5-12-2022

An examination of working memory in subtle and mild cognitive impairment

Kara Eversole
James Madison University

An Examination of Working Memory in Subtle and Mild Cognitive Impairment

Kara Eversole

A thesis submitted to the Graduate Faculty of

JAMES MADISON UNIVERSITY

In

Partial Fulfillment of the Requirements

for the degree of

Master of Arts in Psychological Sciences

Department of Graduate Psychology

May 2022

FACULTY COMMITTEE:

Committee Chair: Bernice Marcopulos, PhD, ABPP

Committee Members/Readers:

Yu Bao, PhD

Kethera Fogler, PhD

David Libon, PhD

Dedication Page

This thesis is dedicated to my academic family and friends for their unconditional support, guidance, and dedication to my growth. I would like to express my sincerest gratitude to my advisor, Dr. Bernice Marcopulos, for her generous mentorship and her patience with my "words." Thank you for everything Bernice, I am eternally grateful. Being your mentee was the highlight of my time in graduate school.

I am incredibly grateful to my family and friends for their support and unwavering faith in me. I would also like to thank the members of my thesis committee, Drs. Yu Bao, Kethera Fogler, and David Libon, for their mentorship, feedback, and commitment to my growth as a student and researcher.

Furthermore, I would like to thank my clinical supervisors at the University of Virginia Department of Neurology, Drs. Kathleen Fuchs, Carol Manning, Agu Rossetti, Shannon Reilly, Jennifer Romano Morris, and Julian Garcia, for their time and commitment to my training in neuropsychology. Finally, I want to express gratitude and appreciation to the patients at the New Jersey Institute for Successful Aging Memory Assessment Program, who donated these data to contribute to advances in the scientific community.

Table of Contents

List of Tables

List of Figures

Abstract

Mild cognitive impairment (MCI) is abnormal cognitive decline that may be indicative of an insidious process such as dementia. Individuals with MCI are largely independent in their daily functioning but are at risk of further decline. To more deeply understand the working memory deficits associated with age-related cognitive decline, Lamar and colleagues developed a working memory task with no discontinuation rule: the Backwards Digit Task (BDT). Prior BDT research has demonstrated that individuals with mild cognitive impairment have lower overall scores on this task, and that different subtypes of MCI are more prone to certain errors. Research has not been done to examine if individuals with different MCI subtypes perform differently on individual trials. This current study examined the variability in any- and serial-order sequencing difficulty in the 5-span BDT trials across different levels of cognitive impairment (i.e., cognitively normal, subtle cognitive impairment, amnestic MCI, and mixed/dysexecutive MCI). Results indicated that the mixed/dysexecutive MCI group had significantly lower serial-order sequencing difficulty on all trials and lower any-order sequencing difficulty on trials 15 and 17. A positive effect of education was seen on trials 15, 20, and 21 when utilizing serial-order sequencing difficulty. Furthermore, more capture and transposition errors were made in the mixed/dysexecutive MCI group. These results highlight the diagnostic utility of process approach data collection in differentiating MCI subtypes. Additional implications for future clinical practice and research are discussed.

Keywords: mild cognitive impairment, neuropsychological assessment, process approach

I. Introduction

Memory is one of the most common presenting problems in referrals for neuropsychological evaluations (Rabin et al., 2016). While memory declines occur in normal, healthy aging, more rapid and significant declines may be indicative of a neurodegenerative process such as dementia. Dementia is an umbrella term indicating that an individual is experiencing significant cognitive difficulties and impairment in their daily functioning in the absence of any medical, psychiatric, or neurological disorder. In 2015, 46.8 million people worldwide had dementia, and this number was expected to almost double and more than triple by 2030 and 2050 (Prince et al., 2015). Dementia can cost families as much as $89,000 annually, and result in significant emotional distress for both the individual and care providers (Jutkowitz et al., 2017). Early detection of dementia can help slow disease progression by addressing modifiable risk factors that promote decline such as poor cardiovascular health, substance use, and depression (Chen et al., 2009). Furthermore, early detection of dementia allows the affected individual and their loved ones to collaboratively plan ahead while they are still capable of making important decisions, discussing their care as well as end of life matters.

Currently, mild cognitive impairment (MCI) is generally considered an intermediary stage between healthy cognitive aging and abnormal cognitive decline (Figure 1). In MCI, individuals are experiencing significant cognitive difficulties but remain largely independent in their functioning. Prevalence of MCI in adults older than 60 has been shown to range from 6.7% to 25.2% with increased rates for men, and rates increasing with age and lower levels of education (Petersen et al., 2018; Langa & Levine,

2014). While some individuals with MCI eventually develop dementia, this is not always the case, with conversion rates ranging from 20 to 40%, (Limongi et al., 2017). The variability in prevalence and conversion rates is widely recognized and can be attributed to several factors such as population selection and methodological differences (Matthews et al., 2008). Regardless of disease trajectory, MCI denotes a clinically meaningful decline that warrants monitoring. There are several subtypes of mild cognitive impairment that indicate the nature of the individual's deficits (e.g., amnestic for individuals with memory deficits,). Impairment is objectively measured through neuropsychological assessment, a "comprehensive assessment and integration of cognitive, emotional, and behavioral domains in consideration of contextual factors," and individual's total scores are compared to those of healthy controls (Block et al., 2017).

While total scores on tests may indicate the *presence* of impairment, they do not provide insight on the *nature* of impairment. The Boston Process Approach seeks to examine the process of how someone obtained a certain score on a neuropsychological test. Many neuropsychological assessments have discontinuation rules so that a task will be discontinued after so many unsuccessful trials. By discontinuing a task early, an examiner limits the amount of data collected, potentially missing important patterns in a patient's performance. To understand more deeply the working memory deficits associated with mild cognitive impairment that may not be captured by tests that are discontinued, Lamar and colleagues developed the Backwards Digit Task (BDT). Comprised of 21 trials and no discontinuation criteria, this task asks participants to repeat 3, 4, and 5-digit strings of numbers in the reverse order they were presented.

Previous BDT research has demonstrated that individuals with mild cognitive impairment have lower overall scores on this task, and that different subtypes of MCI are more prone to certain errors. Research has not been done to examine if individuals with different MCI subtypes perform differently on individual trials. The primary aim of the current study is to examine item level sequencing difficulty (adapted from the classical test theory definition of item level) of the BDT across different subtypes of MCI. If variability is found among trial level difficulty, post hoc analyses were planned to be conducted to examine the contributing factors (i.e., error types).

II. Literature Review

2.1 Mild Cognitive Impairment

2.1.1 Historical Background of the Construct of Mild Cognitive Impairment. In 1982, Reisberg and colleagues proposed the Global Deterioration Scale (GDS) to outline the disease stages of primary degenerative dementia and expand upon the three previously established phases: early “forgetfulness”, intermediate “confusional”, and late “dementia.” This scale delineated 7 stages that can be clinically identified: (1) no cognitive impairment (2) very mild cognitive decline (3) mild cognitive decline (4) moderate cognitive decline (5) moderately severe cognitive decline (6) severe cognitive decline and (7) very severe cognitive decline. Six years later in 1988, Reisberg and colleagues sought to develop more detailed descriptions to characterize the cognitive changes associated with the stages outlined by the GDS. It was in this manuscript that the concept of mild cognitive impairment (MCI) was again referenced, describing the cognitive difficulties associated with stage 3 of the GDS. Throughout research up to 1993, the construct of mild cognitive impairment served as a generic label, with no

systematic criteria delineating this condition. Research from 1983 to 1993 has used MCI in describing individuals who made 1 to 2 errors on Mental Status Questionnaire (Eastwood et al., 1983) and individuals who showed cognitive impairment but were not demented (Zemcov et al., 1985; Loewenstein et al., 1989; Loewenstein et al., 1991; John et al., 1992; Reed et al., 1993; Lesser et al., 1993).

Throughout the 80's and early 90's, terminology varied (e.g., mild cognitive decline or impairment), partially reflecting that there was no widely accepted construct referring to abnormal cognitive decline. In 1993, the International Classification of Diseases introduced research criteria for 'mild cognitive disorder' (World Health Organization), shortly followed by the fourth edition of the Diagnostic and Statistical Manual (DSM-IV) providing research criteria for 'mild neurocognitive decline' (American Psychiatric Association (APA), 1994). The World Health Organization (WHO) divided mild cognitive disorder into two subtypes: associated with a physical disorder and not associated with a physical disorder. WHO's research criteria established mild cognitive disorder as a differential diagnosis, i.e., the cognitive impairment must occur in the absence of dementia, amnestic disorders, delirium, postencephalitic syndrome, postconcussional syndrome, or psychoactive substance use. Additionally, in order to meet criteria for mild cognitive disorder per WHO's 1993 criteria, the individual must have abnormalities or declines on quantified assessments (e.g., neuropsychological tests), and the cognitive dysfunction (reported by the individual or a reliable informant) must be present for the majority of the time for at least two weeks. The DSM-IV criteria for mild neurocognitive disorder share some similarities with WHO's criteria, particularly with symptom duration (i.e., at least two weeks), objective decline (i.e., as indicated by

quantified assessment), and as a differential diagnosis (i.e., delirium, dementia, amnestic disorder, another mental disorder does not explain deficits). The DSM-IV criteria also outlined that there must be evidence of a neurologic or medical condition related to the cognitive deficits. Moreover, the DSM-IV states that the level of cognitive impairment and impact on everyday functioning is mild, but that these deficits represent a decline from previous level of functioning and cause marked distress/impairment in social, occupational, or other important areas.

The criteria delineated by the WHO and APA provided a uniform definition of what mild cognitive impairment was (and was not) which set the stage for more robust inclusion and exclusion criteria within MCI research, although there is still heterogeneity around this construct across medical disciplines. By identifying individuals with abnormal cognitive decline (i.e., MCI), the emphasis in dementia research shifted towards early diagnosis and treatment, as well as MCI etiology classification (Golomb, Kluger, & Ferris, 2004).

