognitive reserve, where the cognitive reserve is hypothesized to have a direct effect on one latent variable, executive functioning, and indirect effect on five other latent variables: i.) verbal memory, ii.) visual memory, iii.) visuospatial processing, iv.) language, and v.) global cognitive status (see Figure 3). In this model, the effects of cognitive reserve on lower-level cognitive processes and global cognitive status are hypothesized to be mediated through changes in executive functioning.

Model Estimation and Evaluation

The two hypothesized models were tested in R (v. 4.2) using a robust-maximum likelihood estimation (MLM) procedure, as the assumption of multivariate normality was violated in our sample. MLM estimators use Satorra-Bentler scaling correction (Satorra & Bentler, 1988) to generate robust standard errors and fit statistics.

Model estimates for both hypothesized models were generated by analyzing the covariance matrix for all 23 variables (i.e., 3 cognitive reserve proxies, 16 neuropsychological variables, 4 covariates). Both models were evaluated and compared using several fit indices, including chi-squared test of absolute fit, Standardized Root Mean Square Residual (SRMR), Root Mean Square Error of Approximation (RMSEA; Browne & Cudeck, 1993), Bentler's Comparative Fit Index (CFI; Bentler, 1990), Tucker-Lewis Index (Tucker & Lewis, 1973), and Akaike Information Criterion (Akaike, 1987). Cut-off values for the acceptable fit were based on Hu and Bentler (1999) proposed criteria (RMSEA < .06, SRMR < .08, CFI > .95, TLI > .95).

Parameter estimates were evaluated based on standardized coefficients, standard errors, and generated z-score statistics ($p < .05$).

Modification indices were requested in addition to fit indices to identify parameters that could be either removed or added to improve model fit (Ullman, 2013). The Wald test (Wald, 1943) was used as the main criterion for removal of non-significant parameters (Ullman, 2013) and the Lagrange Multiplier (LM) test was used as the main criterion for the addition of parameters (based on magnitude and significance of LM statistic). The decision to add or remove parameters was based on the combination of prior theory and magnitude/significance of the LM test (Ullman, 2013). Model estimates were revaluated and compared after each modification to determine the optimal solution.

Research Question #3: Multiple Regression Analysis

Multiple Regression Analysis and Relative Weight Analysis

A series of two-step hierarchical regression analyses and relative weight analyses were performed on the same dataset to evaluate the individual relationships between the three cognitive reserve proxies (educational attainment, mental workplace demands, crystallized intelligence), covariates, and composite scores for i.) verbal memory, ii.) visual memory, iii.) executive functioning, iv.) visuospatial processing, v.) language, and vi.) global cognitive status. Composite scores for all six cognitive domains were calculated by averaging converted z-scores on domain-specific tests of neuropsychological functioning. In order to retain consistency throughout the planned analyses, z-scores for the indicator variables included in the revised measurement models for both SEM models were averaged for each cognitive domain. For each regression model, age, gender, total number of vascular risk factors, and depression diagnosis were entered in the first block of the regression analyses, and years of formal education, average

mental workplace demands total score, and raw score on the WASI-Vocabulary test were entered into the second block.

A total of six regression models were constructed to answer research question #3. Relative weight analyses were performed for each regression model to determine the relative importance of each predictor in all regression models. All regression analyses were performed using the GradPack in SPSS. 28.0.0.1 for macOS. Relative weight analyses were performed using an online tool called RWA-Web (Tonidandel & LeBreton, 2015). Missing data were imputed using the expectation-maximization procedure in SPSS. Significance of predictor variables in each regression model was determined based on a *p*-value of .05 or lower.

Assumption Testing

Prior to conducting the regression analyses, a series of univariate tests were performed to assess overall suitability of the imputed data set for regression analysis. All eight of the core assumptions of multiple regression analysis were examined statistically: a.) normality, b.) absence of outliers, c.) absence of multicollinearity and singularity, d.) linearity, e.) independence of errors, f.) homoscedasticity of errors, g.) sample size, h.) independence of observations. Normality was evaluated by inspecting the distribution of the standardized scores on the i.) verbal memory composite, ii.) visual memory composite, iii.) executive functioning composite, iv.) visuospatial processing composite, v.) language skills composite, and vi.) global cognitive status composite across the entire sample. Histograms and scatterplots between the regression standardized predicted value (ZPRED) and regression standardized residuals (ZRESI) for all six composites. Violations to normality were identified by examining the shape (e.g., normal curve for histogram) and distribution of generated graphs. ZRESI/ZPRED scatterplots were also used to evaluate heteroscedasticity (i.e., violation to assumption of homoscedasticity)

and linearity. Violations to homoscedasticity were identified through a visual examination of the scatterplot. Abnormal clustering (i.e., 'coning' of data [i.e., abnormal scatter, where datapoints are at differing distances from the regression line], multiple clusters) and non-linear lines on the P-P plot were treated as violations to linearity and homoscedasticity.

Influential observations were identified by computing Cook's distance for each of the observations in the data set. Observations with a Cook's distance greater than one were removed from the data set. Outliers on the criterion variable were identified through a combination of case wise diagnostics and computed standardized residuals. A stringent cut-off value of 2.5 was used. Outliers on the predictor variables were identified using computed Mahalanobis distance and corresponding *p*-values. Observations with a Mahalanobis *p*-value less than .001 were treated as outliers in the data set. Violations to the assumption of absence of outliers and influential observations were defined as the presence of influential observations (i.e., Cook's distance > 1) in the data set. To evaluate multicollinearity, collinearity diagnostics were performed and interpreted, appropriately. Variance Inflation Factor (VIF) and tolerance values were used to assess the presence of multicollinearity. Pearson r correlations between predictors were also used to evaluate multicollinearity. Pearson r correlations greater than .9, VIF values greater than 10, and tolerance values less than .10 were treated as violations to the above assumption. Independence of errors were evaluated using a computed Durbin-Watson statistic. Values less than 1.5 and greater than 2.5 were treated as violations to the assumption of independence of errors. Sample size (i.e., greater than $n = 20$ per predictor; $n = 140$) and independence of observations (i.e., absence of nesting) were achieved through careful design of this study.

A series of multiple regression analyses were performed with age, gender, vascular risk factors, depression diagnosis, years of formal education, average of mental workplace demand

variables, WASI-I Vocabulary raw scores as the predictor variables in each model and composite cognitive scores as the criterion variable in each model to evaluate the above assumptions. Visual inspection of the generated residual scatterplots and histograms revealed significant violations to the assumption of normality for the i.) visuospatial processing composite (i.e., negative skew and leptokurtic distribution), and ii.) global cognitive status composite (i.e., negative skew and leptokurtic distribution). An analysis of computed standardized residuals revealed a total of eight univariate outliers for the visuospatial processing composite ($N = 224$ for analyses using this criterion variable following removal of outliers), one univariate outlier for the language skills composite ($N = 231$), and six outliers for the global cognitive status composite ($N = 225$). No univariate outliers were identified for the verbal memory composite, visual memory composite, or executive functioning composite ($N = 232$). Computation of Cook's distance and Mahalanobis distance revealed no influential observations or multivariate outliers.

Following outlier removal, regression analyses was performed again to re-evaluate the assumptions. Case wise diagnostics revealed no additional influential observations (i.e., Cook's distance < 1) post-outlier removal and residual histograms for the visuospatial processing composite and language skills composite appeared normally distributed, with the exception of global cognitive status which was slightly skewed. Visual inspection of the residual scatterplots and P-P plots revealed no significant violations to homoscedasticity or linearity and collinearity diagnostics revealed no evidence of multicollinearity or singularity (VIF < 10, tolerance > .10). Independence of errors was supported for all six models, evident by Durbin Watson statistics ranging from 1.5-2.5. Sample size and independence of observations were also supported based on number of observations included and experimental design.

CHAPTER 3

RESULTS

Descriptive Statistics

Table 1 shows descriptive statistics for sociodemographic variables and cognitive reserve proxies for the total sample, and separately for patients within the sample that were diagnosed with mild cognitive impairment and participants determined to experience normal cognitive functioning.

Table 1

Sample Characteristics: Demographic Factors and Cognitive Reserve Proxies

Demographic Factor	Total Sample (n = 232)	Normal Cognitive Aging (n = 113)	Mild Cognitive Impairment (n = 119)
Age in years			
Mean (Standard Deviation)	76.0 (8.2)	74.2 (8.3)	77.7 (7.8)
Min–Max	52-96	52-94	54-96
Gender Identification			
% Female	53.0	61.9	44.5
% Male	47.0	38.1	55.5
Languages			
% Monolingual (English)	58.6	59.5	57.9
% Multilingual	41.4	40.5	42.1
Depression			
% yes	20.3	24.8	16.0
Cognitive Reserve			
Educational Attainment in years			
Mean (Standard Deviation)	13.5 (3.3)	13.2 (3.0)	13.8 (3.5)
Min–Max	3–21	5–19	3–21
Mental Workplace Demands			
Mean (Standard Deviation)	3.9 (0.7)	3.8 (0.8)	4.0 (0.7)
Min–Max	1.7-5.3	1.7-5.3	1.9-5.3
WASI-I Vocabulary Subtest Raw Score			
Mean (Standard Deviation)	58.8 (11.8)	60.0 (11.4)	57.8 (12.1)
Min–Max	18-80	31-80	18-76
Chronic Health Conditions			
Total Number of Cardiovascular Risk Factors			
Mean (Standard Deviation)	1.4 (1.2)	1.2 (1.2)	1.6 (1.2)
Min–Max	0–5	0–4	0–5
Hypertension			
% yes	49.1	46.9	51.3
Elevated Cholesterol/Conditions Affecting Blood Cholesterol			
% yes	45.7	39.8	51.3
Diabetes (Type I or II)			
% yes	10.3	8.0	12.6
History of Stroke (TIA, Mild Stroke, Stroke)			
% yes	12.1	8.8	15.1
History of Peripheral Vascular Disease and/or Aneurysm			
% yes	1.7	0.9	2.5
History of Heart Condition or Heart Surgery			
% yes	23.7	19.5	27.7

Note. WASI-I = Wechsler Abbreviated Scale of Intelligence. N = 232.

The sample consisted of a mostly an even split of males and females (47% male, 53% female). Patients were between the ages of 52 and 96 years old and on average reported a diagnosis of at least one vascular condition (M = 1.43, SD = 1.19). 48.7% of the sample consisted of patients experiencing with normal cognitive aging, whereas the remaining 51.3% were diagnosed with mild cognitive impairment. Of those experiencing normal cognitive aging, 61.9% were female and 38.1% were male. Conversely, 55.5% of those diagnosed with mild cognitive impairment were male and 44.5% were female. Approximately one fifth (20.3%) of the total sample was diagnosed with depression at the time of the assessment and two fifths (41.4%) spoke more than one language. A higher percentage of normal cognitive aging group were diagnosed with depression at the time of the assessment compared to the mild cognitive impairment group.

In general, the sample was moderately educated, held mildly mentally demanding occupations, and scored in the average range on the WASI-I Vocabulary subtest, indicating that they on average, possessed moderate levels of cognitive reserve. Scores on all three cognitive reserve proxies did not significantly differ between patients diagnosed with mild cognitive impairment and patients experiencing normal cognitive aging (see Appendix C, Table 1C).

School teacher, administrative assistant, retail salesperson, general manager, and bookkeeper/auditing clerk were among the most frequently reported occupations for the total sample (see Table 2). A list of all occupations reported within the sample can be found in Table 1B of Appendix B. Occupations are listed based on their O*NET SOC codes.

Table 2

Most Frequently Reported Occupations

Occupation Titles	*N*	%
Average of all *Teacher* Occupations (Elementary/Middle/High School)	18	7.8
Average of all *Administrative Assistant* Occupations	17	7.3
Retail Salesperson	13	5.6
General and Operations Manager	10	4.3
Bookkeeping, Accounting, and Auditing Clerks	9	3.9

Note. $N = 232$. % = percent of total sample.

Of the 10 O*NET mental workplace demand variables, patients' occupations predominately involved cognitive activities such as organizing, planning, and prioritizing work; updating and using relevant knowledge; making decisions and solving problems; and processing information (see Table 3). The largest variance in ratings were for the skills analyzing data or information. Ratings for all 10 O*NET variables did not significantly differ between patients diagnosed with mild cognitive impairment and individuals experiencing normal cognitive aging (see Appendix C, Table 2C).

Table 3

Descriptive Statistics for Mental Workplace Demands

Mental Workplace Demand Variables[a]	Mean (SD)	Min–Max
Judging the Qualities of Objects, Services, or People	3.5 (0.7)	1.2–5.4
Processing Information	4.0 (0.9)	1.2–6.3
Evaluating Information to Determine Compliance with Standards	3.7 (0.9)	0.9–5.9
Analyzing Data or Information	3.7 (1.0)	0.3–6.6
Making Decisions and Solving Problems	4.3 (0.9)	1.6–6.2
Thinking Creatively	3.9 (0.9)	1.5–5.9
Updating and Using Relevant Knowledge	4.5 (0.9)	1.5–6.5
Developing Objectives and Strategies	3.3 (0.9)	1.1–5.7
Scheduling Work and Activities	3.6 (0.8)	1.4–5.1
Organizing, Planning, and Prioritizing Work	4.7 (0.8)	2.3–5.8
Average	3.9 (0.7)	1.7–5.3

Note. $N = 227$. SD = Standard Deviation. [a] = values represent the degree to which the activity is required to perform the occupation (rated by occupational analysts).

A reliability analysis performed on the 10 O*NET mental workplace demand variables revealed that all 10 variables shared a high degree of internal consistency (see Table 4).

Table 4

*Reliability Analysis for O*NET Mental Workplace Demand Variable*

	Cronbach's Alpha	# of Items
O*NET MWD Variable Reliability Analysis	0.96	10

Note. MWD = Mental Workplace Demands. $N = 227$.

Educational attainment, mental workplace demands, and scores on the Vocabulary subtest shared small to medium correlations with each other. Overall, the strongest correlation was between educational attainment and mental workplace demands, whereas the weakest correlation was between WASI-I Vocabulary score and mental workplace demands (see Table 5).

Table 5

Correlations Between Cognitive Reserve Proxies

		Educational Attainment	Mental Workplace Demands	WASI-I Vocabulary
Educational Attainment	*r*	1.0	.51	.48
	p	-	< .001	< .001
Mental Workplace Demands	*r*	.51	1.0	.29
	p	< .001	-	< .001
WASI-I Vocabulary	*r*	.48	.29	1.0
	p	< .001	< .001	-

Note. $N = 232$. r = Pearson Correlation.

Table 6 shows descriptive statistics for neuropsychological performance of the sample before imputation.