2.1.2 Mild Cognitive Impairment Progression. There are several subtypes that further classify mild cognitive impairment. These subtypes are named after the nature of the impairment that the individual is experiencing, and include: amnestic (issues with memory), dysexecutive (issues with executive functions), and mixed (issues with two or more of these areas).

Research has repeatedly shown that individuals with amnestic MCI (aMCI) are more likely to progress to dementia, specifically Alzheimer's dementia, compared to those with a non-amnestic MCI subtype (Glynn et al., 2021, Yaffe et al., 2006; Ravaglia et al., 2005). Individuals with aMCI that progressed to dementia tended to have abnormal

results of functional neuroimaging (specifically left-dominant asymmetrical patterns of atrophy and hypometabolism), poor episodic memory, one copy or two copies of APOE e4 allele, and/or had another impaired domain (in addition to memory) (Landau et al., 2010; Kondo et al., 2016; Michaud et al., 2017). Prior literature has also demonstrated that those with multi-domain MCI (regardless of memory impairment) are at a greater risk of converting to dementia compared to those with single-domain MCI (Han et al., 2012), but recent meta-analyses have shown conversion rates to be similar for these two groups (Oltra-Cucarella et al., 2018; Glynn et al., 2021). Conversion risk has also shown to be higher in individuals with atrial fibrillation, low serum folate levels, and depressive symptoms, and individuals who converted tended to be older, and have a lower Mini-Mental Status Examination scores, higher prevalence of atrophy, higher baseline mean plasma total homocysteine levels, and higher serum high density lipoprotein (HDL) levels (Gabryalawicz et al., 2006; Kida et al., 2016; Ravaglia et al., 2005).

It appears that the presence of memory impairment is the key risk factor for conversion to dementia, as individuals with aMCI have shown a higher risk for dementia than individuals with single and multi-domain nonamnestic MCI (Oltra-Cucarella et al., 2018). Similarly, older studies found that individuals with multi-domain *amnestic* MCI had the highest risk for conversion compared to single-domain MCI subtypes and multi-domain nonamnestic MCI, and the presence of at least one ε4 allele and deficits in memory and psychomotor speed/executive function abilities predicted conversion to dementia (Gabryalawicz et al., 2006; Tabert et al., 2006; Espinosa et al., 2013; Maioli et al., 2007).

2.2 Neuropsychological Assessment

2.2.1 The Role of Neuropsychology in Diagnosing MCI. A neuropsychological assessment examines an individual's cognition and behavior with a battery of standardized tests. These evaluations incorporate information from clinical interview(s) with patients and/or family members, medical records, and test data to understand a person's cognitive functioning and identify contributing factors. While an older adult may present with cognitive declines, these deficits may be from reversible factors such as sleep or mood. In cases such as this, a neuropsychologist can provide reasonable evidence that the cognitive dysfunction is unlikely due to a neurodegenerative process but due to modifiable factors. As psychologists, these providers are aptly positioned to address psychosocial issues and provide psychoeducation to improve functioning.

One of the criteria for mild cognitive impairment is objective cognitive deficits as measured by quantified assessments. There are differing cutoffs for what level of impairment is considered to be mild cognitive impairment, but one of the most common criteria used is the Jak/Bondi criteria. In their 2009 paper, Jak and colleagues investigated the applicability of diagnostic criteria for clinical subtypes of mild cognitive impairment. From this study, they established comprehensive, liberal, and conservative criteria. Liberal criteria considered those scoring 1 standard deviation below normative expectations as impaired compared to the 1.5 standard deviation cutoff for conservative criteria. In an effort to balance reliability and sensitivity, comprehensive criteria defined impairment as at least two performances in a cognitive domain scoring 1 standard deviation below normative expectations. Researchers found that the comprehensive criteria showed more diagnostic stability over time, with 93% of patients remaining

stable in their diagnoses (i.e., normal or MCI), compared to the liberal (81%) and conservative criteria (74%) (Jak et al., 2009). In an effort to operationalize cognitive decline earlier, Edmonds and colleagues proposed the stage of subtle cognitive impairment (2015). Researchers defined subtle cognitive impairment as impaired scores (i.e., below one standard deviation) on two measures on *different* cognitive domains in the context of general intact daily functioning (e.g., ability to pay bills, cook). This study demonstrated that subtle cognitive decline, instead of biomarkers, may be one of the earliest markers of the progression to Alzheimer's disease (AD) and a more robust predictor of conversion from MCI to AD. Cognitive declines can be the first signal of a dementia process and warrant monitoring.

Neuropsychological assessments play a key role in the diagnosis of mild cognitive impairment as they address the three major criteria of the disorder. A neuropsychological evaluation can aid in differential diagnosis by identifying other conditions that better explain deficits, quantitatively measure cognitive functioning, and evaluate functioning in basic and instrumental activities of daily living.

2.2.2 Neuropsychological Assessment Approaches. There are various approaches in neuropsychological data collection and interpretation, but the differences can be seen along two continuums: "fixed" vs. "flexible" in battery construction/data collection and "quantitative/normative based" vs. "qualitative/process-based" in data interpretation (Vanderploeg, 2001). In a fixed battery approach, a fixed set of tests is administered to each patient regardless of their referral or symptomatology (Orsini et al., 2013). Comparatively, in a flexible approach, a battery is constructed around each patient's presenting concerns and symptomology. As these are on a continuum, a

neuropsychologist may have a mixed battery and have portions that are fixed and flexible. Regarding data interpretation, quantitative or normative based approaches examine overall scores and compare them to averages from similar patient populations. Qualitative or process-based data interpretation focuses on *how* an examinee arrived at a solution. Again, these approaches are on a spectrum and can be used in conjunction with one another, examining quantitative data and behavioral observations in the context of one another.

The Boston process approach is defined as the "method of assessment that emphasizes the qualitative aspects of how patients attempt to solve problems" (Long, 1999). The origins of the Boston Process Approach are rooted in early twentieth-century Gestalt psychology, particularly in the theory that the individual (yet harmonized) elements of behavior greatly inform us about brain-behavior relationships (Ashendorf, Swenson, & Libon, 2013). The process approach perspective recognizes that a final solution can "be arrived at via diverse processes which themselves may reflect the activity of distinctly different structures in the central nervous system" (Kaplan, 1988). While overall scores on neuropsychological assessments may denote the presence and/or severity of impairment, process approach analysis assesses the nature of the examinee's performance, analyzing HOW a patient got a certain score.

For example, the Montreal Cognitive Assessment (MoCA) is a brief cognitive screening tool that assesses the presence of cognitive dysfunction (Nasreddine et al., 2005). This 30-point brief cognitive screening test covers several cognitive domains including visuoconstructional abilities, memory, and language. If two individuals were to achieve a total score 25 on this measure, both of their performances would be considered

impaired as it falls below the cutoff score of 26 (Nasreddine et al., 2005). While their scores suggest the presence of impairment, it does not inform the examiner about the *nature* of the impairment. For example, the first individual may not have remembered any of the words that they were instructed to remember for later which led to a 5-point deduction in their overall score. The second individual may have been disoriented, unable to tell the examiner the correct day, month, year, and current place and city, resulting in a 5-point deduction in their overall score. While their total scores are identical, there are two different performance patterns suggesting different cognitive profiles and issues (i.e., respectively: amnestic/memory problems vs. disoriented to time and location).

2.2.3 Classical Test Theory. Classical Test Theory (CTT), also known as true score theory, states that an observed score on a test is composed of a true score (i.e., score that would be obtained if there were no errors in measurement) and an error term (i.e., test score deviance from true score) (Alagumalai & Curtis, 2005; Cappelleri et al., 2014). Errors are assumed to be randomly distributed with a mean a zero, and are unrelated to observed or true scores (Kline, 2005). The true score is the variable of interest to examiners, but true scores and error terms are latent variables (i.e., variables that cannot be observed/measured directly) (Alagumalai & Curtis, 2005). To draw inferences about an individual's true score, assumptions are made about the error term and by doing so, a true score can be estimated (Alagumalai & Curtis, 2005).

Although CTT focuses on test-level information, item-level data are important factors to examine/consider. Item level-analyses can provide insight on factors such as reliability, discriminability, difficulty, which are particularly important in neuropsychological measurement development and construction, as each item should be

contributing to the overall measure. Item difficulty, generally denoted as a *P*-value, reflects the proportion of individuals who correctly answered an item (Kline, 2005). These values range from 0 to 1, with a high *P*-value indicating an easier item (i.e., a higher proportion of the sample getting the item correct), and a low *P*-value indicating a more difficult item (i.e., a lower proportion of the sample getting the item correct).

This current study was interested in examining item level difficulty on the *participant* level, defining difficulty of an item as the proportion of the sequence they correctly provided. This term was coined as 'sequencing difficulty,' which is also referred to as trial difficulty or trial accuracy. For example, if a participant correctly provided 3 out of the 5 numbers, their sequencing difficulty would be ⅗, or 0.6 (60%). This parallel but nontraditional application of item difficulty reflects the magnitude of the errors for a given item.

2.2.4 Digit Span. A common task given in neuropsychological assessments is digit span, a task that can be found on numerous tests such as the Wechsler Adult Intelligence Scale (WAIS) and Repeatable Battery for the Assessment of Neuropsychological Status Update. The origins of this task dates back to Gottfried Leibniz (1646-1716), who suggested that individuals have a limited capacity to hold or process information in their mind, terming this capacity the span of apperception (Wambach, 2011). In the nineteenth century, Herman Ebbinghaus demonstrated how span could be utilized to examine memory and learning, investigating the number of trials it took to learn sequences of nonsense syllables (Richardson, 2007). On average, Ebbinghaus found that seven syllables could be correctly recited after only one reading, stating that this number was "a measure of [ideas that one] can grasp in a single, unitary, conscious act" (p. 109). In

1886, Jacobs proposed that this was a marker of linguistic capacity, which he referred to as “the threshold of verbal memory.” He repeated Ebbinghaus’ procedure in 1887 with schoolchildren ages 11 to 20, and found the ability to reproduce sequences increased (i.e., could remember longer sequences) with age and education. In 1892, Bolton expanded on this work by presenting 8 to 15-year-old children sequences of between five and eight digits, finding the “memory-span” was typically maxxed out at six digits and inferred that “the memory-span measures the power of concentrated and prolonged attention” (p. 379). Binet and Simon included this attention task in a preliminary series of intelligence tests in 1905, marking the advent of the task ‘digit span’ in standardized testing.

Digit span is typically composed of two test conditions: one in which the client is asked to repeat the numbers in the same order (forwards), and another in which the client is asked to repeat the numbers in the reverse order (backwards). While digit span forwards is considered to measure how many units of information a person can hold, tapping into immediate, rote attention, digit span backwards is viewed as a test of working memory, as the patient has to mentally rearrange the auditory stimuli (Ashendorf et al., 2013). While these two conditions are often combined as one subtest (e.g., digit span on Weschler Adult Intelligence Scale), these tasks represent related but separate psychological constructs.

Traditional digit span tasks (i.e., those included in Weschler batteries such as Weschler Memory Scale) measure simple attention and working memory (in forward and backwards/sequencing conditions, respectively) and have demonstrated predictive utility in various populations. In older adults, impairment on the Weschler digit span has been shown to predict cognitive decline in individuals with subjective memory concerns (Kurt

et al., 2011). In a model with biomarkers and demographic variables, digit span also aided in predicting the time in which subjects with MCI would convert to dementia (Ewers et al., 2012). However, this test has shown inconsistent discriminant ability, as patients with cognitive impairments have performed similar to their respective controls. For example, individuals with memory disorders (i.e., mild cognitive impairment, dementia) have shown similar performance as control subjects on this task (Djordjevic et al, 2008; Traykov et al., 2007). This similarity is not shown across all studies, with controls demonstrating higher scores than patients with MCI and dementia (Binnewijzend et al., 2012).

2.3 Fuster's Theory & Backwards Digit Span

2.3.1 Fuster's Theory. Executive control is the selection and coordination of goal-directed behaviors, and is a key variable of interest in neuropsychological evaluations (Collins & Koechlin, 2012). This top-down mental process involves various domains and skills (including attention, working memory, inhibition) to implement reasoning, problem-solving, and mental planning (Schoenberg & Scott, 2011; Emrani et al., 2021). Proposed by Joaquín Fuster, the model of 'executive attention' temporally integrates and organizes information to enhance goal-directed behavior, and is served by three distinct but highly integrated mechanisms: working memory, preparatory set, and inhibitory control (Fuster, 2009; Fuster, 2002).

Working memory is the temporary storage of information for the solution of a problem or for a mental process (Fuster, 2002). Preparatory set is priming of sensory and motor neural structures for the performance of an act contingent on a prior event, and consequently the working memory of that event (Fuster, 2015). Inhibitory control is a

large factor in selective attention, suppressing any internal or external influences that may interfere with task(s) at hand (Fuster, 2015). Working memory can be thought of as attention to the past while preparatory set can be conceptualized as attention towards the future (Emrani et al., 2021). Inhibitory control acts as a stabilizer, quieting any irrelevant stimuli. The Backwards Digit Task (discussed below) is largely rooted in Fuster's theory of executive attention, as this task relies on the successful operation of this system.

2.3.2 Backwards Digit Task. Although it is commonly a subtest of a larger battery (such as Wechsler Adult Intelligence Scale, Wechsler Memory Scale, and Battery for the Assessment of Neuropsychological Status), digit span can also be a standalone task. As mentioned before, digit span forwards and backwards measure different constructs, and there is utility in looking at these tasks independent of one another, hence the creation of the Backwards Digit Task (BDT), first described by Lamar et al. (2007). Lamar and colleagues created this assessment to measure various components of working memory to gain a deeper understanding of the specific working memory deficits associated with patients with memory disorders. The BDT consists of seven trials of 3-, 4- and 5-digit span lengths for a total of 21 trials. As this test was constructed to assess working memory and not maximum span length, the digit length was capped at 5, as average backwards span lengths have been shown to range from 4 to 6 (Kessels et al., 2008; Woods et al., 2008). This test is administered using the standardized WAIS-R digit span backwards procedures but there is no discontinuation rule, and all clients receive all 21 trials. When creating this test, the developers strategically placed consecutive numbers in the 4- and 5-span trials. For the 4-span trials, sequential numbers were positioned in either the first and third or second and fourth positions, e.g., 1825 or 9314. For the 5-span

trials, contiguous numbers were positioned in the middle three positions, e.g., 16873. This placement was done to elicit potential executive errors, identifying a participant's capacity to disengage from the stimulus.

Previous research with the Backwards Digit Task is limited, and the majority of studies examine how different clinical populations perform on the task. Lamar and colleagues (2007) examined the relationship between white matter disease severity and working memory in dementia. Working memory was operationally defined as performance on the BDT using serial order scores (i.e., amount of correct numbers an individual was able to recall in the correct placement) and any order scores (i.e., amount of correct numbers an individual was able to recall regardless of placement). In this study, a negative relationship was found between levels of white matter disease and serial order recall on BDT (i.e., individuals with greater white matter disease had lower serial order scores than those with lower levels of white matter disease). While there was no difference in any order recall between the different levels of white matter disease, the variance of any order performance was explained by dementia severity. These findings were further explored by the same research team and an association was found between serial order recall and left-sided white matter disease (i.e., the degeneration of myelin), with higher levels of white matter disease (especially in the posterior horn and frontal centrum semiovale) associated with lower serial order recall scores (Lamar et al., 2008). The centrum semiovale is the common central mass of white matter in horizontal sections of the brain just above the level of the lateral ventricles, and is where many fibers cross to facilitate the transfer of information in the brain (Fernandez-Miranda et al., 2012). The frontal centrum semiovale and posterior horn are parts of the fronto-striatal (important in

attention) and thalamo-frontal loop (important in executive functioning) and the deficits seen in working memory are believed to be due to disruption of these connections, which corresponds with neuroimaging findings (Deary et al., 2006; Lamar et al., 2008; Morris et al., 2016; Guo et al., 2021).

Later research showed that lower serial order recall scores were associated with increased frailty (defined as “a medical syndrome with multiple causes and contributors that is characterized by diminished strength, endurance, and reduced physiologic function that increases an individual's vulnerability for developing increased dependency and/or death"), and higher serial order recall performance on BDT was related to increased scores on letter fluency among individuals with MCI (Ahmed et al, 2015; Ginsberg et al, 2017). Work has also examined how individuals with Parkinson’s disease (PD) with mild cognitive impairment (MCI) perform on the BDT. In comparison to those with PD and normal cognition, participants with PD-MCI showed mild impairment in any order recall and compared to performance on any order recall, showed greater deficits in serial order recall (Bezdicek et al., 2021). Furthermore, the difference in serial order recall increased as the task progressed.

Prior research on the Backwards Digit Task has focused on performance patterns within different clinical populations, with minimal work examining the item level difficulty behind this task. Traditionally, neuropsychological assessments are composed of items of increasing difficulty to identify the upper limit of the examinee’s abilities. Whether this holds true for the BDT is unknown, and while one may presume that the BDT has similar pattern of difficulty as other digit span tasks, this has not been formally examined.

Emrani and colleagues have examined BDT performance patterns (e.g., frequencies and occurrences of transposition errors, perseverations, and omissions, and response times for individual numbers in each trial) in different subtypes of mild cognitive impairment. In their 2018 study, when researchers compared those with mixed and dysexecutive MCI to individuals with amnestic MCI (aMCI) and with no MCI, no difference was found in the scores for positions 1 and 2 of the 5-span block. The mixed and dysexecutive MCI group showed lower scores in positions 3 and 4 than the non-MCI group, and lower scores in position 5 than the non-MCI and aMCI groups. In other words, researchers found that individuals in the mixed and dysexecutive MCI group showed a recency effect in their responses, as they performed similarly to individuals without MCI at the start of the trials, but showed impaired performance in the last three positions. This pattern of performance reflects derailed temporal gradients, i.e., declining performance on executive tests over time, as demonstrated in prior research (Eppig et al., 2012). Individuals in the mixed and dysexecutive MCI group showed more transposition errors (i.e., switching the positions of two numbers) than the non-MCI and aMCI groups, and more omissions and perseverations than the non-MCI group. Researchers proposed that these error patterns are reflective of subcortical white matter alterations (i.e., leukoaraiosis), as individuals with leukoaraiosis have been shown to produce more omissions and transpositions (Hampstead et al., 2010).

Emrani and colleagues (2021) examined latency times of responses in the 5-span trials, comparing individuals with MCI and individuals without MCI. While the average total time for each trial did not differ, individuals without MCI were slower to provide responses for positions 2 and 4, and those with MCI were slower to provide a response

for position 3. Researchers proposed that these time differences reflect differing amounts of cognitive resources required. In other words, individuals without MCI devoted more cognitive resources to the numbers before and after the middle position, while those with MCI devoted more cognitive resources to the middle number. Emrani and colleagues posited that individuals without MCI have a greater capacity to devote cognitive resources to the task which they do so preemptively, and dedicate cognitive resources in the latter half to ensure implementation of instructions. Similarly, they may be taking longer in the beginning as they are preparing the sequence for output (Hurlstone et al., 2014). Conversely, individuals with MCI need more time to produce a response but had a smaller capacity of cognitive resources to do so, devoting the most time (i.e., cognitive resources) mid-task in an effort to sustain the mental set. Compared to individuals without MCI, participants with mild cognitive impairment made more dysexecutive errors and displacement errors. These findings demonstrate differences in test performance as a function of time within a trial between those with and without MCI (Emrani et al., 2021).