Table 6

Sample Characteristics: Neuropsychological Performance Across All Variables – Non-Imputed Dataset

	n	Total Sample	*n*	Normal Cognitive Aging	*n*	MCI
		Mean (SD)		Mean (SD)		Mean (SD)
Word List 1 (/48)	232	23.90 (6.98)	113	27.55 (6.24)	119	20.44 (5.79)
Word List 2 (/24)	232	10.72 (5.82)	113	14.00 (4.87)	119	7.61 (4.88)
Word List Recognition (/36)	232	31.25 (4.49)	113	33.54 (2.63)	119	29.08 (4.82)
Complex Figure 1 (/20)	232	8.65 (4.43)	113	10.50 (3.84)	119	6.89 (4.24)
Complex Figure 2 (/20)	232	7.96 (4.66)	113	10.11 (3.89)	119	5.92 (4.42)
Complex Figure Recognition (/10)	232	5.75 (2.95)	113	6.93 (2.57)	119	4.63 (2.85)
Sequences (/57)	231	49.46 (6.49)	112	50.48 (5.64)	119	48.50 (7.09)
Spatial Location (/46)	149	33.24 (9.55)	79	34.44 (9.96)	70	31.89 (8.93)
Digit Span (/30)	228	14.97 (4.00)	113	15.40 (3.96)	115	14.47 (4.0)
Complex Figure Copy and Clocks (/57)	232	47.71 (5.87)	113	48.75 (6.14)	119	46.71 (5.44)
Trail Making Test: Part A	230	62.55 (34.86)	111	51.19 (17.28)	119	73.15 (42.95)
Matrix Reasoning[a]	231	16.82 (7.37)	113	18.34 (7.45)	118	15.36 (7.03)
Phonemic Fluency	232	11.58 (4.97)	113	12.49 (4.92)	119	10.72 (4.88)
Practical Problem Solving and Conceptual Shifting (/30)	211	17.38 (12.62)	102	18.85 (12.42)	109	16.01 (12.7)
Similarities (/48)	192	31.92 (7.76)	92	34.08 (6.74)	100	29.93 (8.14)
Trail Making Test: Part B	228	163.89 (79.30)	112	142.85 (73.18)	116	184.2 (79.99)
Boston Naming Test (/60)	230	46.74 (9.99)	112	49.23 (7.56)	118	44.37 (11.39)
Semantic Fluency	232	32.50 (0.86)	113	37.56 (10.25)	119	27.69 (9.12)
Mini-Mental Status Exam (/30)	200	27.67 (2.11)	97	28.36 (1.7)	103	27.01 (2.26)

Note. Data presented in this table include scores from the non-imputed dataset.
[a] Maximum raw score is 32 for patients aged 45-79 and 28 for patients aged 80 or older.

Table 7 shows the bivariate correlations between all the variables included in the proposed SEM models. Overall, the correlational analysis shows that the cognitive reserve proxies are significantly correlated, as are the measures of verbal memory, visual memory, and language skills. Apart from one non-significant weak correlation between Digit Span and Practical Problem Solving and Conceptual Shifting, measures of executive functioning were significantly correlated.

Table 7

Correlation Between Variables in Proposed Structural Models

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1. age	1.00																						
2. gender	.09	1.00																					
3. VRF	.31**	.10	1.00																				
4. DEP	-.29**	-.06	-.10	1.00																			
5. education	-.03	.15*	-.01	-.11	1.00																		
6. MWD	.08	.27**	.13	-.15*	.50**	1.00																	
7. VOC	.06	.06	-.02	-.09	.48**	.28**	1.00																
8. WL1	-.19**	-.26**	-.09	.01	.18**	-.003	.24**	1.00															
9. WL2	-.19**	-.26**	-.11	.07	.14*	.01	.20**	.79**	1.00														
10. WLREC	-.06	-.18**	.05	.12	.16*	.02	.14*	.64**	.75**	1.00													
11. CF1	-.27**	.04	-.10	.10	.15*	.08	.22**	.51**	.60**	.56**	1.00												
12. CF2	-.31**	.01	-.07	.13	.14*	.05	.22**	.53**	.63**	.61**	.92**	1.00											
13. CFREC	-.29**	-.01	-.09	.16*	.09	-.04	.19**	.50**	.56**	.54**	.79**	.83**	1.00										
14. PREAS	-.18**	-.19**	.03	.06	.12	.01	.22**	.17*	.12	.19**	.12	.19**	.13*	1.00									
15. TMTB	-.14*	.004	-.07	.04	.27**	.09	.43**	.37**	.33**	.26**	.39**	.37**	.29**	.23**	1.00								
16. MR	-.16*	.04	-.12	.04	.37**	.17**	.51**	.35**	.30**	.20**	.41**	.40**	.36**	.24**	.58**	1.00							
17. SEQ	<.001	.11	-.07	-.09	.34**	.24**	.52**	.33**	.28**	.20**	.28**	.28**	.19**	.17*	.55**	.48**	1.00						
18. DSPN	.16*	.03	-.01	-.17*	.18**	.09	.36**	.26**	.13*	.14*	.15*	.15*	0.06	.003	.41**	.34**	.38**	1.00					
19. VISSP	-.19**	-.03	-.09	.04	.22**	.04	.41**	.37**	.35**	.30**	.43**	.46**	.37**	.25**	.48**	.48**	.46**	.19**	1.00				
20. BNT	-.19**	.06	-.16*	-.002	.40**	.23**	.60**	.28**	.33**	.22**	.36**	.37**	.30**	.20**	.42**	.47**	.52**	.26**	.54**	1.00			
21. SEMF	-.24**	-.19**	-.15*	.02	.16*	.004	.43**	.52**	.44**	.31**	.29**	.34**	.32**	.28**	.56**	.44**	.47**	.32**	.39**	.52**	1.00		
22. PHF	-.002	-.14*	-.08	-.06	.28**	.04	.53**	.36**	.30**	.14*	.14*	.15*	.10	.19**	.48**	.41**	.50**	.38**	.28**	.45**	.66**	1.00	
23. MMSE	-.07	-.14*	-.03	.03	.12	-.02	.32**	.44**	.47**	.46**	.45**	.50**	.39**	.14*	.44**	.37**	.29**	.33**	.39**	.39**	.39**	.35**	1.00

Note. * = $p < .05$, ** = $p < .01$. VRF = vascular risk factor, DEP = depression diagnosis, MWD = average of mental workplace demand variables, VOC = WASI-I Vocabulary subtest raw score, WL1 = Word List 1, WL2 = Word List 2, WLREC = Word List Recognition, CF1 = Complex Figure 1, CF2 = Complex Figure 2, CFREC = Complex Figure Recognition, PREAS = Practical Problem Solving and Conceptual Shifting, TMTB = Trail Making Test: Part B (Positive-Keyed), MR = Matrix Reasoning, SEQ = Sequences, DSPN = Digit Span, VISSP = Complex Figure Copy and Clocks, BNT = Boston Naming Test, SEMF = Semantic Fluency, PHF = Phonemic Fluency, MMSE = Mini-Mental Status Exam. TMTB is positively keyed, where lower scores represent lower performance. $N = 229$. For gender, 0 = female, 1 = male.

Research Question #1: Direct and Indirect Effects of Cognitive Reserve on Cognitive Functioning

Model 1: Generalized Effects of Cognitive Reserve on Cognitive Functioning

Structural equation models were analyzed using the lavaan package (0.6-15; Rosseel, 2012) in R. Fit statistics indicated that the model had poor fit for the data (Satorra-Bentler χ^2 (196, N = 229) = 621.61, $p < .001$, SRMR = .093, R-RMSEA = .098 [.089, .106], R-CFI = .84, R-TLI = .79). Modification indices suggested the addition of several paths to the model to improve fit, however, it was decided not to proceed with these changes, as the suggested changes were either not supported by prior theory (e.g., adding Phonemic Fluency as an indicator of visual memory) or would result in identification problems (e.g., correlating error terms).

Parameter estimates for the measurement portion of the model showed that all indicators significantly loaded onto their respective factors (see Table 8). Standardized loadings ranged from .28 for Practical Problem Solving and Conceptual Shifting to .98 for Complex Figure 2. Of the three measures associated with cognitive reserve, WASI-I Vocabulary had the strongest loading, suggesting that it is the best measure of cognitive reserve in the sample. Word List 2 appeared to be best measure of verbal memory, with a factor loading of β = .94. Complex Figure 2 appeared to be the best measure of visual memory, with a factor loading of β = .98. Trail Making Test B (β = .76) appeared to be the best measure of executive functioning and Semantic Fluency appeared to be the best measure of language skills (β = .80). Factor loadings for the visuospatial processing factor and global cognitive status factor were both β =.88.

Residual variances ranged from .04 (Complex Figure 2) to .92 (Practical Problem Solving and Conceptual Shifting, mental workplace demands), indicating that the model is poor at explaining variance in Practical Problem Solving and Conceptual Shifting as well as mental

workplace demands. Other variables with large residual variances include educational attainment (β =.76) and Digit Span (β =.78).

Table 8

Model 1: Measurement Model: Factor Loadings and Error Coefficients

Indicators	*β*	*B*	*SE*	*z*	*SMC* (R^2)	*ε β*	*ε B*	*ε SE*	*ε z*
Cognitive Reserve	-	-	-	-	-	1.00[a]	2.36	0.66	3.58**
→ Education	.47	1.00	-	-	.22	.78	8.33	0.73	11.40**
→ WASI-I Vocabulary	.70	5.39	0.72	7.46**	.49	.51	70.83	6.88	10.29**
→ Mental Workplace Demands	.29	1.39	0.26	5.45**	.09	.92	49.11	4.67	10.53**
Verbal Memory	-	-	-	-	.41	.59	17.39	2.09	8.34**
→ Word List 2	.94	1.00	-	-	.88	.12	4.14	1.15	3.62**
→ Word List 1	.85	1.09	0.06	17.31**	.72	.29	13.94	1.84	7.57**
→ Word List Recognition	.78	0.65	0.04	15.20**	.61	.39	7.86	1.05	7.52**
Visual Memory	-	-	-	-	.37	.63	12.86	1.25	10.29**
→ Complex Figure 2	.98	1.00	-	-	.96	.04	0.89	0.32	2.83**
→ Complex Figure 1	.94	0.91	0.03	35.98**	.88	.12	2.40	0.39	6.21**
→ Complex Figure Recognition	.84	0.55	0.02	23.60**	.71	.29	2.48	0.26	9.73**
Executive Functioning	-	-	-	-	.90	.11	1.22	0.83	1.48
→ Practical Problem Solving and Conceptual Shifting	.28	1.00	-	-	.08	.92	0.89	8.67	15.52**
→ Trail Making Test B	.76	1.76	0.40	4.35**	.58	.42	2.40	3.28	7.98**
→ Matrix Reasoning	.73	1.58	0.37	4.25**	.54	.46	2.48	3.04	8.24**
→ Digit Span	.49	0.57	0.14	3.99**	.24	.76	12.12	1.62	7.48**
→ Sequences	.72	1.28	0.33	3.86**	.52	.48	17.82	2.40	7.43**
Language Skills	-	-	-	-	.82	.18	9.13	2.87	3.18**
→ Boston Naming Test	.71	1.00	-	-	.51	.49	49.44	5.47	9.04**
→ Semantic Fluency	.80	1.20	0.13	9.45**	.63	.37	43.21	6.71	6.44**
→ Phonemic Fluency	.72	0.50	0.06	8.16**	.52	.49	11.96	1.57	7.64**
Visuospatial Functioning	-	-	-	-	.54	.46	8.90	1.82	4.88**
→ Complex Figure Copy and Clocks	.88	1.00	-	-	.78	.22	5.47	-	-
Global Cognitive Status	-	-	-	-	.45	.55	1.78	0.49	3.66**
→ Mini Mental Status Exam	.88	1.00	-	-	.78	.22	0.92	-	-
Covariates									
Age	-	-	-	-	-	1.00	67.39[a]	6.4	10.54**
Vascular Risk Factors	-	-	-	-	-	1.00	1.41[a]	0.11	13.07**
Gender	-	-	-	-	-	1.00	0.25[a]	0.002	115.27**
Depression Diagnosis	-	-	-	-	-	1.00	0.16[a]	.02	10.37

Note. *β* = standardized beta coefficient, B = unstandardized beta coefficients, SMC = Squared Multiple Correlations, z = z-value, *ε* = error, WASI-I = Wechsler Abbreviated Scale of Intelligence. * = $p < .05$, ** = $p < .01$. Scores on Trail Making Test: Part B were transformed (i.e., divided by 10) and scores on Mental Workplace Demands were transformed (i.e., multiplied by 10) to ensure equal variance in the model. [a] represents total variance since variable is defined as an exogenous variable in the model.

Parameter estimates for the structural paths representing the direct effects of cognitive reserve on cognitive functioning are presented in Table 9. Interpretation of parameter estimates is

limited due to poor model fit, however, observed effects will be discussed below as they pertain to the proposed hypotheses. Parameter estimates are likely biased, thus, observed effects should be interpreted with caution.

Cognitive reserve had a significant positive effect on verbal memory, visual memory, executive functioning, visuospatial processing, language skills, and global cognitive status. Cognitive reserve had the strongest effects on executive functioning, followed by language skills, visuospatial processing, global cognitive status, verbal memory, and visual memory.

Age had a significant negative effect on all cognitive domains, except executive functioning and global cognitive status. Gender had a significant effect on verbal memory, language skills, and global cognitive status, with females demonstrating on average better performance than males. Total number of vascular risk factors and depression diagnosis did not have a significant effect on any one cognitive domain.

Post-hoc modification was performed on the model to test the stability of parameter estimates under the conditions of improved fit. Modifications were performed for the sole purposes of improving model fit to increase the reliability of the solution. Ultimately these modifications were not included in the final solution as they either showed mixed or insufficient research evidence or did not adhere with the overall objectives of this study (e.g., *a priori* decision to treat endogenous latent variables as orthogonal). Modifications included: correlating the errors between educational attainment and mental workplace demands and adding a covariance path between the verbal memory and visual memory factors. Results from this solution will not be reported here, as these analyses were strictly exploratory in nature. Following post-hoc changes, model fit improved significantly. RMSEA and SRMR values were acceptable after model modifications. Parameter estimates remained stable when compared to the

original solution and patterns of statistical significance and standardized beta-weights largely remained unchanged in the modified solution, with the exception of cognitive reserve no longer being significantly associated with gender in the modified solution. Thus, results from this exploratory analysis suggest that the observed structural relationships are robust to poor model fit.

Table 9

Model 1: Structural Model: Regression Coefficients and Statistical Tests

Indicators	*β*	*B*	*SE*	*z*	*p*
Cognitive Reserve → Verbal Memory	**.57**	**2.02**	**0.38**	**5.32**	**< .001**
age → Verbal Memory	**-.17**	**-0.11**	**0.05**	**-2.14**	**.03**
Vascular Risk Factors → Verbal Memory	.01	0.05	0.36	0.13	.90
gender → Verbal Memory	**-.37**	**-4.00**	**0.81**	**-4.96**	**< .001**
Depression Diagnosis → Verbal Memory	.10	1.34	1.03	1.30	.19
Cognitive Reserve → Visual Memory	**.54**	**1.58**	**0.29**	**5.42**	**< .001**
age → Visual Memory	**-.31**	**-0.17**	**0.04**	**-4.11**	**< .001**
Vascular Risk Factors → Visual Memory	.03	0.12	0.27	0.43	.67
gender → Visual Memory	-.05	-0.48	0.64	-0.75	.45
Depression Diagnosis → Visual Memory	.13	1.49	0.82	1.83	.07
Cognitive Reserve → Executive Functioning	**.96**	**2.14**	**0.57**	**3.77**	**< .001**
age → Executive Functioning	-.13	-0.05	0.04	-1.41	.16
Vascular Risk Factors → Executive Functioning	-.05	-0.15	0.22	-0.65	.51
gender → Executive Functioning	-.11	-0.78	0.56	-1.39	.17
Depression Diagnosis → Executive Functioning	.10	0.81	0.69	1.18	.24
Cognitive Reserve → Visuospatial Functioning	**.72**	**2.07**	**0.39**	**5.34**	**<. 001**
age → Visuospatial Functioning	**-.21**	**-0.11**	**0.05**	**-2.46**	**.01**
Vascular Risk Factors → Visuospatial Functioning	-.02	-0.06	0.28	-0.23	.82
gender → Visuospatial Functioning	-.15	-1.30	0.68	-1.91	.06
Depression Diagnosis → Visuospatial Processing	.10	1.12	0.91	1.23	.22
Cognitive Reserve → Language Skills	**.89**	**4.16**	**0.62**	**6.69**	**<. 001**
age → Language Skills	**-.20**	**-0.17**	**0.06**	**-2.96**	**<. 001**
Vascular Risk Factors → Language Skills	-.09	-0.53	0.42	-1.24	.21
gender → Language Skills	**-.28**	**-4.04**	**0.98**	**-4.12**	**<. 001**
Depression Diagnosis → Language Skills	.06	0.98	1.3	0.76	.45
Cognitive Reserve → Global Cognitive Status	**.67**	**0.79**	**0.16**	**5.05**	**< .001**
age → Global Cognitive Status	-.07	-0.02	0.02	-0.75	.46
Vascular Risk Factors → Global Cognitive Status	.03	0.04	0.12	0.33	.74
gender → Global Cognitive Status	**-.27**	**-0.99**	**0.28**	**-3.55**	**< .001**
Depression Diagnosis → Global Cognitive Status	.12	0.54	0.39	1.36	.17

Note. β = standardized beta coefficient, B = unstandardized beta coefficients, SMC = Squared Multiple Correlations, z = z-value. Bolded values indicate statistical significance ($p < .05$).