2.4 Current Investigation

Mild cognitive impairment is generally considered as an intermediate phase between healthy aging and dementia that signals abnormal cognitive decline. This condition encompasses various subtypes that have shown different clinical trajectories. Individuals with mild cognitive impairment have shown deficits on the Backwards Digit Task, a test based on Fuster's model of 'executive attention,' with recent work examining the difference in clinical presentations across the subtypes. This current investigation

aims to further examine the clinical presentation of different MCI subtypes, particularly their performance on the Backwards Digit Task.

III. Methodology

3.1 New Jersey Institute for Successful Aging Memory Assessment Program (MAP)

3.1.1 Memory Assessment Program (MAP). Participants in this study were recruited from the New Jersey Institute for Successful Aging Memory Assessment Program (MAP). This diagnostic program is for adults over 54 years old who are experiencing memory or language problems, difficulty with planning and organization, decreased ability to carry out basic daily activities, or loss of motivation. Referrals came from a primary care physician, family member or caregiver, or from a self-referral. Through the program, an interdisciplinary team of geriatricians, geriatric psychiatrists, neuropsychologists, and social workers work alongside each other to address the needs and goals of patients and caregivers.

The program typically requires two or three separate appointments. At the initial evaluation, patients meet with a physician and a social worker. The physician performs a physical evaluation, documents the patient's medical and social history, and briefly assesses cognitive and functional domains. Additionally, the physician will discuss any additional issues relevant to the patient/their family member(s) (e.g., advanced care planning, safety concerns). At this appointment, a physician would order an MRI study of the brain and appropriate blood serum tests (i.e., B12 folate, thyroid function) to evaluate reversible causes of dementia. The social worker interviews the patient and their family member(s) about family and social history, assesses current level of functioning,

identifies helpful services and resources, and provides information on resources and disease-related education.

Patients have a second appointment with a neuropsychologist during which they undergo a neuropsychological evaluation. The neuropsychological assessment was administered by a trained research assistant or licensed psychologist. The neuropsychological protocol included the following tests: Mini-Mental Status Examination, Geriatic Depression Scale (short form), Boston revision of Wechsler Memory Scale Mental Control subtest, verbal fluency (FAS), semantic fluency (animals), Trials Part B, 60-item Boston Naming Test, Wechsler Adult Intelligence Scale III Similarities subtest, California Verbal Learning Test, 9-word short form. All participants also received the Backwards Digit Span Task. Per clinical judgment of the psychologist, other tests were given as needed as a part of standard clinical care, including: Wechsler Memory Scale Symbol Span and Logical Memory subtests, Wechsler Adult Intelligence Scale, 3rd edition, Digit Span and Digit Symbol subtests, Trails Part A, Judgment of Line Orientation, Pennsylvania Verbal Learning Test, clock drawing test, Wide Range Achievement Test word reading subtest, Functional Activities Questionnaire, Neuropsychiatric Inventory Questionnaire, Everyday Cognition scales (ECog), Brief Visuospatial Memory Test.

Before the patient's last appointment, there is an interdisciplinary team conference, composed of individuals from social work, geriatric psychiatry, and neuropsychology, in which the team determines a diagnosis for the patient. In this meeting, the team also discusses a patient-centered plan of care and prepares a comprehensive report for the patient and their family member(s). At their final

appointment, the patient and their family member(s) meet with the physician they initially saw, who reviews the test results and diagnosis in depth. The provider may prescribe medication to help with their memory problems and address other interventions pertaining to mood and behavior, safety, daily functioning, or sleep. The social worker is also involved in this appointment, as they meet with the patient and their family member(s) to review recommendations, answer any questions, and provide additional information about community-based resources.

3.1.2 Participants. Data was collected at the New Jersey Institute for Successful Aging Memory Assessment Program (MAP) from patients seen from February 2016 to March 2019. Individuals were excluded if they had a history of head injury, dementia, substance abuse, and major psychiatric disorders including major depression, epilepsy, B12, folate, or thyroid deficiency. The criteria for MCI included the evidence of cognitive impairment (via performance on neuropsychological measures) relative to age and education, preservation of general functional abilities (indicated by intact scores on standardized questionnaires completed by a knowledgeable family member). The diagnosis of MCI was determined for each patient at an interdisciplinary team conference, composed of individuals from social work, geriatric psychiatry, and neuropsychology. All participants had a knowledgeable family member available to provide information regarding their functional status via standardized questionnaires. Participants in this sample were predominately white, well-educated ($\mu = 14.74 \pm 2.65$), and female (72.1%) (see Table 1).

3.2 Classification of Subtle and Mild Cognitive Impairment

3.2.1 Classification of Mild Cognitive Impairment. Jak/Bondi comprehensive criteria was used to identify mild cognitive impairment, and individuals with MCI scored greater than one standard deviation below normative expectations on 2 of 3 tests in a given domain (Jak et al., 2009). For classification for presence and subtype of mild cognitive impairment, nine test scores were used spanning three domains: executive control (comprised of 3 tests: Trail Making Test Part B, Boston revision of Mental Control subtest from Wechsler Memory Scale, letter fluency (FAS form)), language (comprised of 3 tests: Boston Naming Test, semantic fluency (animals form), Wechsler Adult Intelligence Scale, 3rd edition, similarities subtest), and verbal memory (three scores from the California Verbal Learning Test, 9 word short form: total immediate free recall, delayed free recall, delayed recognition discriminability measure). Impairment in the executive control domain resulted in a classification of dysexecutive MCI, impairment in the verbal episodic memory domain resulted in a classification of amnestic MCI, and impairment in naming/lexical access resulted in a classification of language MCI. (Of note, there were no individuals who were only impaired in the domain of language.) Impairment in two or more domains resulted in a classification of mixed MCI. Prior research has demonstrated similar neuropsychological performance between individuals with mixed and dysexecutive MCI (Bondi et al., 2014; Thomas et al., 2017; Eppig et al., 2012). Due to this and a small sample size, these groups were combined to form a mixed/dysexecutive MCI group.

3.2.2 Classification of Subtle and Mild Cognitive Impairment. For classification of subtle mild cognitive impairment, criteria from Edmonds and colleagues

(2015) was utilized, and individuals who had two tests in different domains below one standard deviation were classified as having subtle MCI. Individuals who had one or no tests below one standard deviation were categorized into a control group (i.e., no mild cognitive impairment).

3.3 Backwards Digit Task (BDT)

3.3.1 Backwards Digit Task Scoring. There are two types of scores for the Backwards Digit Span Test: serial order and any order. For both types of scores, each numeric response is scored for a score of zero or one, with the highest possible score being the number of items in a trial. In serial order scoring, a response is counted as correct only if the correct number is said in the correct placement. In any order scoring, a response is counted as correct if a number from the sequence is successfully given in the participant's response, regardless of placement. Below is an example to further demonstrate this scoring method.

Stimulus item: 12345	Correct response: 54321
Participant response: 52431	
Serial order: 52431 Score = 2/5	Any order: 52431 Score = 5/5

If an individual were to say 52431, their serial order score would be 2, as the first and last numbers (1 and 5) are the correct responses *and* in the correct positions. For this same response, their any-order score would be 5, as they successfully repeated all of the numbers in the sequence.

Sequencing difficulty was operationally defined by the individual's score divided by the number of items in a trial multiplied by 100. By examining sequencing difficulty (values ranging from 0 to 100) instead of scores (values ranging from 0 to 5), potential restriction of range issues are avoided. When range is restricted, Type II error (false negative) increases and effects may be underestimated or undetected (Bruce, 2018). By transforming the data linearly, the data model is clearer without introducing measurement error.

3.3.2 Backwards Digit Test Error Types. The error types that were examined in this study are described below and the reader is provided with example items to help illustrate these concepts. This information is also presented in table format (Table 2).

Anticipation errors are when a number appears earlier in the sequence than it is supposed to. Conversely, postponement is the opposite of anticipation, and a number appears later in the sequence than it is supposed to. These errors are further classified by the distance in which the number is displaced. In a five-span trial for example, an anticipation -4 error would mean that the number was four positions away from the correct position.

Capture errors can be categorized in four different ways. These errors are either between or within trials, and forward or backward. Between-trial capture errors occur when a number from either of the preceding two trials is pulled into the current response, creating a consecutive string of digits (e.g., 123 instead of 173). Within-trial capture errors occur when an individual groups numbers within the same trial, creating a consecutive string of digits. Both within-trial and between-trial capture errors are either forward or backward, indicating the order of the numbers. (i.e., Forward errors indicate

the numbers provided are in ascending order, and backward errors indicate the numbers provided are in descending order.)

Perseverations are an inappropriate repetition of a number. There are two types of perseverations, categorized by what item is being repeated. In a between-trial perseveration, a number from the preceding two trials is pulled into the current response. In a within-trial perseveration, a number within the trial is repeated.

3.4 Research Questions

The current study is an extension of the work done by Emrani and colleagues, further examining the performance patterns of MCI subtypes of the Backwards Digit Test. On this test, research by Emrani and colleagues (2018, 2021) and Eppig and colleagues (2012) has demonstrated that individuals with mixed and dysexecutive MCI have declining performance over the trial and produce more errors than those without MCI. For my primary analyses, I examined the difficulty of each trial in the 5-digit span block of the Backwards Digit Test within a sample of individuals with mild cognitive impairment to assess if the difficulty progresses with consecutive trials. I hypothesized that the mixed and dysexecutive group would show a temporal derailment as the task progresses, as shown within-trial in prior research (Eppig et al., 2012; Emrani et al., 2018). I hypothesized that the amnestic, subtle, and non-MCI groups would not show temporal derailment. Difficulty is defined and measured as trial sequencing accuracy, calculated by dividing the total numbers correct by the total numbers in the trial block multiplied by 100. Any-order and serial-order trial accuracy was examined. If trial difficulty varied across the different subtypes of MCI, I planned to further investigate these findings by examining which trials show the most variability.

As a secondary analysis, to examine potential sources of variability in trial difficulty, I investigated different types of errors (i.e., perseverations, anticipation and postponement, and capture errors), the descriptions of which can be found below. Given the prior research on MCI subtype performance on the BDT, I hypothesized that the mixed/dysexecutive group would have lower trial accuracy scores and anticipated a recency effect in their performance, with the discrepancy of trial accuracy scores becoming larger as the trials progress. Relatedly, I hypothesized that the mixed/dysexecutive group would make more errors (of all types) than those without MCI, and post hoc analyses examined what types of errors were driving this variability in trial accuracy. I did not anticipate the amnestic and subtle MCI groups would make a significant amount of errors given prior research. If there would be a significant difference, I anticipated this effect size to be small.

3.5 Statistical Analyses

3.5.1 Preliminary ANOVAs and Chi-Square Analyses. Prior to statistical analyses, tests were conducted to assess for statistically significant differences between groups. One-way analysis of variance tests were conducted to assess for differences in quantitative demographic variables (i.e., age, education), and chi-square tests were conducted to assess for differences in sex.

3.5.2 Assumptions Testing. First, all assumptions associated with hierarchical regression were tested. For violated assumptions, appropriate steps were taken to address the source of the violation. The assumptions testing procedures and methods to address violated assumptions are reported in the results section.

Hierarchical regression is a part of the general linear model (GLM), which refers to the conventional model of a continuous response variable given continuous and/or categorical predictors. The GLM is composed of two parts: the model for the means (i.e., a weighted linear function of an individual's values on predictor variables) and the model for the variance (i.e., an error term, capturing any variability). Together, these two parts provide a predicted value. In calculating a model that fits the data of the sample, ordinary least squares (OLS) estimation is used. OLS aims to minimize the sum of squared error, or the distance between the observed data point and the regression line. In this estimation method, there are assumptions that are made and must be tested to ensure proper application of OLS.

Ordinary least squares estimation assumes that the model is correctly specified. This means that the relationship between the dependent variable and independent variables is linear, and all important independent variables are included in the model. To test for this assumption, polynomial terms for variables were computed and tested for inclusion. If a polynomial (i.e., nonlinear) term explains a significant amount of variance (indicated by a significant F change), it was included in the model to ensure proper specification. All potentially important independent variables were included on the first step to control for any variance that they may be contributing. In prior research, younger adults, individuals with higher levels of education, and men have shown better performance backwards digit tasks (Bopp & Verhaeghen, 2005; Jorm et al., 2004; Hester et al., 2004). By being entered in on the first step, variance from these known factors that influence performance on neurocognitive testing (i.e., age, sex, and education) are accounted for.

OLS assumes that there is no measurement error in the independent variables. Since the variables included in this study are patient responses on tests at one time point and demographic data, there are no pertinent reliability aspects to examine. Given that only two individuals working alongside each other were responsible for data collection, it is assumed that the variables in this study were collected without error. OLS assumes that the residuals (i.e., errors) have a normal distribution and constant variance (i.e., are homoscedastic). The errors should be unrelated to any of the predictors or predicted outcome, and should have a constant variance across any given value of X.

Additionally, the errors should have a normal distribution with a mean of zero. This assumption can be violated when there is a non-normal distribution, a non-linear model, or presence of large outliers (as OLS seeks to minimize the distance between the regression line and the data). OLS is fairly robust to violations of homoscedasticity but if this violation is extreme, I planned to utilize weighted least squares estimation instead of OLS. If the errors had a non-normal distribution, I assessed for outliers (i.e., scores that are ± 3.3 standard deviations from the mean, using the Tabachnick & Fidell (2013) criteria) and removed them from the sample for analysis. Violations of linearity have already been conducted and addressed when ensuring proper specification of the model.

Lastly, OLS assumes that the residuals are independent of one another, meaning that errors are statistically independent and uncorrelated with each other as a result of random sampling. Therefore, knowing the value of the error term tells us nothing about the values of X or Y. Since random sampling was utilized for the current sample, this assumption has been met.

3.5.3 Main Hierarchical Regression Analyses. After testing for assumptions, hierarchical regressions were conducted to assess for variability in serial and any order trial accuracy across the different MCI subtypes via IBM SPSS Statistics (v.27). Trial accuracy was entered as the dependent variable. The MCI groups (non-MCI, subtle MCI, amnestic MCI, and mixed/dysexecutive MCI) were dummy coded to allow for comparisons between group means. Since there are four groups, there are 3 dummy codes (*k - 1)* needed for one comparison. The demographic variables of age and years of education were centered. Centering was done by subtracting the means of age and education from each value of age and education. Centering helps control for multicollinearity (or overlap) between predictors because when the mean is bigger, the predictors are more highly correlated with the interaction (Aiken & West, 1991). Variability of known factors that influence performance on neurocognitive testing (i.e., centered age, sex, and centered education) were controlled for by being entered in on the first step. Any interactions and polynomials that contributed a significant amount of variance were included on the second step to ensure proper model specification. For the last step, dummy coded MCI groups were entered to examine the remaining variability that MCI subtype is explaining in trial difficulty. These steps were repeated four times, as new dummy codes needed to be entered on the last step to compare all of the groups.

The methods stated above were used, as hierarchical regression was utilized to assess for differences in error type frequencies across different types of mild cognitive impairment. Variability of known factors that influence performance on neurocognitive testing (i.e., centered age, sex, and centered education) were controlled for by being entered in on the first step, any significant interactions and polynomials were included on

the second step to ensure proper model specification, and dummy coded MCI groups were entered on the last step. This procedure was repeated four times, as new dummy codes needed to be entered on the last step to compare all groups.

For all regressions, I assessed statistical significance by looking at the model summary, specifically the F change value of the largest model. If this was significant, I looked at the coefficients table to determine what variable(s) are significantly contributing to the model. For any significant variables, I examined practical significance by looking at effect sizes, specifically partial eta squared values, to examine what trials show the most variability. The larger the effect size, the more unique variability that variable is explaining in the dependent variable.

3.5.4 Primary Analyses. Multiple regression analyses were conducted to evaluate the variability in serial and any order sequencing accuracy across the different MCI subtypes, and blockwise entry was utilized to control for the variability due to age, education, and sex. A total of 136 people who were seen in the New Jersey Institute for Successful Aging Memory Assessment Program (MAP) were included in this study, and were categorized into clinical subgroups (i.e., cognitively normal, subtle mild cognitive impairment, amnestic cognitive impairment, or mixed/dysexecutive mild cognitive impairment) based on Edmonds criteria and Jak/Bondi comprehensive criteria (Edmonds et al., 2015; Jak et al., 2009). In the sample, 53 participants were cognitively normal (i.e., no impairment or impairment on one test), 18 participants had subtle cognitive impairment, 30 participants had amnestic MCI, and 35 participants had dysexecutive/mixed MCI.

IV. Results

4.1 Preliminary Analyses

4.1.1 Preliminary ANOVAs and Chi-Square Analyses. One-way analysis of variances were conducted to assess for differences in age and education. Age ($F(3,132) = 1.31$) and education ($F(3,132) = 1.42$) did not significantly vary across groups (p's > .05). Similarly, the proportion of men and women was not significantly different across groups, X^2 (3, N = 136) = 1.97, $p > .05$. The means and standard deviations of age and education, as well as the proportion of women in each category, can be found in Table 1.

4.1.2 Assumptions Testing. Three cases were identified as outliers, as they had extreme z-scores on total any order or serial order scores of the 5-span block (i.e., ± 3.3 standard deviations from the mean, using the Tabachnick & Fidell (2013) criteria), and were excluded from analyses.

To statistically assess for the presence of heteroscedasticity, the variable age was divided into three groups of equivalent size. Residuals for age were produced by conducting hierarchical regressions for serial and any order trial accuracy for each five-span trial. Across the three age groups, the ratio of the largest to the smallest conditional variance of the age residuals was examined for each set of residuals. The same procedure was repeated for education. As all ratios were under 10 (criteria from Cohen et al., 2003), the assumption of homoscedasticity was considered met. To assess for the assumption of normally distributed residuals, the residuals were plotted in a histogram with a normal curve overlaid. OLS is fairly robust to violations of this assumption, particularly in cases with large sample sizes and where the magnitude of the violation is not extreme (Cohen

et al., 2003). The distribution of the residuals appears normal with a mean very close to zero, supporting the assumption of normality.

To ensure correct model specification, polynomials and interaction terms were tested for significance. Quadratic and polynomial terms were created for age and education by raising them to the power of 2 (for the quadratic term) and 3 (for the cubic term). To test for inclusion, the centered independent variable (i.e., age or education) and its polynomial terms were entered into hierarchical regressions, with any order or serial order trial accuracy scores as the dependent variable. The centered independent variable (e.g., centered age) was entered on the first step, the quadratic term for age was entered on the second step, and the cubic term for age was entered on the third and last step. Polynomial terms that explained a significant amount of variance were planned to be included in the main analyses. No quadratic or cubic terms for age or education were found to be significant (all p's > .05) and were therefore not included in main analyses.

Interaction terms were calculated, and all combinations of the following variables were constructed to create interaction terms: centered age, centered education, sex, and dummy coded group membership. To test for inclusion, interactions were entered in on the last step of hierarchal regressions, following entry of demographic variables (i.e., centered age and education, sex) and dummy coded groups. Several significant interactions were found; however, all interactions had small effect sizes (f^2 < .15, per Cohen (1988)) and all but two had insufficient power (i.e., power < .80). Additionally, the variability of the covariates was to be accounted for by using blockwise entry on the step preceding the entry of dummy coded groups. For these reasons, interactions were not

included in the final models. (See Appendix for significant interactions and power analyses.)