Estimated covariances between the different covariates, as well as between the covariates and cognitive reserve, can be found in Table 10 below. Cognitive reserve was significantly associated with gender in our sample, with males on average demonstrating higher levels of cognitive reserve than females. Two significant covariances were found between covariates, age and total number of vascular risk factors, and depression diagnosis and total number of vascular risk factors. Age was positively associated with total number of vascular risk factors, suggesting that as age increases, number of vascular risk factors increase. Depression diagnosis was negatively associated with age, suggesting that a depression diagnosis was more common with younger patients in the sample.

Table 10

Model 1: Covariances

Covariance	*r*	*Cov*	*SE*	*z*	*p*
Cognitive Reserve ↔ age	.07	0.83	1.14	0.73	.46
Cognitive Reserve ↔ Vascular Risk Factors	.01	0.01	0.16	0.08	.93
Cognitive Reserve ↔ gender	**.19**	**0.15**	**0.07**	**1.98**	**.048**
Cognitive Reserve ↔ Depression Diagnosis	-.18	-0.11	0.06	-1.75	.08
age ↔ Vascular Risk Factors	**.31**	**3.00**	**0.64**	**4.72**	**< .001**
gender ↔ Depression Diagnosis	-.06	-0.01	0.01	-0.98	.33
Vascular Risk Factor ↔ gender	.10	0.06	0.04	1.58	.11
age ↔ gender	.09	0.35	0.27	1.30	.19
age ↔ Depression Diagnosis	**-.29**	**-0.95**	**0.25**	**-3.78**	**< .001**
Vascular Risk Factor ↔ Depression Diagnosis	-.10	-0.05	0.03	-1.52	.13

Note. β = standardized beta coefficient, B = unstandardized beta coefficients, SE = Standard Error, z = z-value. Bolded values indicate statistical significance ($p < .05$).

Model 2: Hierarchical Effects of Cognitive Reserve on Cognitive Functioning

Fit statistics indicated that the second model also had poor fit for the data (Satorra-Bentler χ^2 (196, N = 229) = 590.61, $p < .001$, SRMR = .093, R-RMSEA = .095 [.086, .103], R-CFI = .85, R-TLI = .81). Modification indices suggested the addition of several paths to the model to improve fit, however, it was decided not to proceed with these changes, as the

suggested changes were not supported by prior theory and were unlikely to meaningfully improve model fit.

Parameter estimates for the measurement portion of the model showed that all indicators significantly loaded onto their respective factors (see Table 11). Standardized loadings ranged from .28 for Practical Problem Solving and Conceptual Shifting to .98 for Complex Figure 2. Factor loadings, residual variances, and SMC for Cognitive Reserve and all six cognitive domains were generally consistent with Model 1 (see Table 11).

Table 11

Model 2: Measurement Model: Factor Loadings and Error Coefficients

Indicators	*β*	*B*	*SE*	*z*	*SMC* (R^2)	*ε β*	*ε B*	*ε SE*	*ε z*
Cognitive Reserve	-	-	-	-	-	1.00	3.86[a]	0.85	4.52**
→ Education	.60	1.00	-	-	.36	.64	6.83	0.70	9.81**
→ WASI-I Vocabulary	.83	4.99	0.63	7.89**	.69	.31	43.64	10.00	4.36**
→ Mental Workplace Demands	.40	1.51	0.22	7.02**	.16	.84	44.92	4.38	10.27**
Verbal Memory	-	-	-	-	.41	.59	17.45	2.09	8.33**
→ Word List 2	.94	1.00	-	-	.88	.13	4.21	1.15	3.66**
→ Word List 1	.85	1.09	0.06	17.29**	.72	.28	13.84	1.84	7.54**
→ Word List Recognition	.78	0.65	0.04	15.13**	.61	.39	7.86	1.04	7.53**
Visual Memory	-	-	-	-	.37	.63	12.81	1.26	10.19**
→ Complex Figure 2	.98	1.00	-	-	.96	.04	0.90	0.31	2.89**
→ Complex Figure 1	.94	0.91	0.03	36.09**	.88	.12	2.39	0.39	6.18**
→ Complex Figure Recognition	.84	0.55	0.02	23.63**	.71	.29	2.48	0.26	9.73**
Executive Functioning	-	-	-	-	.60	.40	4.55	2.25	2.03*
→ Practical Problem Solving and Conceptual Shifting	.28	1.00	-	-	.08	.92	134.76	8.62	15.63**
→ Trail Making Test B	.75	1.75	0.40	4.34**	.56	.44	27.38	3.22	8.51**
→ Matrix Reasoning	.72	1.56	0.37	4.23**	.51	.49	26.41	2.92	9.05**
→ Digit Span	.48	0.57	0.14	3.96**	.23	.77	12.24	1.63	7.53**
→ Sequences	.71	1.28	0.33	3.85**	.50	.50	18.42	2.41	7.63**
Language Skills	-	-	-	-	.79	.21	10.17	2.73	3.73**
→ Boston Naming Test	.69	1.00	-	-	.48	.52	52.69	5.70	9.25**
→ Semantic Fluency	.82	1.27	0.14	9.12**	.66	.34	39.51	6.44	6.13**
→ Phonemic Fluency	.73	0.52	0.06	8.09**	.53	.47	11.57	1.55	7.48**
Visuospatial Functioning	-	-	-	-	.54	.46	8.86	1.81	4.91**
→ Complex Figure Copy and Clocks	.88	1.00	-	-	.78	.22	0.92	-	-
Global Cognitive Status	-	-	-	-	.46	.54	1.77	0.48	3.70**
→ Mini Mental Status Exam	.88	1.00	-	-	.78	.22	5.47	-	-
Covariates									
Age	-	-	-	-	-	1.00	67.39[a]	6.4	10.54**
Vascular Risk Factors	-	-	-	-	-	1.00	1.41[a]	0.11	13.07**
Gender	-	-	-	-	-	1.00	0.25[a]	0.002	115.27**
Depression Diagnosis	-	-	-	-	-	1.00	0.16[a]	.02	10.37**

Note. β = standardized beta coefficient, B = unstandardized beta coefficients, SMC = Squared Multiple Correlations, z = z-value, ε = error, WASI-I = Wechsler Abbreviated Scale of Intelligence. * = $p < .05$, ** = $p < .01$. Scores on Trail Making Test B were transformed (i.e., divided by 10) and scores on mental workplace demands were transformed (i.e., multiplied by 10) to promote equal variance in the model. [a] represents total variance since variable is defined as an exogenous variable in the model.

Parameter estimates for the structural paths representing the direct effects of cognitive reserve on executive functioning and indirect effects on other cognitive domains are presented in Table 12. Estimates depicting the direct effects of cognitive reserve indicated that cognitive

reserve had a significant positive effect on executive functioning. Estimates depicting the indirect effects of cognitive reserve were also significant, as executive functioning was found to have significant positive effect on verbal memory, visual memory, visuospatial processing, language skills, and global cognitive status.

Age had a significant negative effect on language skills. Gender had a significant effect on verbal memory, language skills, and global cognitive status, with females demonstrating on average better performance than males. Total number of vascular risk factors and depression diagnosis did not have a significant effect on any one cognitive domain.

Like for Model 1, post-hoc modification were performed on the model to test the stability of parameter estimates under the conditions of improved fit. Modifications were performed for the sole purposes of improving model fit to increase the reliability of the solution. Modifications included: correlating the errors between educational attainment and mental workplace demands, correlating the errors between Phonemic Fluency and Semantic Fluency and adding a covariance path between the verbal memory and visual memory factors. Following post-hoc changes, model fit improved significantly. RMSEA, SRMR, and CFI values were acceptable after model modifications. Parameter estimates remained relatively stable when compared to the original solution and patterns of statistical significance and standardized beta-weights largely remained unchanged in the modified solution. Thus, results from this exploratory analysis suggest that the observed structural relationships are robust to poor model fit.

Table 12

Model 2: Structural Model: Regression Coefficients and Statistical Tests

Direct Effects	*β*	*B*	*SE*	*z*	*p*
Cognitive Reserve → Executive Functioning	**.77**	1.32	**0.34**	**3.87**	**< .001**
age → Executive Functioning	-.13	-0.05	0.03	-1.66	.10
Vascular Risk Factors → Executive Functioning	-.06	-0.17	0.19	-0.88	.38
gender → Executive Functioning	-.05	-0.30	0.44	-0.69	.49
Depression Diagnosis → Executive Functioning	.04	0.30	0.55	0.54	.59
Executive Functioning → Verbal Memory	**.56**	**0.90**	**0.26**	**3.49**	**< .001**
age → Verbal Memory	-.10	-0.07	0.04	-1.58	.11
Vascular Risk Factors → Verbal Memory	.04	0.18	0.30	0.58	.57
gender → Verbal Memory	**-.30**	-3.24	**0.67**	**-4.86**	**<.001**
Depression Diagnosis → Verbal Memory	.04	0.56	0.79	0.72	.48
Executive Functioning → Visual Memory	**.53**	**0.71**	**0.19**	**3.69**	**< .001**
age → Visual Memory	**-.24**	**-0.13**	**0.03**	**-4.02**	**< .001**
Vascular Risk Factors → Visual Memory	.06	0.22	0.22	1.01	.31
gender → Visual Memory	.01	0.11	0.54	0.20	.84
Depression Diagnosis → Visual Memory	.08	0.89	0.68	1.31	.19
Executive Functioning → Language Skills	**.85**	**1.76**	**0.44**	**3.98**	**< .001**
age → Language Skills	-.09	-0.07	0.05	-1.63	0.10
Vascular Risk Factors → Language Skills	-.04	-0.24	0.31	-0.78	0.44
gender → Language Skills	**-.18**	**-2.53**	**0.76**	**-3.31**	**.001**
Depression Diagnosis → Language Skills	-.04	-0.60	0.88	-0.68	0.50
Executive Functioning → Visuospatial Processing	**.71**	**0.93**	**0.24**	**3.83**	**< .001**
age → Visuospatial Processing	-.12	-0.07	0.04	-1.65	.10
Vascular Risk Factors → Visuospatial Processing	.02	0.07	0.23	0.30	.77
gender → Visuospatial Processing	-.06	-0.53	0.56	-0.96	.34
Depression Diagnosis → Visuospatial Processing	.03	0.33	0.67	0.50	.62
Executive Functioning → Global Cognitive Status	**.66**	**0.36**	**0.09**	**3.98**	**< .001**
age → Global Cognitive Status	.01	<0.01	0.02	0.17	.86
Vascular Risk Factors → Global Cognitive Status	.06	0.09	0.10	0.93	.35
gender → Global Cognitive Status	**-.19**	**-0.69**	**0.24**	**-2.91**	**.004**
Depression Diagnosis → Global Cognitive Status	.05	0.23	0.30	0.77	.44
Indirect Effects	***β***	***B***	***SE***	***z***	***p***
Cognitive Reserve → Verbal Memory	.43	-	-	-	-
Cognitive Reserve → Visual Memory	.41	-	-	-	-
Cognitive Reserve → Language Skills	.65	-	-	-	-
Cognitive Reserve → Visuospatial Processing	.55	-	-	-	-
Cognitive Reserve → Global Cognitive Status	.51	-	-	-	-

Note. β = standardized beta coefficient, B = unstandardized beta coefficients, SMC = Squared Multiple Correlations, R = Reliability estimate, z = z-value. Bolded values indicate statistical significance ($p < .05$).

No significant relationships were found between the covariates and cognitive reserve in the second model. Age had a significant positive relationship with total number of vascular risk factors, and depression diagnosis had a significant negative relationship with age. Estimated covariances can be found in Table 13 below.

Table 13

Model 2: Covariances

Covariance	*r*	*Cov*	*SE*	z	*p*
Cognitive Reserve ↔ age	.06	0.92	1.19	0.77	.44
Cognitive Reserve ↔ Vascular Risk Factors	<.01	<0.01	0.16	0.02	.99
Cognitive Reserve ↔ gender	.14	0.14	0.08	1.82	.07
Cognitive Reserve ↔ Depression Diagnosis	-.14	-0.11	0.07	-1.70	.09
age ↔ Vascular Risk Factors	**.31**	**3.00**	**0.64**	**4.72**	**< .001**
gender ↔ Depression Diagnosis	-.06	-0.01	0.01	-0.98	.33
Vascular Risk Factor ↔ gender	.10	0.06	0.04	1.58	.11
age ↔ gender	.09	0.35	0.27	1.30	.19
age ↔ Depression Diagnosis	**-.29**	**-0.95**	**0.25**	**-3.78**	**< .001**
Vascular Risk Factor ↔ Depression Diagnosis	-.10	-0.05	0.03	-1.52	.13

Note. β = standardized beta coefficient, B = unstandardized beta coefficients, SE = Standard Error, z = z-value. Bolded values indicate statistical significance ($p < .05$).

Research Question #2: Model Comparison

Because of poor model fit, Hypothesis 2 (Model 2 will provide greater overall fit for our data compared to Model 1) is not supported. Fit statistics for Model 1 and Model 2 did not meet Hu and Bentler (1999) criteria for absolute, incremental, or parsimonious fit indices. Fit statistics for Model 2 were marginally better than Model 1 (i.e., lower chi-square statistic, SRMR, R-RMSEA, and higher R-CFI, and R-TLI), however, differences were not considerable (see Table 14).

Table 14

Fit Indices for Structural Models

Model	S-B Scaled χ^2	*df*	Moments	Parameters	SRMR	R-RMSEA	R-RMSEA (90% CI)	R-CFI	R-TLI
Model 1	621.61	196	276	80	.093	.098	(.089, .106)	.84	.79
Model 2	590.61	196	276	80	.093	.095	(.086, .103)	.85	.81

Note. S-B = Satorra-Bentler Correction, SRMR = Standardized Root Mean Square Residual, R-RMSEA = Robust Root Mean Square Error of Approximation, R-CFI = Robust Bentler's Comparative Fit Index, R-TLI = Robust Tucker-Lewis Index.

The AIC for Model 2 (28334.32) was lower than Model 1 (28359.89), indicating that Model 2 did a slightly better job at accounting for the data than Model 1. Differences are however marginal; thus, values should be interpreted with caution.

Parameter estimates for the measurement components of Models 1 and 2 were generally consistent with prior theory, with the exception of Practical Problem Solving and Conceptual Shifting which was shown to be a poor indicator of executive functioning in both models. Parameter estimates for the structural components of Models 1 and 2 were generally comparable, in terms of direct effects and covariances. Direct effects depicted in Model 1 and Model 2 were comparable in strength (i.e., standardized beta-coefficients), with the largest effects observed between i.) cognitive reserve and executive functioning, ii.) cognitive reserve/executive functioning and language skills, and iii.) cognitive reserve/executive functioning and visuospatial processing.

Research Question #3: Independent Effects of Cognitive Reserve Proxies on Cognitive Functioning

Prior to the relative weight analysis, a series of two-step hierarchical multiple regression analyses were performed to determine the degree to which *sociodemographic variables* (i.e., age, gender, total number of vascular risk factors, depression diagnosis) and *cognitive reserve proxies* (i.e., educational attainment, mental workplace demands, crystallized intelligence) account for

the variance in scores on composite measures of i.) verbal memory, ii.) visual memory, iii.) executive functioning, iv.) visuospatial processing, v.) language skills, and vi.) global cognitive status. Composite scores for all six cognitive domains were calculated by averaging converted z-scores on domain-specific tests of neuropsychological functioning. Beta-weights, standard errors, confidence intervals, goodness-of-fit measures, and correlation statistics for all six regression models are presented and discussed in greater detail below.

Multiple Regression Model 1: Effect of Cognitive Reserve Proxies on Verbal Memory

Predictors in this model accounted for a total of 16% of the variance in scores on the verbal memory composite (R^2 = .16, Adj R^2 = .14). Results from the first block analysis revealed that the included sociodemographic variables were statistically significant predictors (F(4, 227) = 5.6, p < .001) and accounted for approximately 9.0% of the variance in the scores on the verbal memory composite (R^2 = .09, Adj R^2 =.07; see Table 15). Results from the second block analysis revealed that addition of cognitive reserve proxies accounted for a statistically significant change in R^2, suggesting that the included cognitive reserve proxies predict scores on the verbal memory composite above and beyond the included sociodemographic variables (ΔR^2 = .07, F(3, 224) = 6.5, p < .001). Addition of educational attainment, mental workplace demands, and crystallized intelligence to the regression model accounted for an additional 7.3% of the variance in scores on the verbal memory composite.

The significant predictors in this model were age (B = -0.02, SE = 0.01, t(231) = -2.2, p = .03), gender (B = -0.50, SE = 0.12, t(231) = -4.3, p < .001), and scores on the WASI-I vocabulary subtest (B = .01, SE = 0.01, t(231) = 2.6, p = .009). Overall, increased age (r = -.17) and being male (r = -.26) were associated with worse performance on measures of verbal memory. Beta-weights indicate that every 1 – unit increase in age is associated with a reduction of

approximately 0.02 on the verbal memory composite, whereas being a male was associated with a reduction of 0.5 in z-score. Conversely, scoring higher on the WASI-I Vocabulary subtest—measure of crystallized intelligence—was associated with better performance on verbal memory measures (r = .22), whereby increase in one point on the WASI-I Vocabulary subtest was associated with an increase of 0.01 z-score on the verbal memory composite. Significance of these predictors are further demonstrated by their part and partial correlations (see Table 15), for which age, gender, and WASI-I Vocabulary scores uniquely account for 2%, 7%, and 3% of the total variation in the verbal memory composite, respectively.

Table 15

Hierarchical Regression Analysis: Predictive Relationship Between Cognitive Reserve Proxies and Verbal Memory

		95% Confidence Interval				Correlations for Predictor Variables				
Variable	*B*	LL	UL	*SE*	*β*	Zero-Order	Partial	Part	R^2	ΔR^2
Step 1									.09	.09*
(Constant)	1.41	0.28	2.55	0.58	-	-	-	-		
Age	-0.02	-0.03	-0.001	0.01	-.15	-.17	-.14	-.13		
Gender	-0.45	-0.68	-0.22	0.12	-.25	-.26	-.25	-.25		
Number of Vascular Risk Factors	0.02	-0.09	0.12	0.05	.02	-.05	.02	.02		
Depression Diagnosis	0.04	-0.26	0.33	0.15	.02	.07	.02	.02		
Step 2									.16	.07*
(Constant)	0.12	-1.18	1.42	0.66	-	-	-	-		
Age	-0.02	-0.03	-0.001	0.01	-.15	-.17	-.14	-.13		
Gender	-0.50	-0.72	-0.27	0.12	-.28	-.26	-.28	-.26		
Number of Vascular Risk Factors	0.02	-0.07	0.12	0.05	.03	-.05	.03	.03		
Depression Diagnosis	0.10	-0.18	0.39	0.15	.05	.07	.05	.04		
Education	0.04	<0.01	0.08	0.02	.14	.18	.12	.11		
Mental Workplace Demands	-0.02	-0.20	0.16	0.09	-.02	.02	-.02	-.01		
WASI-I Vocabulary	0.01	0.004	0.03	0.01	.19	.22	.17	.16		

Note. β = standardized beta coefficient, B = unstandardized beta coefficients, SE = standard error, LL = lower limit, UL = upper limit, WASI = Wechsler Abbreviated Scale of Intelligence. $N = 232$. * $p < .05$.

Multiple Regression Model 2: Effect of Cognitive Reserve Proxies on Visual Memory

Results from the first block analysis revealed that included sociodemographic variables were statistically significant predictors ($F(4, 227) = 6.2$, $p < .001$) and accounted for approximately 10.0 % of the variance in the scores on the visual memory composite ($R^2 = .10$, Adj $R^2 = .08$; see Table 16). Beyond age, gender, vascular risk factors, and depression diagnosis, scores on all three cognitive reserve proxies explained a total of 6.1% of total variance in scores on the visual memory composite ($R^2 = .06$, $F(3, 224) = 5.4$, $p = .001$; see Table 16). Performance

on the visual memory composite was significantly predicted by patients' age (B = -0.04, SE = 0.01, $t(231) = -4.5$, $p < .001$) and scores on the WASI-I Vocabulary subtest (B = .02, SE = 0.01, $t(231) = 3.4$, $p < .001$). Patients' age ($sr^2 = .08$) explained approximately double the amount of variance in scores on the visual memory composite compared to crystallized intelligence (sr^2 = .04), suggesting that in our sample age was more important than cognitive reserve in predicting visual memory performance. Together, all seven predictor variables (i.e., three cognitive reserve proxies, four covariates) explained a total of 16% of variances in scores on the visual memory composite ($R^2 = .16$, Adj $R^2 = .13$).

Table 16

Hierarchical Regression Analysis: Predictive Relationship Between Cognitive Reserve Proxies and Visual Memory

		95% Confidence Interval				Correlations for Predictor Variables				
Variable	*B*	LL	UL	*SE*	*β*	Zero-Order	Partial	Part	R^2	ΔR^2
Step 1									.10	.10*
(Constant)	2.44	1.23	3.65	0.62	-	-	-	-		
Age	-0.03	-0.05	-0.02	0.01	-.29	-.31	-.27	-.27		
Gender	0.08	-0.16	0.31	0.12	.04	.01	.04	.04		
Number of Vascular Risk Factors	0.003	-0.10	0.11	0.05	.004	-.09	.004	.004		
Depression Diagnosis	0.14	-0.17	0.44	0.16	.06	.14	.06	.06		
Step 2									.16	.06*
(Constant)	1.35	-0.01	2.72	0.69	-	-	-	-		
Age	-0.04	-0.05	-0.02	0.01	-.30	-.31	-.29	-.28		
Gender	0.05	-0.19	0.29	0.12	.03	.01	.03	.02		
Number of Vascular Risk Factors	0.01	-0.09	0.11	0.05	.02	-.09	.02	.01		
Depression Diagnosis	0.19	-0.11	0.48	0.15	.08	.14	.08	.08		
Education	0.01	-0.04	0.05	0.02	.02	.14	.02	.01		
Mental Workplace Demands	-0.003	-0.19	0.18	0.09	-.003	.05	-.002	-.002		
WASI-I Vocabulary	0.02	0.01	0.03	0.01	.24	.23	.22	.21		

Note. β = standardized beta coefficient, B = unstandardized beta coefficients, SE = standard error, LL = lower limit, UL = upper limit, WASI = Wechsler Abbreviated Scale of Intelligence. $N = 232$. * $p < .05$.

Multiple Regression Model 3: Effect of Cognitive Reserve Proxies on Executive Functioning

In contrast to what was found for verbal and visual memory, the included sociodemographic variables entered into the first block analysis did not explain a significant portion of variance in patients' scores on the executive functioning composite ($F(4, 227) = 0.91$, $p = .460$). Less than five percent of the variance in scores on the executive functioning composite was explained by age, gender, vascular risk factors, and depression diagnosis ($R^2 = .02$, Adj $R^2 = .000$). By comparison, the included cognitive reserve proxies explained approximately 36% of

the variance in executive functioning performance ($\Delta R^2 = .36$, $F(3, 224) = 43.7$, $p < .001$). Performance on the executive functioning composite was significantly predicted by both patients' age ($B = -0.01$, $SE = 0.01$, $t(231) = -2.1$, $p = .03$) and scores on the WASI-I Vocabulary subtest ($B = .03$, $SE = < .01$, $t(231) = 9.0$, $p < .001$; see Table 17). Patients' age uniquely accounted for 1% of variance in the executive functioning composite, whereas crystallized intelligence accounted for 22% of the variation. Collectively, the included sociodemographic variables and cognitive reserve proxies explained a total of 38% of variances in scores on the executive functioning composite ($R^2 = .38$, Adj $R^2 = .36$).

Table 17

Hierarchical Regression Analysis: Predictive Relationship Between Cognitive Reserve Proxies and Executive Functioning

Variable	*B*	95% Confidence Interval		*SE*	*β*	Correlations for Predictor Variables			R^2	ΔR^2
		LL	UL			Zero-Order	Partial	Part		
Step 1									.02	.02
(Constant)	0.74	-0.15	1.62	0.45	-	-	-	-		
Age	-0.01	-0.02	-0.005	0.01	-.11	-.10	-.10	-.10		
Gender	-0.002	-0.18	0.18	0.09	-.001	-.01	-.001	-.001		
Number of Vascular Risk Factors	-0.02	-0.10	0.05	0.04	-.04	-.07	-.04	-.04		
Depression Diagnosis	-0.11	-0.34	0.12	0.12	-.06	-.03	-.06	-.06		
Step 2									.38	.36*
(Constant)	-1.35	-2.19	-0.51	0.43	-	-	-	-		
Age	-0.01	-0.02	-0.001	0.01	-.12	-.10	-.14	-.11		
Gender	-0.07	-0.21	0.08	0.08	-.05	-.01	-.06	-.05		
Number of Vascular Risk Factors	-0.01	-0.07	0.05	0.03	-.02	-.07	-.02	-.02		
Depression Diagnosis	-0.02	-0.20	0.17	0.09	-.01	-.03	-.01	-.01		
Education	0.03	-0.003	0.05	0.01	.12	.38	.12	.09		
Mental Workplace Demands	-0.02	-0.12	0.11	0.06	-.002	.19	-.002	-.001		
WASI-I Vocabulary	0.03	0.02	0.04	0.003	.54	.59	.52	.47		

Note. β = standardized beta coefficient, B = unstandardized beta coefficients, SE = standard error, LL = lower limit, UL = upper limit, WASI = Wechsler Abbreviated Scale of Intelligence. $N = 232$. * $p < .05$. * $p < .05$.

Multiple Regression Model 4: Effect of Cognitive Reserve Proxies on Visuospatial Processing

Both the included sociodemographic variables ($R^2 = .05$, Adj $R^2 = .03$, $F(4, 219) = 2.8$, $p = .028$) and cognitive reserve proxies ($\Delta R^2 = .11$, $F(3, 216) = 9.1$, $p < .001$) explained a significant portion of variance in patients' scores on the visuospatial processing composite (see Table 18). Combined, all seven predictors accounted for approximately 16% of variance in scores on the visuospatial processing composite ($R^2 = .16$, Adj $R^2 = .13$). Performance on the visuospatial processing composite was significantly predicted by patients' age ($B = -0.02$, $SE =$

0.01, $t(223) = -3.3$, $p = .001$) and scores on the WASI-I Vocabulary subtest ($B = 0.02$, $SE = < .01$, $t(223) = 4.9$, $p < .001$). Of the significant predictors in this model, crystallized intelligence uniquely accounted for 10% of the variance in visuospatial processing, whereas age accounted for approximately 4%.

Table 18

Hierarchical Regression Analysis: Predictive Relationship Between Cognitive Reserve Proxies and Visuospatial Processing (Spatial Processing Composite on the KBNA)

		95% Confidence Interval				Correlations for Predictor Variables				
Variable	*B*	LL	UL	*SE*	*β*	Zero-Order	Partial	Part	R^2	ΔR^2
Step 1									.05	.05*
(Constant)	1.44	0.55	2.34	0.46	-	-	-	-		
Age	-0.02	-0.03	-0.01	0.01	-.20	-.19	-.19	-.18		
Gender	0.06	-0.11	0.24	0.09	.05	.03	.05	.05		
Number of Vascular Risk Factors	-0.04	-0.11	0.04	0.04	-.06	-.11	-.06	-.06		
Depression Diagnosis	-0.12	-0.35	0.10	0.11	-.08	-.01	-.07	-.07		
Step 2									.16	.11*
(Constant)	0.65	-0.36	1.66	0.51	-	-	-	-		
Age	-0.02	-0.03	-0.01	0.01	-.23	-.19	-.22	-.21		
Gender	0.05	-0.13	0.22	0.09	.04	.03	.04	.04		
Number of Vascular Risk Factors	-0.02	-0.09	0.05	0.04	-.04	-.11	-.04	-.03		
Depression Diagnosis	-0.09	-0.30	0.13	0.11	-.05	-.01	-.05	-.05		
Education	-0.004	-0.04	0.03	0.02	-.02	.12	-.02	-.02		
Mental Workplace Demands	-0.06	-0.20	0.07	0.07	-.07	.02	-.06	-.06		
WASI-I Vocabulary	0.02	0.01	0.03	0.004	.35	.31	.32	.31		

Note. β = standardized beta coefficient, B = unstandardized beta coefficients, SE = standard error, LL = lower limit, UL = upper limit, KBNA = Kaplan Baycrest Neurocognitive Battery, WASI = Wechsler Abbreviated Scale of Intelligence. $N = 224$. * $p < .05$.

Multiple Regression Model 5: Effect of Cognitive Reserve Proxies on Language Skills

Both sociodemographic variables ($\Delta R^2 = .06$, $F(4, 226) = 3.4$, $p = .011$) and cognitive reserve proxies ($\Delta R^2 = .38$, $F(3, 223) = 49.74$, $p < .001$) accounted for a significant portion of

variance in scores on the language skills composite (R^2 = .44, Adj R^2 = .42), however, cognitive reserve was shown to be a better predictor in the model, accounting for 38% of the total sample variance, compared to sociodemographic variables which accounted for only 6% of the variance. Similar to verbal memory, performance on the language skills composite was significantly predicted by patients' age (*B* = -0.02, *SE* = 0.01, *t*(230) = -3.3, *p* = .001), gender (*B* = -0.20, *SE* = 0.09, *t*(230) = -2.3, *p* = .021), and crystallized intelligence (*B* = .04, *SE* = < .01, *t*(230) = 10.3, *p* < .001; see Table 19). Being a female, scoring higher on the WASI-I Vocabulary subtest, and being younger were all associated with better performance on a composite measuring patient's oral language skills and abilities. Patients' age (sr^2 = .03) and gender (sr^2 = .01) accounted for approximately 4% of the variance in scores on the language composite, whereas crystallized intelligence uniquely accounted for over one third of the total variance (sr^2 = .36).