4.2 Primary Analyses

4.2.1 Power Analyses for Primary Analyses. The effect sizes (f^2) for regressions were calculated by hand by dividing their explained variance (R^2) over the total unexplained model variance (i.e., $1 - R^2$) (Selya et al., 2012). A post-hoc power analysis was conducted using G*Power (Version 3.1) (Erdfelder et al., 1996).

Post-hoc power analyses for regressions examining trial 15 serial-order sequencing difficulty revealed high statistical power, yielding power estimates of .99 for all comparisons. In analyzing trial 16 serial-order sequencing difficulty, when comparing the groups to the subtle cognitive impairment and amnestic MCI group, high statistical power was found (.89). High statistical power was found (.88) when comparing groups to the cognitively normal group for trial 16 serial-order sequencing difficulty. For trial 17 serial-order sequencing difficulty, high statistical power was found (.89) when comparing the cognitively normal and subtle cognitive impairment group to the other groups. High statistical power was found (.91) when comparing the amnestic MCI group to the other groups on trial 17 serial-order sequencing difficulty. For trial 18 serial-order sequencing difficulty, high statistical power was found (.97) when comparing the subtle cognitive impairment and amnestic MCI groups to the other groups. High statistical power was found (.96) when comparing the cognitively normal group to the other groups on trial 18 serial-order sequencing difficulty. For trial 19 serial-order sequencing difficulty, insufficient statistical power was found when comparing groups to the cognitively normal group (.70), subtle cognitive impairment group (.69), and amnestic MCI group (.66). In

analyzing trial 20 serial-order sequencing difficulty, when comparing the groups to the subtle cognitive impairment and amnestic MCI group, high statistical power was found (.94). High statistical power was found (.93) when comparing groups to the cognitively normal group for trial 20 serial-order sequencing difficulty. Post-hoc power analyses for regressions examining trial 21 serial-order sequencing difficulty revealed high statistical power, yielding power estimates of 1.00 for all comparisons.

4.2.2 Primary Analyses Findings for Serial-Order Sequencing Difficulty. The mixed/dysexecutive MCI group had significantly lower serial-order sequencing difficulty than the other clinical subgroups (Figure 2). For trial 15 serial-order sequencing difficulty, there was a significant amount of variance explained by education and clinical groups. When utilizing dummy codes to compare groups to the cognitively normal group, two predictors explained 18.7% of the variance (R^2 = .187, $F(6,129) = 4.904$, $p < .001$, f^2 = .230). The mixed/dysexecutive MCI group had significantly lower serial-order sequencing difficulty scores on trial 15 than the cognitively normal group (b = -16.279, $p < .001$, η_p^2= .073), and education was found to positively correlate with sequencing difficulty (b = 2.313, p = .002, η_p^2= .061). When utilizing dummy codes to compare groups to the subtle cognitive impairment group, two predictors explained 17.7% of the variance (R^2 = .177, $F(5,130) = 5.582$, $p < .001$, f^2 = .215). The mixed/dysexecutive MCI group had significantly lower serial-order sequencing difficulty scores on trial 15 than the subtle cognitive impairment group (b = -18.156, $p < .001$, η_p^2= .101), and education was found to positively correlate with sequencing difficulty (b = 2.293, p = .003, η_p^2= .060). When utilizing dummy codes to compare groups to the amnestic MCI group, two predictors explained 16.5% of the variance (R^2 = .165, $F(4,131) = 6.485$, $p < .001$, f^2 =

.198). The mixed/dysexecutive MCI group had significantly lower serial-order sequencing difficulty scores on trial 15 than the amnestic MCI group (b = -16.237, p < .001, η_p^2= .089), and education was found to positively correlate with sequencing difficulty (b = 2.462, p = .001, η_p^2= .071).

For trial 16 serial-order sequencing difficulty, there was a significant amount of variance explained by clinical groups. When utilizing dummy codes to compare groups to the cognitively normal group, one predictor explained 11.2% of the variance (R^2 = .112, F(6,129) = 2.707, p = .004, f^2 = .126). The mixed/dysexecutive MCI group had significantly lower serial-order sequencing difficulty scores on trial 16 than the cognitively normal group (b = -19.645, p < .001, η_p^2= .095). When utilizing dummy codes to compare groups to the subtle cognitive impairment group, one predictor explained 10.9% of the variance (R^2 = .109, F(5,130) = 3.168, p = .001, f^2 = .122). The mixed/dysexecutive MCI group had significantly lower serial-order sequencing difficulty scores on trial 16 than the subtle cognitive impairment group (b = -18.525, p < .001, η_p^2= .094). When utilizing dummy codes to compare groups to the amnestic MCI group, one predictor explained 10.3% of the variance (R^2 = .103, F(4,131) = 3.761, p < .001, f^2 = .115). The mixed/dysexecutive MCI group had significantly lower serial-order sequencing difficulty scores on trial 16 than the amnestic MCI group (b = -17.104, p < .001, η_p^2= .089).

For trial 17 serial-order sequencing difficulty, there was a significant amount of variance explained by clinical groups. When utilizing dummy codes to compare groups to the cognitively normal group, one predictor explained 11.5% of the variance (R^2 = .115, F(6,129) = 2.790, p = .008, f^2 = .130). The mixed/dysexecutive MCI group had

significantly lower serial-order sequencing difficulty scores on trial 17 than the cognitively normal group (b = -14.424, p = .007, η_p^2= .052). When utilizing dummy codes to compare groups to the subtle cognitive impairment group, one predictor explained 10.9% of the variance (R^2 = .109, $F(5,130) = 3.184$, p = .004, f^2 = .122). The mixed/dysexecutive MCI group had significantly lower serial-order sequencing difficulty scores on trial 17 than the subtle cognitive impairment group (b = -15.914, p = .002, η_p^2= .071). When utilizing dummy codes to compare groups to the amnestic MCI group, one predictor explained 10.9% of the variance (R^2 = .109, $F(4,131) = 4.009$, $p < .001$, f^2 = .122). The mixed/dysexecutive MCI group had significantly lower serial-order sequencing difficulty scores on trial 17 than the amnestic MCI group (b = -16.041, $p < .001$, η_p^2= .080).

For trial 18 serial-order sequencing difficulty, there was a significant amount of variance explained by clinical groups. When utilizing dummy codes to compare groups to the cognitively normal group, one predictor explained 14.6% of the variance (R^2 = .146, $F(6,129) = 3.680$, $p < .001$, f^2 = .171). The mixed/dysexecutive MCI group had significantly lower serial-order sequencing difficulty scores on trial 18 than the cognitively normal group (b = -23.185, $p < .001$, η_p^2= .120). When utilizing dummy codes to compare groups to the subtle cognitive impairment group, one predictor explained 14.4% of the variance (R^2 = .144, $F(5,130) = 4.388$, $p < .001$, f^2 = .168). The mixed/dysexecutive MCI group had significantly lower serial-order sequencing difficulty scores on trial 18 than the subtle cognitive impairment group (b = -22.314, $p < .001$, η_p^2= .123). When utilizing dummy codes to compare groups to the amnestic MCI group, one predictor explained 13.7% of the variance (R^2 = .137, $F(4,131) = 5.190$, $p < .001$, f^2 =

.159). The mixed/dysexecutive MCI group had significantly lower serial-order sequencing difficulty scores on trial 18 than the amnestic MCI group (b = -20.575, p < .001, η_p^2 = .116).

For trial 19 serial-order sequencing difficulty, there was a significant amount of variance explained by clinical groups. When utilizing dummy codes to compare groups to the cognitively normal group, one predictor explained 7.9% of the variance (R^2 = .079, $F(6,129)$ = 1.832, p = .042, f^2 = .086). The mixed/dysexecutive MCI group had significantly lower serial-order sequencing difficulty scores on trial 19 than the cognitively normal group (b = -16.069, p = .004, η_p^2 = .061). When utilizing dummy codes to compare groups to the subtle cognitive impairment group, one predictor explained 7.3% of the variance (R^2 = .073, $F(5,130)$ = 2.039, p = .024, f^2 = .079). The mixed/dysexecutive MCI group had significantly lower serial-order sequencing difficulty scores on trial 19 than the subtle cognitive impairment group (b = -14.516, p = .007, η_p^2 = .054). When utilizing dummy codes to compare groups to the amnestic MCI group, one predictor explained 6.8% of the variance (R^2 = .068, $F(4,131)$ = 2.380, p = .009, f^2 = .073). The mixed/dysexecutive MCI group had significantly lower serial-order sequencing difficulty scores on trial 19 than the amnestic MCI group (b = -13.142, p = .009, η_p^2 = .050).

For trial 20 serial-order sequencing difficulty, there was a significant amount of variance explained by education and clinical groups. When utilizing dummy codes to compare groups to the cognitively normal group, two predictors explained 12.8% of the variance (R^2 = .128, $F(6,129)$ = 3.153, p = .010, f^2 = .147). The mixed/dysexecutive MCI group had significantly lower serial-order sequencing difficulty scores on trial 20 than the

cognitively normal group (b = -16.487, p = .002, η_p^2= .065), and education was found to positively correlate with sequencing difficulty (b = 1.767, p = .035, η_p^2= .031). When utilizing dummy codes to compare groups to the subtle cognitive impairment group, two predictors explained 12.6% of the variance (R^2 = .126, $F(5,130) = 3.757$, p = .004, f^2 = .144). The mixed/dysexecutive MCI group had significantly lower serial-order sequencing difficulty scores on trial 20 than the subtle cognitive impairment group (b = -17.311, p < .001, η_p^2= .078), and education was found to positively correlate with sequencing difficulty (b = 1.758, p = .036, η_p^2= .030). When utilizing dummy codes to compare groups to the amnestic MCI group, two predictors explained 11.9% of the variance (R^2 = .119, $F(4,131) = 4.4217$ p = .001, f^2 = .135). The mixed/dysexecutive MCI group had significantly lower serial-order sequencing difficulty scores on trial 20 than the amnestic MCI group (b = -15.647, p = .001, η_p^2= .071), and education was found to positively correlate with sequencing difficulty (b = 1.905, p = .021, η_p^2= .036).