Table 19

Hierarchical Regression Analysis: Predictive Relationship Between Cognitive Reserve Proxies and Language Skills

		95% Confidence Interval				Correlations for Predictor Variables				
Variable	*B*	LL	UL	*SE*	*β*	Zero-Order	Partial	Part	R^2	ΔR^2
Step 1									.06	.06*
(Constant)	1.46	0.42	2.50	0.53	-	-	-	-		
Age	-0.02	-0.03	-0.003	0.01	-.17	-.18	-.15	-.15		
Gender	-0.13	-0.34	0.08	0.11	-.08	-.10	-.08	-.08		
Number of Vascular Risk Factors	-0.07	-0.17	0.02	0.05	-.11	-.16	-.10	-.10		
Depression Diagnosis	-0.18	-0.44	0.09	0.14	-.09	-.02	-.09	-.08		
Step 2									.44	.38*
(Constant)	-0.98	-1.95	-0.01	0.49	-	-	-	-		
Age	-0.02	-0.03	-0.01	0.01	-.18	-.18	-.22	-.17		
Gender	-0.20	-0.37	-0.03	0.09	-.12	-.10	-.15	-.12		
Number of Vascular Risk Factors	-0.06	-0.13	0.02	0.04	-.08	-.16	-.10	-.08		
Depression Diagnosis	-0.06	-0.27	0.15	0.11	-.03	-.02	-.04	-.03		
Education	0.02	-0.01	0.05	0.02	.07	.33	.08	.06		
Mental Workplace Demands	-0.05	-0.18	0.08	0.07	-.04	.11	-.05	-.04		
WASI-I Vocabulary	0.04	0.03	0.05	0.004	.60	.60	.57	.52		

Note. β = standardized beta coefficient, B = unstandardized beta coefficients, SE = standard error, LL = lower limit, UL = upper limit, WASI = Wechsler Abbreviated Scale of Intelligence. $N = 231$. * $p < .05$.

Multiple Regression Model 6: Effect of Cognitive Reserve Proxies on Global Cognitive Status

Like executive functioning, when combined, all four sociodemographic variables did not account for a significant portion of variance in scores on the global cognitive status composite ($F(4, 220) = 1.9$, $p = .113$; see Table 20). In contrast, the cognitive reserve proxies accounted for a significant portion of variance in our sample ($\Delta R^2 = .11$, $F(3, 217) = 9.0$, $p < .001$). Of the included sociodemographic variables, only gender was a significant predictor of performance on the global cognitive status composite ($B = -0.2$ $SE = 0.11$, $t(224) = -2.1$, $p = .040$), where in our

sample females on average performed better than males. Like the other five regression models, crystallized intelligence was the only significant cognitive reserve proxy to predict performance on the composite measure (B = .02, SE = 0.01, $t(224) = 4.3$, $p < .001$). Comparatively, crystallized intelligence (sr^2 = .07) accounted for a larger portion of variance than gender (sr^2 = .02). Together, all seven predictor variables explained a total of 14% of variances in scores on the global cognitive status composite (R^2 = .14, Adj R^2 = .11).

Table 20

Hierarchical Regression Analysis: Predictive Relationship Between Cognitive Reserve Proxies and Global Cognitive Status (Mini Mental Status Exam)

		95% Confidence Interval				Correlations for Predictor Variables				
Variable	*B*	LL	UL	*SE*	*β*	Zero-Order	Partial	Part	R^2	ΔR^2
Step 1									.03	.03
(Constant)	1.22	0.07	2.36	0.58	-	-	-	-		
Age	-0.01	-0.03	0.002	0.01	-.13	-.11	-.12	-.12		
Gender	-0.24	-0.46	-0.01	0.12	-.14	-.14	-.14	-.14		
Number of Vascular Risk Factors	0.03	-0.07	0.13	0.05	.04	-.01	.04	.04		
Depression Diagnosis	-0.12	-0.41	0.17	0.15	-.06	-.01	-.06	-.05		
Step 2									.14	.11*
(Constant)	0.14	-1.17	1.45	0.67	-	-	-	-		
Age	-0.01	-0.03	0.001	0.01	-.13	-.11	-.12	-.11		
Gender	-0.23	-0.46	-0.01	0.11	-.14	-.14	-.14	-.13		
Number of Vascular Risk Factors	0.05	-0.05	0.15	0.05	.07	-.01	.07	.07		
Depression Diagnosis	-0.07	-0.35	0.21	0.14	-.03	-.01	-.03	-.03		
Education	0.02	-0.02	0.06	0.02	.08	.15	.07	.06		
Mental Workplace Demands	-0.17	-0.34	0.01	0.09	-.14	-.05	-.13	-.12		
WASI-I Vocabulary	0.02	0.01	0.03	0.01	.31	.29	.28	.27		

Note. β = standardized beta coefficient, B = unstandardized beta coefficients, SE = standard error, LL = lower limit, UL = upper limit, WASI = Wechsler Abbreviated Scale of Intelligence, MMSE = Mini-Mental Status Exam. N = 225. * $p < .05$.

Relative Weight Analysis

Following each regression analysis, a follow-up relative weight analysis was performed to determine the relative contribution of each predictor variable in explaining our samples' variance across all six cognitive composites. Table 21 shows the raw relative weights and confidence intervals for each cognitive reserve proxy as predictors in all six regression models. Raw relative weights are often used as an estimate of effect size (Tonidandel & LeBreton, 2015), whereby the raw weight represents the proportion of variance in the criterion variable.

Table 21

Raw Relative Weights for Cognitive Reserve Proxies

	Verbal Memory	Visual Memory	Executive Functioning	Visuospatial Processing	Language Skills	Global Cognitive Status
	raw [BC-CI]	raw [BC-CI]	raw [BC-CI]	raw [BC-CI]	raw [BC-CI]	raw [BC-CI]
Crystallized Intelligence	.04 [.005, .097]	.05 [.011, .110]	.28 [.203, .365]	.10 [.033, .174]	.31 [.230, .404]	.08 [.029, .156]
Educational Attainment	.02 [.004, .060]	.01 [.001, .034]	.07 [.033, .109]	.01 [.001, .018]	.05 [.021, .103]	.02 [.004, .047]
Mental Workplace Demands	< .01 [.001, .005]	< .01 [.0003, .003]	.01 [.005, .037]	< .01 [.0003, .005]	.01 [.002, .015]	.01 [.002, .047]

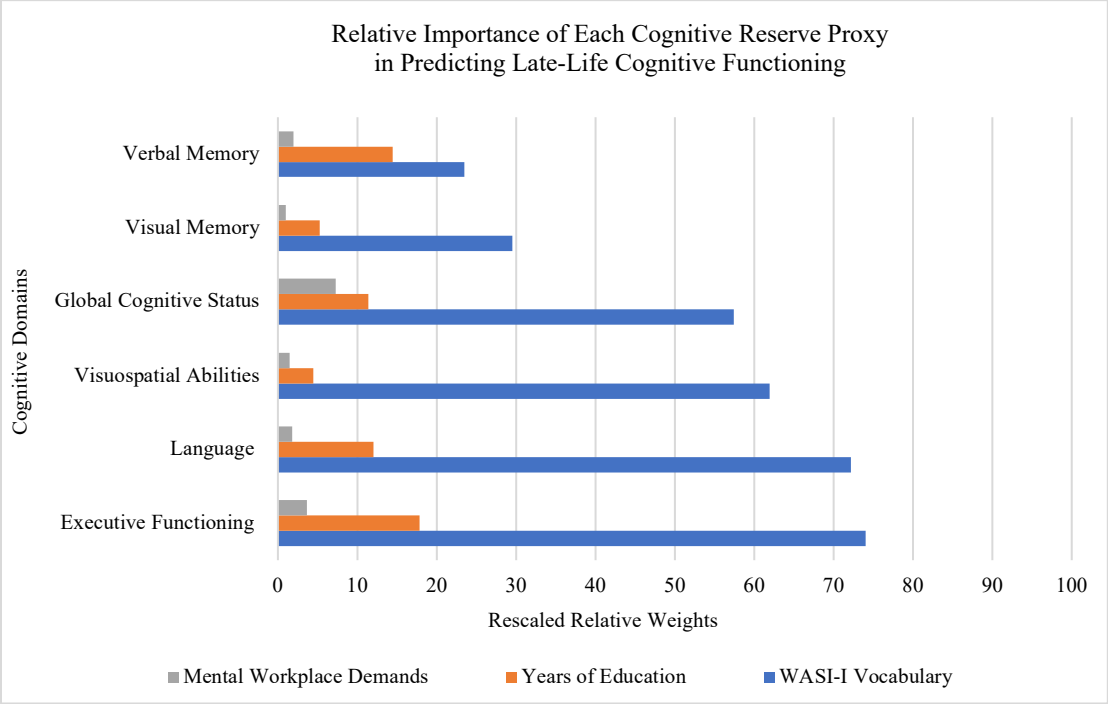
Note. BC-CI = Bias-Corrected Confidence Intervals. Crystallized intelligence was measured through patients' raw scores on the WASI-I Vocabulary subtest.

Rescaled relative weights represent how much the predicted variance in the criterion variable is explained by any one predictor variable. Values for this statistic can range from 0 to 100, with higher values reflecting greater amounts of contribution to the predicted variance. Rescaled relative weights for crystallized intelligence (i.e., scores on the WASI-I Vocabulary subtest) ranged from 23 for verbal memory to 74 for executive functioning. Put simply, this means crystallized intelligence explains 74% of the *predicted/explained* variance in scores on the executive functioning composite within our sample. Rescaled relative weights for educational attainment ranged from 4 for visuospatial processing to 18 for executive functioning. Rescaled

relative weights for mental workplace demands ranged from 1 for visual memory to 7 for global cognitive status. Of the three cognitive reserve proxies, crystallized intelligence was the most important in predicting neuropsychological performance across all six cognitive domains. Figure 5 depicts the rescaled relative weights for all three cognitive reserve proxies across all six regression models.

Figure 5

Rescaled Relative Weights for Cognitive Reserve Proxies



Note. Years of formal education represent patients' educational attainment and scores on the WASI-I Vocabulary subtest represent patients' level of crystallized intelligence.

Tests of statistical significance evaluated whether the relative weights for each cognitive reserve proxy differed significantly from a relative weight generated for a random variable, which was set to have a population variance of 0 (Tonidandel & LeBreton, 2015). None of the relative weights for the three cognitive reserve proxies were statistically significant in terms of predicting verbal memory or visual memory performance. Conversely, relative weights for

crystallized intelligence were found to be statistically significant in terms of predicting executive functioning, visuospatial processing, language skills, and global cognitive status. Similarly, relative weights for years of education (i.e., educational attainment) were statistically significant in predicting executive functioning, language skills, and global cognitive status. Relative weights for mental workplace demands were not statistically significant in any one of the six regression models, suggesting that the relative contribution of mental workplace demands in each predictive model was not significantly different than that of a randomly generated variable (Tonidandel & LeBreton, 2015).

CHAPTER 4

GENERAL DISCUSSION AND CONCLUSIONS

This thesis examined the relationship between cognitive reserve and neuropsychological performance of older adults without dementia by exploring the cumulative (i.e., combined) and independent (i.e., individual) effects of cognitive reserve proxies on different cognitive domains. Latent variable modelling techniques and multiple regression analyses were used to evaluate which cognitive domains are most impacted by cognitive reserve and which cognitive reserve proxy is the best predictor of late-life neuropsychological functioning. For the purposes of this study, cognitive reserve was operationalized in terms of three separate proxy indicators: educational attainment, mental workplace demands, and crystallized intelligence.

In general, latent variable modelling techniques proved to be an insufficient method of addressing my research questions given limitations within the data and constructed models (i.e., poor model fit). Therefore, findings from this study reflect a combination of results obtained from my limited, yet cautious, interpretation of parameter estimates from SEM analyses and supplemental regression analyses.

Overall, findings from the current study confirmed that individuals with higher levels of cognitive reserve demonstrate better performance on tests of global cognition, as well as specific cognitive domains including verbal memory, visual memory, executive functioning, language, and visuospatial processing. Performance on tests of executive functioning and language skills were shown to be the most closely related to cognitive reserve. Exploratory analyses showed that out of the three cognitive reserve proxies included in the analyses, vocabulary score was the most important in terms of predicting late-life neuropsychological functioning, followed by educational attainment, and mental workplace demands, supporting the overall robustness of

crystallized intelligence as an indicator of cognitive reserve. Together, these findings suggest that (1) cognitive reserve does not benefit all areas of cognitive functioning equally, (2) tasks that require higher levels of cognitive processing are the most influenced by cognitive reserve, and (3) the relationships between cognitive reserve and late-life cognitive functioning depend largely on the proxy used to operationalize reserve.

Structural Equation Modelling: Reasons for Poor Model Fit

Before I discuss the above findings in more detail, it is important to first explore possible reasons for poor fit of the hypothesized models, as the proposed SEM analyses were central to the current study.

In this thesis, I sought to examine the mechanisms in which cognitive reserve influences older adults' neuropsychological performance using structural equation modelling. To test the organizational effects of cognitive reserve on neuropsychological functioning, I constructed two separate structural models. The first model tested the generalized effects of cognitive reserve on neuropsychological performance, whereas the second model tested the hierarchical effects of cognitive reserve, where direct effects on executive functioning and indirect effects on all other cognitive domains were hypothesized. Recent research has suggested that cognitive reserve may only benefit some areas of cognition over others (Lavrencic et al., 2016; Lavrencic et al., 2018a; Zamarian et al., 2021); therefore, it was hypothesized that the second model would provide greater fit than the first model. Findings from the SEM analyses revealed that both of the proposed models provided comparable, yet unacceptable fit for our data. Because of this, interpretation of the organizational effects of cognitive reserve on neuropsychological performance is limited and my hypothesis proposing that Model 2 would provide better fit than Model 1 could not be appropriately tested.

The difficulty finding a model with acceptable fit stands in contrast to previous studies that have used SEM to evaluate the effects of cognitive reserve on cognitive functioning and reported good to acceptable fit for their models in similar samples (Delgado-Losada et al., 2019; Feldberg et al., 2021; Giogkaraki et al., 2013; Lojo-Seoane et al., 2014; Mitchell et al., 2012). For example, Lojo-Seoane et al. (2014) found acceptable fit for their proposed model, which tested the direct and indirect effects of cognitive reserve on late-life cognitive functioning in a sample of 326 older adults with subjective memory complaints. It should be noted, however, that the model tested in Lojo-Seoane et al. (2014) study was less complex than the ones tested in the current study (i.e., 19 observed variables versus 23 observed variables; 49 parameters estimated versus 80 parameters estimated), and also the sample size was larger (i.e., 326 versus 229).

Other studies have reported good model fit with a smaller sample size; however, models are much less complex, involving fewer variables and parameters (e.g., Delgado-Losada et al., 2019; Feldberg et al., 2021). Additionally, it should be noted that few studies to date have examined the latent relationships between cognitive reserve and late-life neuropsychological functioning using SEM; therefore, an additional possibility is that results published in the literature are representative of a publication bias, as studies that report poor fit and non-significant findings are less likely to be published (Fanelli, 2011). Alternatively, studies may have been completely abandoned after finding poor fit or revisited after adjusting previously hypothesized models.

Poor model fit is often attributable to underlying problems associated with the measurement and/or structural components of the tested models. In contrast to previous research, the data used in this study's analysis was severely skewed and contained a relatively low number of cases needed based on the complexity of my models. This is likely a reflection of the tests

used in the study as well as the decision to use data that was derived from a sample of older adults seen in a clinical setting. Neuropsychological tests are often designed to detect impairments in a specific cognitive domain. Because of this, many of the tests administered during an evaluation demonstrate a non-normal distribution, where individuals with true impairment score low on the test, whereas others score closer to the ceiling (Lezak et al., 2012). This is particularly relevant to the present study, as many of the measures that were used in the planned analyses (e.g., Practical Problem Solving/Conceptual Shifting, Mini-Mental Status Exam) exhibit these skewed distributions, as they were designed to detect dementia (Strauss et al., 2006). Further, many of the tests are designed to be administered quickly and thus, may exhibit ceiling effects in a population without significant cognitive impairment. Tests like the Trail Making Test also have non-normal distributions (i.e., truncated floor) because of limits of the human cognitive capacity and characteristics of the test (Lezak et al., 2012). In clinical practice, these tests often exhibit large standard deviations that are inflated by few poor performers (Lezak et al., 2012).