For trial 21 serial-order sequencing difficulty, there was a significant amount of variance explained by education and clinical groups. When utilizing dummy codes to compare groups to the cognitively normal group, two predictors explained 20.2% of the variance (R^2 = .202, $F(6,129) = 5.453$, p < .001, f^2 = .253). The mixed/dysexecutive MCI group had significantly lower serial-order sequencing difficulty scores on trial 21 than the cognitively normal group (b = -22.74, p < .001, η_p^2= .114), and education was found to positively correlate with sequencing difficulty (b = 2.407, p = .004, η_p^2= .053). When utilizing dummy codes to compare groups to the subtle cognitive impairment group, two predictors explained 19.9% of the variance (R^2 = .199, $F(5,130) = 6.473$, p < .001, f^2 = .248), The mixed/dysexecutive MCI group had significantly lower serial-order

sequencing difficulty scores on trial 21 than the subtle cognitive impairment group (b = -21.6, $p < .001$, $\eta_p^2 = .114$), and education was found to positively correlate with sequencing difficulty ($b = 2.419$, $p = .004$, $\eta_p^2 = .053$). When utilizing dummy codes to compare groups to the amnestic MCI group, two predictors explained 19.6% of the variance ($R^2 = .196$, $F(4,131) = 7.977$, $p < .001$, $f^2 = .244$). The mixed/dysexecutive MCI group had significantly lower serial-order sequencing difficulty scores on trial 21 than the amnestic MCI group (b = -22.781, $p < .001$, $\eta_p^2 = .141$), and education was found to positively correlate with sequencing difficulty ($b = 2.316$, $p = .005$, $\eta_p^2 = .051$).

As a post-hoc analysis, to statistically assess for potential temporal derailment over trials or a recency effect in serial-order sequencing difficulty within groups, a series of paired samples t-tests were conducted. Insufficient power was found when examining the subtle cognitive impairment group and amnestic MCI group, .52 and .75 respectively. Analyses revealed sufficient statistical power when examining the cognitively normal group and mixed/dysexecutive MCI group (.81 and .95, respectively). No significant differences were observed in serial-order sequencing difficulty across trials for the cognitively normal group and mixed/dysexecutive MCI group. For the subtle cognitive impairment group, there was a significant difference between trial 15 serial-order sequencing difficulty (M = 90, SD = 17.15) and trial 16 serial-order sequencing difficulty (M = 77.78, SD = 21.57); $t(17) = 2.17$, $p = .045$, $d = .51$. For the amnestic MCI group, there was a significant difference between trial 20 serial-order sequencing difficulty (M = 72, SD = 27.59) and trial 21 serial-order sequencing difficulty (M = 84.67, SD = 20.8); $t(29) = -2.43$, $p = .021$, $d = .44$.

4.2.3 Power Analyses for Any-Order Sequencing Difficulty. The effect sizes (f^2) for regressions were calculated by hand by dividing their explained variance (R^2) over the total unexplained model variance (i.e., $1 - R^2$) (Selya et al., 2012). A post-hoc power analysis was conducted using G*Power (Version 3.1) (Erdfelder et al., 1996). Post-hoc power analyses for regressions examining trial 15 any-order sequencing difficulty revealed high statistical power, yielding power estimates of .90 when comparing the cognitively normal and amnestic MCI groups to the other groups. In analyzing trial 15 any-order sequencing difficulty, when comparing the groups to the subtle cognitive impairment group, high statistical power was found (.89). For trial 16 any-order sequencing difficulty, insufficient statistical power was found when comparing groups to the cognitively normal group (.71), subtle cognitive impairment group (.69), and amnestic MCI group (.65). For trial 17 any-order sequencing difficulty, high statistical power was found (.83) when comparing the cognitively normal group to the other groups. High statistical power was found (.85) when comparing the subtle cognitive impairment group to the other groups on trial 17 any-order sequencing difficulty. High statistical power was found (.81) when comparing the amnestic MCI group to the other groups on trial 17 any-order sequencing difficulty. Insufficient statistical power was found for trials 18, 19, 20, and 21 any-order sequencing difficulty when comparing groups to the cognitively normal group (.60, .28, .47, .42), subtle cognitive impairment group (.63, .27, .34, .44), and amnestic MCI group (.64, .28, .38, .42).

4.2.4 Primary Analyses Findings for Any-Order Sequencing Difficulty. For trials 16, 18, 19, 20, and 21 any-order sequencing difficulty, there was not a significant amount of variance explained by demographic variables or clinical groups (*p's* > .05).

The mixed/dysexecutive MCI group had significantly lower any-order sequencing difficulty on trials 15 and 17 than the other clinical subgroups (Figure 3). For trial 15 any-order sequencing difficulty, there was a significant amount of variance explained by clinical groups. When utilizing dummy codes to compare groups to the cognitively normal group, one predictor explained 11.9% of the variance (R^2 = .119, F(6,129) = 2.897, p = .021, f^2 = .135). The mixed/dysexecutive MCI group had significantly lower any-order sequencing difficulty scores on trial 15 than the cognitively normal group (b = -5.224, p = .016, η_p^2 = .041). When utilizing dummy codes to compare groups to the subtle cognitive impairment group, one predictor explained 11% of the variance (R^2 = .110, F(5,130) = 3.200, p = .015, f^2 = .124). The mixed/dysexecutive MCI group had significantly lower any-order sequencing difficulty scores on trial 15 than the subtle cognitive impairment group (b = -5.993, p = .004, η_p^2 = .060). When utilizing dummy codes to compare groups to the amnestic MCI group, one predictor explained 10.5% of the variance (R^2 = .105, F(4,131) = 3.843, p = .005, f^2 = .117). The mixed/dysexecutive MCI group had significantly lower any-order sequencing difficulty scores on trial 15 than the amnestic MCI group (b = -5.474, p = .005, η_p^2 = .055).

For trial 17 any-order sequencing difficulty, there was a significant amount of variance explained by clinical groups. When utilizing dummy codes to compare groups to the cognitively normal group, one predictor explained 10% of the variance (R^2 = .100, F(6,129) = 2.391, p = .031, f^2 = .111). The mixed/dysexecutive MCI group had significantly lower any-order sequencing difficulty scores on trial 17 than the cognitively normal group (b = -6.776, p = .008, η_p^2 = .051). When utilizing dummy codes to compare groups to the subtle cognitive impairment group, one predictor explained 9.9% of the

variance (R^2 = .099, $F(5,130) = 2.860$, p = .012, f^2 = .110). The mixed/dysexecutive MCI group had significantly lower any-order sequencing difficulty scores on trial 17 than the subtle cognitive impairment group (b = -7.064, p = .003, η_p^2 = .062). When utilizing dummy codes to compare groups to the amnestic MCI group, two predictors explained 8.6% of the variance (R^2 = .086, $F(4,131) = 3.087$, p = .008, f^2 = .094). The mixed/dysexecutive MCI group had significantly lower any-order sequencing difficulty scores on trial 17 than the amnestic MCI group (b = -6.048, p = .008, η_p^2 = .050), and women had significantly lower any-order sequencing difficulty scores than men (b = -4.46, p = .046, η_p^2 = .028).

As a post-hoc analysis, to statistically assess for potential temporal derailment over trials or a recency effect in any-order sequencing difficulty within groups, a series of paired samples t-tests were conducted. Insufficient power was found when examining the subtle cognitive impairment group and amnestic MCI group, .52 and .75 respectively. Analyses revealed sufficient statistical power when examining the cognitively normal group and mixed/dysexecutive MCI group (.81 and .95, respectively). No significant differences were observed in any-order sequencing difficulty across trials for the cognitively normal group, amnestic MCI group, and mixed/dysexecutive MCI group. For the subtle cognitive impairment group, there was a significant difference between trial 15 any-order sequencing difficulty (M = 98.89, SD = 4.71) and trial 19 any-order sequencing difficulty (M = 91.11, SD = 12.31); $t(17) = 2.36$, p = .030, d = .55. Additionally, within the subtle cognitive impairment group, there was a significant difference between trial 19 any-order sequencing difficulty (M = 91.11, SD = 12.31) and

trial 20 any-order sequencing difficulty (M = 97.78, SD = 6.47); $t(17) = -2.38$, $p = .029$, $d = .56$.

4.2.5 Power Analyses for Error Types. The effect sizes (f^2) for regressions were calculated by hand by dividing their explained variance (R^2) over the total unexplained model variance (i.e., $1 - R^2$) (Selya et al., 2012). A post-hoc power analysis was conducted using G*Power (Version 3.1) (Erdfelder et al., 1996).

For perseverative error analyses, insufficient statistical power was found when comparing groups to the cognitively normal group (.43), subtle cognitive impairment group (.46), and amnestic MCI group (.50). In analyzing capture errors, when comparing the groups to the subtle cognitive impairment and amnestic MCI group, high statistical power was found (.99). High statistical power was found (.98) when comparing groups to the cognitively normal group for capture error variability. Post-hoc power analyses for regressions examining anticipation and postponement errors revealed high statistical power, yielding power estimates of 1.00 for all comparisons.