Practically speaking, violations to multivariate normality and use of a relatively smaller sample size compared to other SEM research (e.g., Giogkaraki et al., 2013; Lojo-Seoane et al., 2014; Mitchell et al., 2012) introduced the presence of negative variances and collinearity problems, which required correction by modifying both models, likely impacting model fit (Farooq, 2016). Exclusion of certain variables reduced the amount of information available for several factors in the measurement model (e.g., visuospatial processing), which inadvertently restricted us from adding additional paths that may have improved model fit. Model fit may have also been impacted by the inclusion of univariate outliers in the analyses. Including patients diagnosed with MCI in this study's analyses likely increased the frequency of univariate outliers

found in the dataset, as individuals with MCI often exhibit specific impairments in one or a few domains, while presenting with otherwise normal cognitive ability in other domains (Petersen, 2004). Use of robust estimation procedures will have likely helped correct for some of their influence on the obtained parameter estimates; however, research has shown that inclusion of outliers can lead to poor fit (Yuan & Zhong, 2013). With a larger sample, we would have greater control over the exclusion of univariate outliers and model estimation procedures that are better suited for the data. Weighted least squares estimation procedures, such as Diagonally Weighted Least Squares and Weighted Least Squares Multivariate are robust to violations to multivariate normality and better suited for dealing data with data that is both continuous and categorical (Li, 2021). Future work would benefit from a larger sample that is able to use these procedures.

Because of the presence of negative variance estimates and missing data, several variables were removed from my original models. This led to the inclusion of single indicator latent variables. From a measurement perspective, it is generally unadvisable to define latent variables with fewer than three indicator variables, as it could impact the reliability of parameter estimates and fit statistics because the error variance for the observed variable must be fixed in order for the latent factor to be identified. Furthermore, few post-hoc modifications can be made for single indicator latent variables, given to their lack of information available. This limitation was particularly relevant to my models, as fit for the measurement portion of my models will have likely improved through the addition of certain paths associated with the included single indicator latent variables. For example, correlating the error terms between Complex Figure 1 Copy and Clocks and Complex Figure 1 would have likely improved model fit, as Complex Figure 1 involves drawing the same figure as the one shown in the Copy/Clocks trail. Adding this error correlation would have, however, led to identification problems, given the restricted

amount of information available for the single indicator visuospatial processing latent factor. Few studies have tested models with fewer than three indicator variables per latent factor (e.g., Delgado-Losada et al., 2019; Mitchell et al., 2012) and none to my knowledge have used single-indicator latent variables. Differences in how latent variables were specified in this study versus previous research may in part explain why the obtained model fit statistics are poor in comparison to other studies that have tested similar relationships.

Poor factor construction may have also contributed to issues with fit. For example, Practical Problem Solving/Conceptual Shifting and Digit Span were shown to have large residual variances, suggesting that my specified model was not explaining a large portion of their variance. Further, Practical Problem Solving/Conceptual Shifting loaded poorly on the executive functioning factor relative to other variables in the model, suggesting that performance on this test may measure different aspects of executive functioning (e.g., semantic memory, cognitive flexibility), not captured by the other four indicator variables included in the model. This is further supported by the weak correlations found between Practical Problem Solving/Conceptual Shifting and other executive functioning variables, such as Digit Span. Problems at the measurement level may therefore explain why my revised models offered poor fit for the data.

Beyond poor factor construction, evidence of poor model fit is also likely associated with underlying issues with my revised measurement model and decision to treat latent endogenous variables (i.e., cognitive domain latent variables) as non-correlated factors. Previous studies that have reported good model fit commonly included covariances between latent factors in their hypothesized models, notably between attention and memory (Mitchell et al., 2012), language and executive functioning (Feldberg et al., 2021), and language and memory (Feldberg et al., 2021). Since a primary goal of this thesis was to model the differential effects of cognitive

reserve on late-life cognitive functioning, I decided to exclude all latent variable covariances in my models.

Other reasons for poor fit may include the decision to avoid correlating error terms in my models. For both Model 1 and Model 2, the requested modification indices indicated that model fit would significantly improve if I were to correlate error terms for educational attainment and mental workplace demands and Phonemic Fluency and Semantic Fluency. While adding these paths would have marginally improved model fit, adjusting models post-hoc to include error correlations is generally cautioned against in SEM analyses, especially if the justification is not defensible by either prior or existing theory. Researchers have shown that oftentimes, adding error correlations can compromise validity of findings (Hermida, 2015) and bias the parameter estimates for the measurement and structural portion of a model (Hermida, 2015; Tomarken & Waller, 2003). Further, evidence of high error covariance is oftentimes due to sampling error, thus, adding error correlations post-hoc will better fit the model to the data but in turn will decrease broader generalizability in the population of interest (Hermida, 2015).

Summary of Main Findings and Implications

Despite the observed poor model fit, several conclusions can be made from this study, with implications for the relevant literature and broader clinical practice. A total of three main findings emerged from the analyses. The first two findings relate to my first research question (Does cognitive reserve produce differential effects across the neuropsychological profiles of older adults in our sample?), whereas the third finding relates to my third research question (Are certain domains of cognitive functioning differentially affected by the three proxies of cognitive reserve—education, occupational complexity, verbal intelligence?). In the following sections, I will discuss how the obtained results align with existing research and provide possible

explanations for the findings. Limitations in the study's design and planned analysis will be discussed in greater detail at the end of this chapter, along with future directions and final conclusions.

As discussed in the preceding sections, obtaining poor model fit for both of my hypothesized models prevented us from sufficiently testing our second research question (Are the effects of cognitive reserve generalized across cognitive domains or hierarchically organized?). Because of this, I do not discuss in detail the main findings related to my second research question, as the existing analyses were inadequate in testing my proposed hypotheses.

Main Finding #1: Cognitive Reserve is Positively Associated with Older Adults' Global Cognition

The first aim of this thesis sought to examine whether cognitive reserve produces differential effects on the neuropsychological profiles of older adults. To address this aim, parameter estimates obtained from both structural models and regression analyses were evaluated to examine the effects of cognitive reserve on older adults' neuropsychological performance. Parameter estimates obtained from Model 1 confirmed that cognitive reserve significantly predicted patients' performance on a measure of global cognitive status, whereby higher levels of cognitive reserve was associated with greater performance[4]. This finding supports my first hypothesis, predicting that individuals with higher levels of cognitive reserve would perform better on tests of global cognitive status. Previous studies have demonstrated the same effect with composite measures of cognitive reserve (Narbutas et al., 2019; Soldan et al.,

[4] Although poor model fit tempers possible conclusions based on these parameter estimates, I ran a supplemental multiple regression analysis using a cognitive reserve composite score with averaged z-scores for all proxies as the predictor. Results indicated that scoring higher on the cognitive reserve composite was associated with greater performance on the global cognitive status measure ($r = .17$, $p = .01$), supporting these conclusions based on Model 1 parameter estimates.

2017; Soldan et al., 2020; Opdebeeck et al., 2015; Gonzales, 2012, Then et al., 2014), and separately with individual proxies (Berezuk et al., 2021; Opdebeeck et al., 2016). As this has primarily been demonstrated amongst cognitively normal older adults (Lee at al., 2020; Lojo-Seoane et al., 2014), findings from this study extend this effect to a sample of older adults who range from cognitively normal to mildly impaired.

Main Finding #2: Cognitive Reserve Does Not Benefit All Areas of Cognitive Functioning Equally

Perhaps the most salient finding from this study's analyses relates to the observed relationship between cognitive reserve and higher-order cognitive abilities. Of the five cognitive domains assessed, cognitive reserve was shown to have the strongest influence on executive functioning and language, followed by visuospatial processing, visual memory, and verbal memory. Similar findings have been reported by Giogkaraki et al. (2013) and Feldberg et al. (2021), whereby cognitive reserve showed strongest effects on executive functions and weakest effects on memory. Presumably, these findings support my hypothesis predicting that cognitive reserve will differentially affect the neuropsychological profiles of older adults, as the relative importance of cognitive reserve proxies in predicting neuropsychological performance differed considerably across domains.

Moreover, within our sample, cognitive reserve accounted for over 80% of the explainable variance in performance on composite measures of executive functioning and language skills, suggesting that underlying differences in cognitive reserve are important in predicting higher-order cognitive abilities, above and beyond age and other variables known to contribute to cognition, such as gender, depression diagnosis, and vascular risk factors. Other studies have demonstrated similar effects, showing that cognitive reserve produces differential

effects on the neuropsychological profiles of older adults, disproportionately influencing higher-order abilities, such as verbal initiation, working memory, and attention (Lavrencic et al., 2016; Lavrencic et al., 2018a; Zamarian et al., 2021).

Participation in activities that promote cognitive reserve throughout the lifespan often involve the repeated use of several executive functions, including inhibition and working memory (Lövdén et al., 2010; Lövdén et al., 2020). For instance, participating in formal and informal educational experiences may provide greater opportunities to strengthen executive abilities throughout adulthood. Continual practice of these skills may explain why individuals with higher levels of cognitive reserve perform better on tests of executive functioning. Continued use of executive skills throughout adulthood may strengthen existing neural networks associated with executive functioning. Further, rather than solely impacting executive functioning through repeated cognitive stimulation, higher levels of cognitive reserve may also indirectly impact executive functioning by increasing one's opportunity to experiences that are associated with better physical health, which is closely related to executive functioning (e.g., Allan et al., 2016; Colcombe et al., 2004). Research has shown that individuals with who have sought out greater amounts of formal and informal educational experiences often work in complex occupations (Hagmann-von Arx et al., 2016) and lead healthier lives (Borgeest et al., 2020), as they have greater access to social (e.g., living in a higher SES neighborhood) and economic resources (e.g., ability to afford nutritious foods), due to their increased status and income (Adelmann, 1987; Rawal et al., 2020; Wolfson et al., 2019; Zimmerman & Woolf, 2014).

From a neural perspective, greater performance on tests of executive functioning among individuals with high levels of cognitive reserve may also reflect differential recruitment of the

prefrontal cortex (Davis et al., 2008; Stern et al., 2019). Pursuing higher levels of education, working in a complex occupation, and acquiring new knowledge through informal and formal educational experiences may each contribute to increased neural efficiency and compensation, leading to the more readied use of alternate networks and compensatory neural activity (Park & Reuter-Lorenz, 2009; Stern, 2009; Stern et al., 2019). Functionally, the prefrontal cortex serves as an important structure within the brains of highly functioning older adults, as it is involved in many well-documented compensatory processes (e.g., overactivation of the prefrontal cortex [Cabeza et al., 2002; Davis et al., 2008], greater between-network connectivity of frontal parietal control network and other large-scale brain networks [Grady et al., 2016]) and is thought to be among of the most flexible/adaptable regions within the aging brain (Park & Reuter-Lorenz, 2009). Prefrontal regions are associated with several executive functions (Diamond, 2013), therefore, the same mechanisms said to underly the association between increased cognitive performance and differential recruitment of the prefrontal cortex in older adults (Davis et al., 2008; Grady et al., 2016) may also explain the close relationship between cognitive reserve and executive functioning, as individuals with higher levels of reserve are believed to be more efficient at recruiting compensatory processes in the face of increased task demands (Stern et al., 2009; Stern et al., 2019).

Language skills, like executive functioning, were also found to be closely related to cognitive reserve in our sample. Of the three cognitive reserve proxies included in the proposed models, crystallized intelligence demonstrated the strongest loading onto the cognitive reserve factor, suggesting that in our sample, cognitive reserve was primarily defined by older adults' performance on the WASI-I Vocabulary subtest. Based on this, the close relationship observed between cognitive reserve and language abilities may be due to how cognitive reserve was

defined in this study, as one would expect that performance on a vocabulary test would strongly predict performance on other language-based measures. An additional explanation for these findings relates to the specific tests and type of language processes measured in this study. Two of the three tests that comprised the language skills factor (i.e., Phonemic Fluency and Semantic Fluency) rely on the use of several executive functions in addition to oral language ability; like many other neuropsychological tests, these measures are not process-pure. Therefore, it is possible that the strong association with cognitive reserve is partially accounted for by the close relationship between cognitive reserve and executive function. Previous studies have supported this idea, suggesting that the influence of cognitive reserve on language functioning may be top-down in nature, where higher order language abilities are more strongly influenced by cognitive reserve than lower-level language abilities (Delgado-Losada et al., 2019; Feldberg et al., 2021). Compared to more basic language tasks, verbal fluency measures are less susceptible to ceiling and floor effects (Hamberger et al., 2022), thus, differences in performance on more complex language-based tasks may be more reflective of underlying differences in cognitive reserve, as reserve promoting factors are less likely to impact performance on basic language tests with lower task demands.

Across all cognitive domains, cognitive reserve was weakest in predicting older adults' verbal and visual memory ability. This suggests that the accumulation of reserve-promoting life experiences has relatively less effect on older adults' ability to encode, consolidate, retrieve, and recognize visual and verbal information. This result is similar to previous findings (Lojo-Seoane et al., 2014; Mitchell et al., 2012). Because our sample contained older adults diagnosed with MCI, it is possible that the weak effects demonstrate that cognitive reserve is not particularly influential in explaining inter-individual differences in memory once performance reaches a

certain stage of impairment. Some researchers have proposed that the relationship between cognitive reserve and memory is weak amongst individuals with MCI because episodic memory impairments are typically the first clinical signs of preclinical dementia (Lojo-Seoane et al., 2014).

Main Finding #3: Crystallized Intelligence is a Robust Proxy of Cognitive Reserve

The final aim of this thesis sought to examine the independent relationships between each of the three cognitive reserve proxies and older adults' neuropsychological performance. To test the importance of each cognitive reserve proxy in predicting late-life cognitive functioning, a series of hierarchical regression models and relative weight analyses were performed with composite measures of verbal memory, visual memory, executive functioning, visuospatial processing, and language ability.

Of the three cognitive proxies included in this study's analyses, crystallized intelligence was the only cognitive reserve proxy to significantly predict neuropsychological functioning after controlling for age, gender, total number of vascular risk factors, and depression diagnosis. Neither educational attainment nor mental workplace demands were statistically significant predictors of performance on any of the cognitive domain composites in our sample. Generally, this finding has been supported in other research, which has shown that crystallized intelligence is a particularly strong indicator of cognitive reserve, demonstrating more robust effects on cognition compared to both other single proxy indicators and composite measures of reserve (Boyle et al., 2021). In theory, crystallized intelligence is a more accurate estimate of one's academic achievement (Williams et al., 2008), as it reflects quality of education and lifetime exposure to cognitively stimulating activities (Boyle et al., 2021). In contrast, educational attainment only reflects exposure to cognitively stimulating activities throughout childhood and

young adulthood. For these reasons, some researchers have proposed that educational attainment may be a static proxy of cognitive reserve, while crystallized intelligence is a dynamic proxy of cognitive reserve (Boyle et al., 2021; Malek-Ahmadi et al., 2017). Comparatively, dynamic proxies have been shown to be more predictive of cognitive performance than static proxies when older adults possess Alzheimer's disease neuropathology (Malek-Ahmadi et al., 2017).

An alternate explanation for these findings is that crystallized intelligence showed the strongest relationships with cognitive functioning because it was the only cognitive reserve proxy measured through performance on a neuropsychological test. This rival hypothesis represents an ongoing issue in this line of research, as relationships involving performance-based measures of cognitive reserve (e.g., vocabulary test) are more susceptible to a third variable problem compared to demographic-based measures of cognitive reserve (e.g., years of formal education), as cognitive tests are generally intercorrelated and affected by shared factors, such as effort, fatigue, attention, and sensory issues (e.g., Leach et al., 2000; Wechsler, 1999); thus, it is difficult to determine whether observed relationships between performance-based measures of cognitive reserve and cognitive functioning are based on variance shared between the constructs themselves or if the relationship represents shared variance that is inherent to the tests being correlated.

Failure to find significant effects for educational attainment in the current analysis may be due to the inclusion of crystallized intelligence in my model, as crystallized intelligence is thought to reflect both formal and informal educational experiences (Boyle et al., 2021; Cattell, 1971), whereas educational attainment simply reflects years spent in formal education. This is supported by results from this study's correlational analysis which showed that, in isolation, educational attainment was positively related to older adults' performance on most tests of verbal

memory, visual memory, language skills, and executive functioning. Broadly speaking, these findings are consistent with previous research (Berezuk et al., 2021; Lavrencic et al., 2018a; Opdebeeck et al., 2016; Zamarian et al., 2021).

Mental workplace demands, on the other hand, did not show as robust correlations to cognitive performance, as crystallized intelligence or educational attainment. Of the 16 neuropsychological tests included in this study, mental workplace demands was only significantly related to performance on two tests of executive functioning and one test of naming ability. Correlations were positive, yet weak in strength. Failure to find robust effects for mental workplace demands in this study is likely due to our small sample size and limited variability in the complexity scores for our sample. Previous studies that have found significant findings had sample sizes ranging from over 900 older adults (Zülke et al., 2021) to over 7000 (Pool et al., 2016). Few patients in our sample held occupations at the tail end of the distribution, meaning most of our sample reported working in moderately complex occupations. Relationships between occupational complexity and late-life cognitive functioning, may therefore, be driven by associations at either end of the distribution.

Lack of significant findings may also indicate that by itself, mental workplace demands are not a strong contributor to cognitive reserve. Like educational attainment, mental workplace demands are thought to be a static indicator of cognitive reserve, as they reflect exposure to cognitively stimulating activities throughout young and middle adulthood, and thus, do not reflect exposure to cognitively stimulating activities past retirement (Malek-Ahmadi et al., 2017). Additionally, unaccounted for interactions between certain workplace variables, such as job control, attitudes towards work, and exposure to physical hazards (e.g., hazardous conditions, environmental conditions), may contribute to whether participation in complex work benefits

late-life cognitive functioning (Andel et al., 2011; Grzywacz et al., 2016; Hussenoeder et al., 2019). For example, if someone who works in a high complexity job perceives their work as stressful, feels as though they have little job control, and holds negative attitudes towards their work, it is possible that mechanisms explaining the relationship between higher complexity and greater cognitive ability are attenuated by these negative factors (Hussenoeder et al., 2019). Neural dysfunction caused by chronic occupational stress may counteract the positive effects of cognitively complex work by reducing overall neural efficiency (Desiderato, 1964; Duan et al., 2015; Stern, 2009). Previous research has supported this, showing that chronic stress and low levels of job control are associated with worse late-life cognitive performance (Andel et al., 2011; Lavretsky & Newhouse, 2012), suggesting that it may be important to consider these factors when evaluating the relationship between occupation and neuropsychological performance.

Together, findings from the final aim of this study offer implications with regards to neuropsychological assessment of older adults. Particularly, findings related to the utility of crystallized intelligence as a proxy of cognitive reserve provide researchers and clinicians with a relatively parsimonious approach to estimating reserve, particularly when other demographically-relevant information is not available (e.g., leisure participation in cognitively stimulating activities).

For a neuropsychological evaluation to be valid and meaningful to the consumer, appropriate comparison of one's scores to a representative normative group must be completed. For decades, neuropsychologists have primarily adjusted scores based on age, education, and gender (e.g., Heaton et al., 2004). Findings from this study support the idea that demographically-adjusted test scores in older adult populations should incorporate not only age,

gender, and education, but also crystallized intelligence (Rentz et al., 2004), by tying in the concept of cognitive reserve. Developing normative data that stratifies based on cognitive reserve level may be particularly informative in detecting underlying neuropathology in older adults, as it would allow for the comparison of expected performance of individuals with high and low levels of reserve. For example, if an individual with high levels of reserve performs well below expectation on tests of executive functioning this may indicate their underlying neuropathology is likely advanced, as performance on these tests are more sensitive to differences in cognitive reserve. While some normative studies provide WAIS IQ-adjusted scores for diverse populations (e.g., Ivnik et al., 1990; Ivnik et al., 1992; Ivnik et al., 1996; Lucas et al., 2005), it may be worth exploring the use of premorbid IQ adjusted scores in older adult populations as well.

Limitations

Perhaps the most outstanding weakness of this research is a failure to test my a priori models. Limitations in the data required modifying the hypothesized structural models to ensure SEM analyses could be conducted and both of my proposed models were rejected due to poor fit. Parameter estimates obtained from poor fitting models are not as stable as those obtained from accepted models, therefore, observed estimates are limited in interpretability as they may not accurately reflect relationships within the data due to poor fit.

Other methodological limitations that impact overall interpretability of this study's findings is the decision to define cognitive reserve as a reflexive latent variable. While I initially sought to test formative models by defining cognitive reserve as formative variable, a warning message indicated that the produced information matrix was not positive definite, which indicated that results generated from these analyses were not reliable. The research team

attempted to diagnose the issue; however, we were unsuccessful in reaching a solution, thus we decided to proceed with defining cognitive reserve as a reflexive variable. A potential criticism of this decision is that rather than depicting the direct effects of cognitive reserve on the cognitive profiles of older adults, the proposed models may instead reflect that cognitive reserve is defined by differences in performance across cognitive domains. In other words, this would infer that instead of testing a structural model, the study's analyses rather tested the factor structure of cognitive reserve.

This challenge parallels a criticism that cognitive reserve is not a distinct enough construct from cognitive ability and that processing speed and working memory ability were proxies of cognitive reserve (Bennett et al., 2006). Later research supported this theory, challenging the discriminant validity of cognitive reserve, as it was shown that several indicators of cognitive reserve were also significant indicators of executive functioning, suggesting that cognitive reserve and executive functioning were one in the same construct (Siedlecki et al., 2009). Findings from these studies were later challenged by Mitchell et al. (2012) who found that cognitive reserve, as defined as a reflexive latent variable, was distinct enough from other domains of cognitive functioning, such as processing speed and executive functioning, such that evidence for discriminant validity was provided. Since then, several studies have tested models where cognitive reserve was defined as a reflexive variable and found good model fit (e.g., Feldberg et al., 2021; Hannigan, 2015), supporting many of the regression-based findings that have been reported in the literature (e.g., Berezuk et al., 2021; Boyle et al., 2021; Opdebeeck et al., 2016).

Regression analyses infer directionality, therefore, evidence of cognitive reserve being a significant predictor of late-life cognitive functioning, above and beyond other variables,

suggests that performance is due to differences in the predictor variable, rather than an indicator of the outcome variable. Nonetheless, one may still argue that cognitive reserve and cognitive functioning are not distinct constructs given previous findings (e.g., Bennett et al., 2006, Siedlecki et al., 2009). Thus, findings from this study's SEM analyses should be interpreted with the consideration that rather than producing effects on executive functioning, cognitive reserve may instead be defined by differences in higher-order abilities.

A third limitation of this study concerns the use of expectation maximization procedures as an imputation method. Significant violations to multivariate normality were observed within the data, thus, overall precision of the imputed data may have been adversely impacted, as the estimation procedure assumes that the data is normally distributed. Bias in the imputed data may have impacted model and parameter estimates, therefore, both statistics should be interpreted with caution. Full information maximization imputation methods would have likely been more precise, however, due to limitations within the data, these procedures could not be performed reliably.

A fourth limitation in this study research relates to our sample. Race and ethnic background data were not available for patients; thus, I was unable to make informed conclusions regarding generalizability of the discussed findings. Lack of ethnic and cultural diversity within a sample can limit overall generalizability and validity of findings. For example, scores on the WASI Vocabulary subtest may not be an accurate reflection of crystallized intelligence in ethnically diverse populations where English is not their primary language (e.g., Razani et al., 2007), as the WASI and WAIS have been validated in only a handful of other languages (e.g., Spanish, French, Dutch), and, to my knowledge, all tests in this sample were administered in English.

Lastly, this study's analyses are based on cross-sectional data, and thus, do not provide any information about the impact of cognitive reserve over time. Because of this, I was unable to examine the impact of cognitive reserve on the cognitive trajectories of older adults. Without longitudinal data, conclusions regarding prognosis (e.g., probability of converting from normal cognitive aging or MCI to dementia) and intervention development are limited. For researchers to accurately assess the overall impact of cognitive reserve on late-life cognitive functioning, longitudinal studies would have to follow individuals starting in childhood to capture the influence of all reserve-promoting activities. Another limitation of cross-sectional data is that it does not allow for the testing of cause-and-effect relationships. To test for these effects, an experimental design would need to be employed, ideally, where older adults' cognitive efficiency (as measured through a functional MRI paradigm) and neuropsychological performance are assessed before and after being assigned to an experimental condition, which includes participation in activities that are hypothesized promote cognitive reserve (e.g., regular engagement in intellectually-stimulating activities). These design-related limitations impact the clinical applicability of the present findings, as it is not possible to accurately deduce whether cognitive reserve is fixed or modifiable. In other words, without longitudinal data we are unable to directly test whether individuals with premorbid higher levels of cognitive reserve tend to choose activities thought to promote reserve or whether participation in certain activities contributes to the development of reserve and in-turn promote cognitive resilience. Moreover, it is unclear based on this study's analyses whether participation in reserve-promoting activities benefit those with lower premorbid levels of reserve or whether individuals with higher levels of reserve are likely to also benefit from participation in such activities. This is an important factor to consider when developing interventions aimed at promoting reserve.

Additionally, use of archival data limited the number and type of measures included in the current research. Because of limited demographic information, I was unable to examine the influence of other dynamic cognitive reserve proxies, like levels of participation in cognitively stimulating activities. Latent cognitive performance variables were also constructed within the constraints of data that was available. Ideally, the proposed models would have included at least three indicators per latent variable; however, I was limited to the test data that was available, some of which demonstrated disproportionate use across the sample (e.g., Similarities, Spatial Location). Prospective research would have also allowed for greater control over missing data and standardization of test administration procedures. Testing is generally quite standardized in a clinical setting; however, it is unclear based on data alone whether certain patients received accommodated assessments or if they required breaks in the standardization, both of which can impact on older adults' performance on neuropsychological tests.

Future Directions

Future studies should focus on re-testing the hypothesized models in a larger sample to evaluate whether poor fit observed in this study was due to poor model design or insufficient power. Larger sample sizes will allow for the use of alternate estimation procedures which are more resistant to violations to multivariate normality, leading to more accurate estimates of model fit and parameters. Analysis with a larger sample would permit testing of both models separately in cognitively normal older adults and patients with MCI to determine whether direct effects of cognitive reserve differ across diagnostic group. Such analyses were not performed with the current dataset, as obtained results would have been significantly underpowered based on sample size for each group (MacCallum et al., 1996).

Since mental workplace demands were not shown to be a significant predictor of neuropsychological performance in our sample, future studies should consider coding social workplace demands in addition to mental workplace demands to evaluate whether combined complexity scores are more closely related to late-life cognitive ability. O*NET has occupational information for 16 different variables that measure social workplace demands (Tsacoumis & Willison, 2010). The 16 variables are categorized into three groups i.) *administering* (e.g., performing administrative activities), ii.) *communicating and interacting* (e.g., communicating with supervisors, peers, and subordinates), and iii.) *coordinating, developing, managing, and advising* (e.g., training and teaching others). Coding this extra occupational information would allow for a more accurate estimation of occupational complexity, as it includes participation in activities that involve different facets of cognitive complexity. For instance, certain jobs, like personal support workers, may not be rated as cognitively complex based on the 10 included variables, however, the activities performed suggest that the occupation is quite socially demanding. Working in a socially complex environment will often involve the use of higher-order cognitive abilities, such as emotional regulation, inhibition, complex attention, and language abilities (e.g., Cramm et al., 2013; Meyer et al., 2015; Ybarra et al., 2008). Exercise of more complex social skills, such as negotiation and conflict resolution, require the use of working memory, processing speed, and other executive functions to hold, manipulate, and respond to social information (Vélez-Coto et al., 2021). Like cognitive stimulating activities, participation in a greater number of social activities is associated with less cognitive decline in older age (James et al., 2011).

Future studies may also benefit from the use of prospective research methods rather than archival data, as this would allow for the inclusion of additional data related to cognitive reserve,

such as years spent in occupation, education quality, and participation in cognitive leisure activities. Prospective research would allow researchers to administer specific measures to evaluate educational quality (e.g., Wide Range Achievement Test, Fourth Edition – Reading Composite; Wilkinson & Robertson, 2006) and participation in leisurely activities (e.g., Lifetime Experiences Questionnaire [LEQ]; Gonzales, 2012), garnering more accurate estimates of cognitive reserve. Longitudinal methods would also allow researchers to evaluate the possible moderating effects of cognitive reserve on rates of cognitive decline. This research could potentially improve methods to detect the presence of neuropathology in individuals with higher levels of cognitive reserve, as clinicians would be able to better detect relative declines in cognitive ability, by creating more accurate and personalized reliable change scores that take into account the influence of certain reserve-promoting factors (Mitchell et al., 2012).

Final Conclusions

Previous research has demonstrated the influence of cognitive reserve on general cognitive functioning, but few researchers have tested the effects of cognitive reserve across a comprehensive set of neuropsychological tests using a combination of multivariate and univariate statistical techniques. Findings from this study address this gap in the literature by providing preliminary evidence supporting the differential effects of cognitive reserve on neuropsychological profiles of older adults without dementia. Rather than benefiting all areas of cognitive functioning equally, this study showed that cognitive reserve demonstrates the strongest relationships with executive functioning and language abilities. Performance on tests of verbal memory, visual memory, and visuospatial processing were also shown to be significantly influenced by cognitive reserve, however, the impact of reserve promoting factors—educational attainment, mental workplace demands, crystallized intelligence—was considerably less than the

effect on higher order cognitive abilities. Further, this study found that after controlling for influence of age, gender, vascular risk factors, and depression diagnosis, crystallized intelligence was the only significant cognitive reserve proxy that predicted neuropsychological performance across all six cognitive domains in our older adult sample, suggesting that the effects of cognitive reserve may largely depend on the proxy indicator used. These findings were further corroborated by a series of follow-up analyses which showed that crystallized intelligence contributed the most out of the three cognitive reserve proxies to differences in older adults' performance in each of the six cognitive domains. It is important to note that findings observed in this study are limited in interpretability, as the primary method used to evaluate my main hypotheses proved to be insufficient due to evidence of poor model fit for both the proposed models. Future studies will re-evaluate the models proposed in this study with a larger sample size to address limitations in the current research caused by poor model fit. Through this, future studies will be able to appropriately test the organizational effects of cognitive reserve.

In conclusion, findings from this study support the validity of cognitive reserve as a potential mechanism explaining inter-individual differences in late-life cognition. Although limited, our findings demonstrate that certain neuropsychological tests may be more sensitive to differences in cognitive reserve over others and that exposure to intellectually stimulating activities and experiences throughout the lifespan may be particularly useful indicator of one's premorbid levels of cognitive reserve. Overall, this study offers a more nuanced understanding of cognitive reserve by not only proposing a multi-dimensional model of cognitive reserve, but also by comparing the influence of several reserve-promoting factors across the comprehensive neuropsychological profiles of a clinical sample of older adults without dementia.

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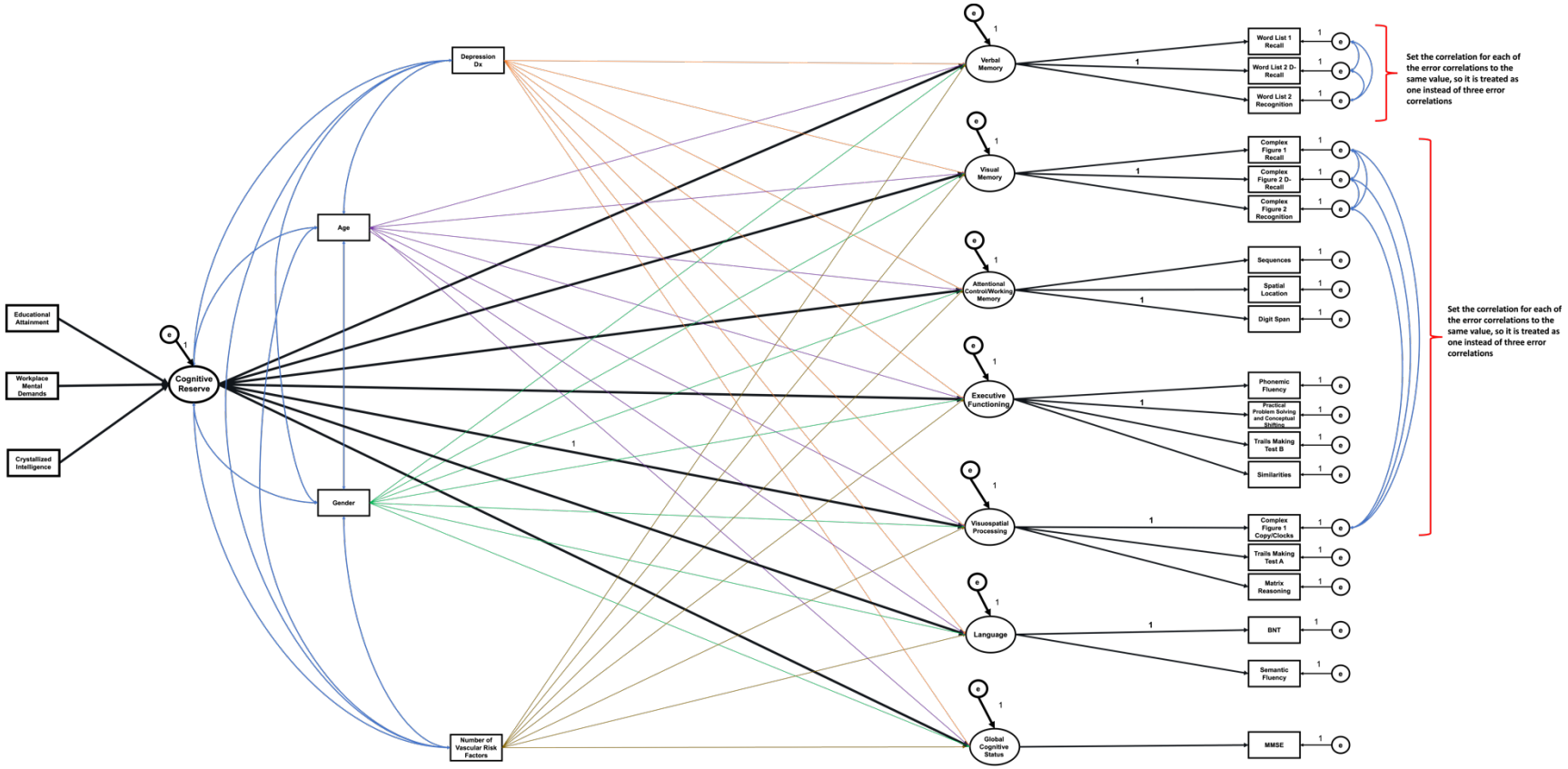
APPENDICES

Appendix A

Original Hypothesized Structural Models

Figure 1A

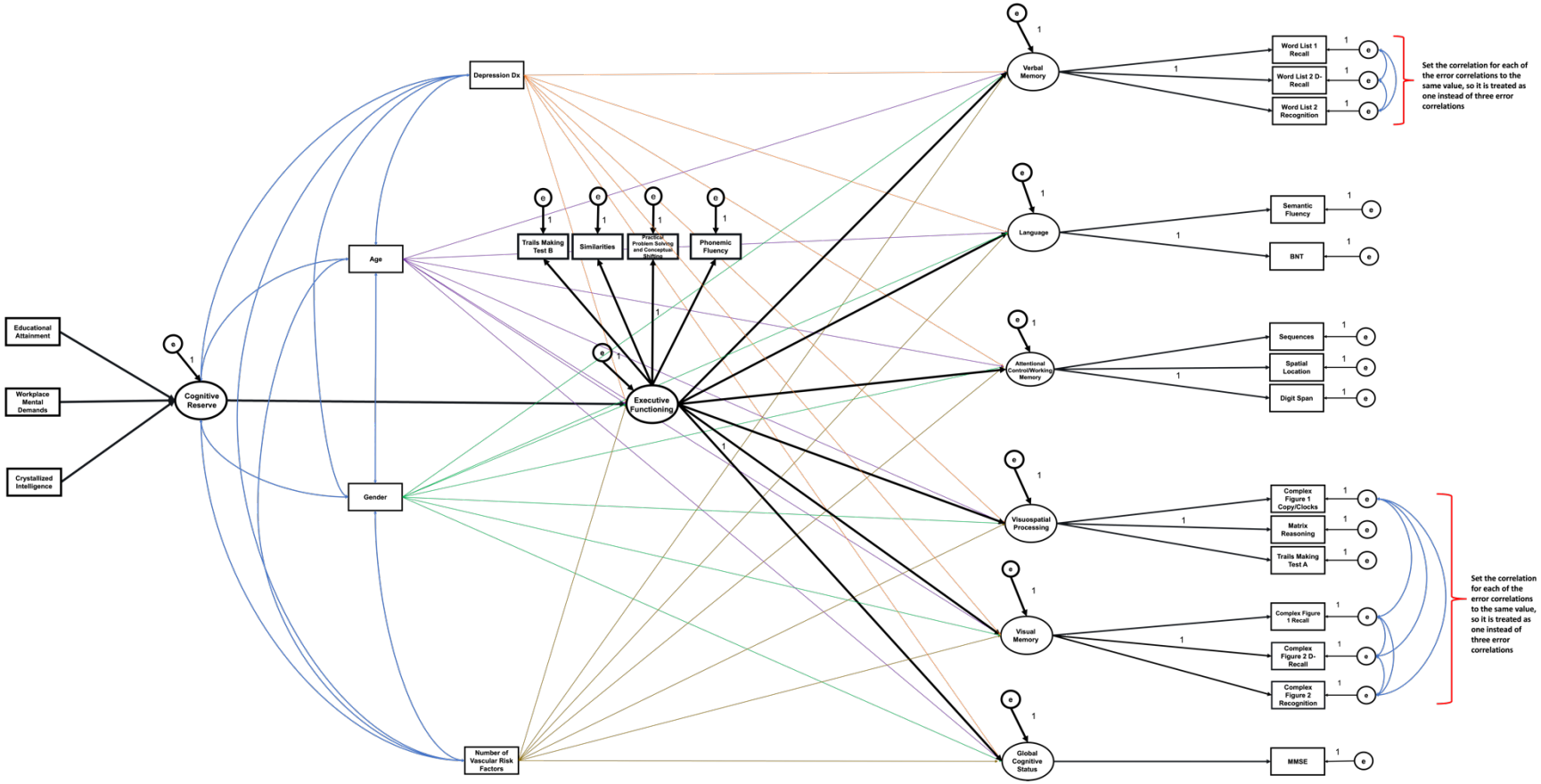
Model 1: Generalized Effects of Cognitive Reserve on Cognitive Functioning



Note. MMSE = Mini-Mental Status Exam, BNT = Boston Naming Test.

Figure 2A

Model 2: Hierarchical Effects of Cognitive Reserve on Cognitive Functioning



Note. MMSE = Mini-Mental Status Exam, BNT = Boston Naming Test.

Appendix B

Occupation Title Analysis

Table 1B

Occupational Titles Reported by the Sample

Occupation Titles	*N*	%
Average of all Teacher Occupational Titles	18	7.8
Average Administrative Assistant	17	7.3
Retail Salesperson	13	5.6
General and Operations Manager	10	4.3
Bookkeeping, Accounting, and Auditing Clerks	9	3.9
Average of all Business-Related Occupations	8	3.4
Lawyer	8	3.4
Accountants and Auditors	6	2.6
Registered Nurses	5	2.2
Average of all Engineering Occupation Titles	4	1.7
First-Line Supervisors of Office and Administrative Support Workers	4	1.7
Homemaker (DOT Title)	4	1.7
Personal Financial Advisors	4	1.7
Average for all Professor Occupation Titles	3	1.3
Bookkeeping, Accounting, and Auditing Clerks &	3	1.3
Chief Executives	3	1.3
Driver/Sales Workers (occupational information is underway for taxi driver, this is the closest title)	3	1.3
Librarians and Media Collections Specialists	3	1.3
Tailors, Dressmakers, and Custom Sewers	3	1.3
General and Operations Manager	2	0.9
Acupuncturists	2	0.9
Architects, Except Landscape and Naval	2	0.9
Average of all Social Worker Occupation Titles	2	0.9
Construction Laborer	2	0.9
Electrical and Electronics Repairers, Commercial and Industrial Equipment	2	0.9
Financial Quantitative Analysts	2	0.9
First-Line Supervisors of Construction Trades and Extraction Workers	2	0.9
Hairdressers, Hairstylists, and Cosmetologists and Choreographer	2	0.9
Laborers and Freight, Stock, and Material Movers, Hand	2	0.9
Medical and Clinical Laboratory Technologists	2	0.9
News Analysts, Reporters, and Journalists	2	0.9
Personal Care Aide	2	0.9
Property, Real Estate, and Community Association Managers	2	0.9
Real Estate Sales Agents	2	0.9
Sales Managers	2	0.9
Rehabilitation Counselors	1	0.4
Administrative Services Managers	1	0.4
Aircraft Mechanics and Service Technicians	1	0.4
Automotive Service Technicians and Mechanics & Businessperson & Locksmiths and Safe Repairers	1	0.4
Average of all Insurance Related Occupation Titles	1	0.4
Average of all Marketing Related Occupation Titles	1	0.4
Average of all Physician Occupational Titles	1	0.4
Average of all Teacher Occupation Titles & Librarian	1	0.4

Average of all Trades and Construction Related Occupation Titles	1	0.4
Average of all Real Estate Occupation Titles	1	0.4
Average of Finance Related Occupation Titles	1	0.4
Biological Technicians and Average of all Administrative Assistant Occupation Titles	1	0.4
Bookkeeping, Accounting, and Auditing Clerks & First-Line Supervisors of Office and Administrative Support Workers	1	0.4
Bookkeeping, Accounting, and Auditing Clerks and Retail Salesperson	1	0.4
Cardiovascular Technologists and Technicians	1	0.4
Civil Engineer	1	0.4
Customer Service Representatives	1	0.4
Dental Assistants	1	0.4
Dentists, General	1	0.4
Dietitians and Nutritionists	1	0.4
Economist & Accountant & Businessperson	1	0.4
Economist & Economics, Postsecondary Teacher	1	0.4
Education and Childcare Administrators, Preschool and Daycare	1	0.4
Electrical and Electronic Engineering Technologists and Technicians	1	0.4
Electrical Engineer	1	0.4
Excavating and Loading Machine and Dragline Operators, Surface Mining	1	0.4
Family Medicine Physician	1	0.4
First-Line Supervisors of Non-Retail Sales Workers	1	0.4
First-Line Supervisors of Retail Sales Workers	1	0.4
Floral Designers	1	0.4
Food Services Manager	1	0.4
Fundraisers	1	0.4
General and Operations Managers	1	0.4
Graphic Designers	1	0.4
Human Resources Specialists	1	0.4
Industrial Machinery Mechanics	1	0.4
Interior Designers	1	0.4
Janitors and Cleaners, Except Maids and Housekeeping Cleaners	1	0.4
Library Assistants, Clerical	1	0.4
Licensed Practical and Licensed Vocational Nurses	1	0.4
Loan Officers	1	0.4
Manicurists and Pedicurists	1	0.4
Marriage and Family Therapists	1	0.4
Media Programming Director & Media Technical Director/Manager	1	0.4
Medical and Health Services Managers	1	0.4
Mental Health and Substance Abuse Social Workers	1	0.4
Mental Health Counselors	1	0.4
Models	1	0.4
Musicians and Singers	1	0.4
Musicians and Singers & Purchasing Manager	1	0.4
Educational Assistant	1	0.4
Nannies	1	0.4
Personal Care Aides	1	0.4
Personal Financial Advisor	1	0.4
Print Binding and Finishing Workers	1	0.4
Print Binding and Finishing Workers and Security	1	0.4
Printing Press Operators	1	0.4
Producers and Directors	1	0.4
Radiologic Technologists and Technicians	1	0.4
Receptionists and Information Clerks	1	0.4
Secretaries and Administrative Assistants, Except Legal, Medical, and Executive	1	0.4
Security Guards	1	0.4

Self-Enrichment Teachers	1	0.4
Shipping, Receiving, and Inventory Clerks	1	0.4
Switchboard Operators, Including Answering Service	1	0.4
Team Assemblers	1	0.4
Teller and Bus Driver, Transit Inner-city	1	0.4
Tellers	1	0.4
Treasurers and Controllers	1	0.4
Veterinary Technologists and Technicians & Average of all Business-Related Occupation Titles (Businessperson)	1	0.4
Wholesale and Retail Buyers, Except Farm Products	1	0.4
Word Processors and Typists	1	0.4

Note. DOT = Dictionary of Occupations Title.

Appendix C

Significance Testing for Cognitive Reserve Proxies Across Diagnostic Groups

Table 1C

Differences in Cognitive Reserve Proxies: Mild Cognitive Impairment Versus Normal Cognitive Aging

	Normal Aging	MCI	*t*	*df*	*p* (2-tailed)
	M (SD)	M (SD)			
Years of Formal Education	13.2 (3.0)	13.8 (3.5)	-1.27	230	.205
Mental Workplace Demands	3.8 (0.8)	4.0 (0.7)	-1.45	230	.148
WASI-I Vocabulary Raw Score	60 (11.4)	57.8 (12.1)	1.44	230	.151

Note. N = 232. Levene's Test of Equal Variances was not statistically significant ($p < .05$) for all comparisons. MCI = mild cognitive impairment, t = t-test statistic, df = degrees of freedom, CI = Confidence Interval.

Table 2C

Differences in Mental Workplace Demand Variables: Mild Cognitive Impairment Versus Normal Cognitive Aging

	Normal Aging	MCI	*t*	*df*	*p* (2-tailed)
	M (SD)	M (SD)			
Judging the Qualities of Objects, Services, or People	3.4 (0.8)	3.6 (0.6)	-1.80	225	.074
Processing Information	3.9 (0.9)	4.1 (0.9)	-1.01	225	.313
Evaluating Information to Determine Compliance with Standards	3.6 (0.9)	3.7 (0.9)	-0.71	225	.479
Analyzing Data or Information	3.6 (1)	3.8 (1)	-1.53	225	.127
Making Decisions and Solving Problems	4.2 (0.9)	4.4 (0.9)	-1.70	225	.090
Thinking Creatively	3.8 (0.9)	4.0 (0.9)	-1.69	225	.093
Updating and Using Relevant Knowledge	4.5 (0.9)	4.6 (0.8)	-0.95	225	.343
Developing Objectives and Strategies	3.2 (0.9)	3.4 (0.9)	-1.57	225	.117
Scheduling Work and Activities	3.5 (0.8)	3.7 (0.8)	-1.54	225	.126
Organizing, Planning, and Prioritizing Work	4.7 (0.8)	4.7 (0.8)	-0.65	225	.518

Note. N = 227. Levene's Test of Equal Variances was not statistically significant ($p < .05$) for all comparisons. MCI = mild cognitive impairment, t = t-test statistic, df = degrees of freedom, CI = Confidence Interval.

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