4.3 Secondary Analyses

4.3.1 Error Types. For perseverative errors, there was not a significant amount of variance explained by demographic variables or clinical groups (*p's* > .05). For capture errors, there was a significant amount of variance explained by education and clinical groups. When utilizing dummy codes to compare groups to the cognitively normal group, one predictor explained 16.5% of the variance ($R^2 = .165$, $F(6,129) = 4.263$, $p < .001$, $f^2 = .198$). The mixed/dysexecutive MCI group had significantly more capture errors cognitively normal group ($b = 1.443$, $p < .001$, $\eta_p^2 = .114$). When utilizing dummy codes to compare groups to the subtle cognitive impairment group, one predictor explained

16.2% of the variance (R^2 = .162, F(5,130) = 5.040, p < .001, f^2 = .193). The mixed/dysexecutive MCI group had significantly more capture errors than the subtle cognitive impairment group (b = 1.368, p < .001, η_p^2 = .114). When utilizing dummy codes to compare groups to the amnestic MCI group, one predictor explained 15.4% of the variance (R^2 = .154, F(4,131) = 5.970, p < .001, f^2 = .182). The mixed/dysexecutive MCI group had significantly more capture errors than the amnestic MCI group (b = 1.254, p < .001, η_p^2 = .106), and education was found to negatively correlate with capture error frequency (b = -.108, p = .042, η_p^2 = .027).

For anticipation errors, there was a significant amount of variance explained by education and clinical groups. When utilizing dummy codes to compare groups to the cognitively normal group, two predictors explained 26.5% of the variance (R^2 = .265, F(6,129) = 7.764, p < .001, f^2 = .361). The mixed/dysexecutive MCI group had significantly more anticipation errors cognitively normal group (b = 2.912, p < .001, η_p^2 = .176), and education was found to negatively correlate with anticipation error frequency (b = -.253, p = .002, η_p^2 = .055). When utilizing dummy codes to compare groups to the subtle cognitive impairment group, two predictors explained 26.5% of the variance (R^2 = .265, F(5,130) = 9.379, p < .001, f^2 = .361). The mixed/dysexecutive MCI group had significantly more anticipation errors than the subtle cognitive impairment group (b = 2.881, p < .001, η_p^2 = .190), and education was found to negatively correlate with anticipation error frequency (b = -.254, p = .002, η_p^2 = .055). When utilizing dummy codes to compare groups to the amnestic MCI group, two predictors explained 26.3% of the variance (R^2 = .263, F(4,131) = 11.708, p < .001, f^2 = .357). The mixed/dysexecutive MCI group had significantly more anticipation errors than the amnestic MCI group (b =

2.794, $p < .001$, $\eta_p^2 = .198$), and education was found to negatively correlate with anticipation error frequency ($b = -.261$, $p = .001$, $\eta_p^2 = .060$).

For postponement errors, there was a significant amount of variance explained by education and clinical groups. When utilizing dummy codes to compare groups to the cognitively normal group, two predictors explained 19.7% of the variance ($R^2 = .197$, $F(6,129) = 5.270$, $p < .001$, $f^2 = .245$). The mixed/dysexecutive MCI group had significantly more postponement errors cognitively normal group ($b = 2.119$, $p < .001$, $\eta_p^2 = .151$), and education was found to negatively correlate with postponement error frequency ($b = -.149$, $p = .028$, $\eta_p^2 = .031$). When utilizing dummy codes to compare groups to the subtle cognitive impairment group, two predictors explained 19.6% of the variance ($R^2 = .196$, $F(5,130) = 6.329$, $p < .001$, $f^2 = .244$). The mixed/dysexecutive MCI group had significantly more postponement errors than the subtle cognitive impairment group ($b = 2.063$, $p < .001$, $\eta_p^2 = .158$), and education was found to negatively correlate with postponement error frequency ($b = -.150$, $p = .027$, $\eta_p^2 = .031$). When utilizing dummy codes to compare groups to the amnestic MCI group, two predictors explained 18.9% of the variance ($R^2 = .189$, $F(4,131) = 7.627$, $p < .001$, $f^2 = .233$). The mixed/dysexecutive MCI group had significantly more postponement errors than the amnestic MCI group ($b = 1.928$, $p < .001$, $\eta_p^2 = .153$), and education was found to negatively correlate with postponement error frequency ($b = -.162$, $p = .015$, $\eta_p^2 = .037$).

V. Discussion

5.1 Primary Analyses

The first goal of this study was to examine trial difficulty by Backwards Digit Test 5-span trial across different clinical groups (i.e., cognitively normal, subtle cognitive

impairment, amnestic MCI, and mixed/dysexecutive MCI). Support for my hypothesis that the mixed/dysexecutive group would have lower trial accuracy scores was revealed from the hierarchical regression analyses examining serial-order sequencing difficulty. Mixed/dysexecutive MCI has significantly lower serial-order sequencing difficulty scores than all the other groups across all trials (Figure 2). Lower sequencing difficulty indicates a more difficult task, as it reflects that fewer numbers were accurately sequenced. It was shown that the mixed/dysexecutive MCI group had significantly more difficulty sequencing number in reverse order, denoting more difficulty with this task. Trials 18 and 21 showed the most variability in serial-order sequencing, having effect sizes ranging from .11 to .14.

As previously mentioned, the Backwards Digit Task is rooted in Fuster's theory of executive attention, as this task relies on the successful operation of this system. Executive attention is comprised of working memory, preparatory set, and inhibitory control, and successful execution of this system requires functional subsystems. Impairments in these domains have been well documented in those with executive dysfunction (Chan et al., 2008; Lezak, 2012). As individuals with mixed/dysexecutive MCI have demonstrated these deficits, one would expect impairment on a test that relies on executive attention. Correspondingly, the mixed/dysexecutive MCI group had poorer performance in serial-order sequencing difficulty. Furthermore, these findings support prior research documenting individuals with mixed/dysexecutive MCI having impaired BDT performance compared to other clinical groups, more specifically making more errors and lower serial-order scores (Emrani et al., 2018; Emrani et al., 2021).

Less variation was seen when utilizing any-order sequencing difficulty, as the only significant differences were seen on trials 15 and 17, with the mixed/dysexecutive MCI having significantly lower any-order sequencing difficulty scores than all the other groups. The mixed/dysexecutive group only had lower any-order sequencing difficulty scores on trials 15 and 17, and no significant differences in any-order sequencing difficulty were found on the other trials (Figure 3). The homogeneity in scores may be due to the simpler nature of the task, tapping into auditory span and immediate, rote attention rather than executive attention. As these differences were seen within the first three trials of the 5-span block, it is possible that the mixed/dysexecutive MCI took longer to successfully comprehend the task compared to the other clinical groups.

Serial-order sequencing difficulty between trials did not significantly vary, suggesting that there is neither temporal derailment across trials nor a recency effect in serial-order sequencing difficulty within the cognitively normal group, amnestic MCI, or mixed/dysexecutive MCI group. The subtle cognitive impairment group did not show temporal derailment but showed a *slight* recency effect for serial-order sequencing difficulty, with better performance on trial 15 compared to 16. The amnestic MCI group showed variability near the end of the task, with lower serial-order sequencing on trial 20 compared to trial 21. Any-order sequencing difficulty between trials did not significantly vary, suggesting that there is neither temporal derailment across trials nor a recency effect in serial-order sequencing difficulty within cognitively normal group, amnestic MCI, or mixed/dysexecutive MCI group. The subtle cognitive impairment group showed more variation between trials, with a significantly lower any-order sequencing difficulty score

on trial 19 compared to trial 15 and 20. This finding may be a result of fatigue mid-test or may be an artifact due to intraindividual variability within a small sample.

Of note, the analyses conducted for the subtle cognitive group and amnestic MCI group revealed insufficient statistical power. Low statistical power can result in spurious statistically significant results, which may be occurring in these analyses (Murphy et al., 2014). Relatedly, multiple comparisons can result in an inflated Type I error rate, and these findings may be false positives (Sato, 1996).

Education and gender were found to have significant effects of serial-order and any-order sequencing difficulty, respectively. On trials 15, 20, and 21, higher levels of education correlated with higher serial-order sequencing difficulty. Higher educational obtainment has been shown to contribute to cognitive reserve, or how flexibly and efficiently an individual can utilize brain resources (Stern, 2002; Bigler & Stern 2015). Consequently, individuals with higher cognitive reserve can generally withstand more advanced disease prior to experiencing cognitive dysfunction (Amato & Goretti, 2016). Education has been shown to facilitate task switching, as those with higher levels of education can more easily transition to another task, potentially granting more flexibility in thinking and protecting against processing speed decline (Moretti et al., 2018; Li et al., 2022). In this study, education may be acting in a similar fashion, helping participants switch to a harder and slightly different task (i.e., from 4-span to 5-span). Furthermore, higher levels of education have been shown to reduce cognitive fatigue (i.e., the decline in cognitive performance during a test), which may be occurring in trials 20 and 21 of BDT (Schwid et al., 2003; Morrow et al., 2015). Education has also been shown to relate to attentional-executive functions, which further supports education's positive effect on

BDT performance (Gómez-Pérez & Ostrosky-Solís, 2017). On trial 17, women had significantly lower any-order sequencing difficulty than men. This finding had a small effect size and occurs in the context of conflicting literature, with men performing better on digit span tasks in some studies, and women outperforming men in other studies (Singh et al., 2010; Choi et al., 2014; Parsons et al., 2005). The observed differences seen across gender in cognitive testing may be a result of different societal and cultural experiences due to gender identity.

5.2 Secondary Analyses

The second goal of this study was to examine error frequency across the clinical groups. Support for my hypothesis that the mixed/dysexecutive group would make more errors was revealed from the hierarchical regression analyses examining capture, anticipation, and postponement errors. No difference in preservation error frequency was found across groups, but the power analyses revealed insufficient power for statistical analyses. Prior research examining BDT errors has grouped perseverative and capture errors together to minimize issues related to restriction of range, which may be occurring with perseverative error analyses in this study, resulting in insufficient power (Emrani et al., 2021). These findings support previous BDT research demonstrating higher rates of transposition errors in individuals with mixed and dysexecutive MCI (Emrani et al., 2018). Capture errors have been associated with dysexecutive impairment and reduced working memory, which supports the finding of increased capture errors within the mixed/dysexecutive MCI group (Stuss et al., 1995; Lamar et al., 1997).

Furthermore, when considering Fuster's theory of executive attention, these errors may originate from dysfunction in one or more of the three integrated systems of working

memory, preparatory set, or inhibitory control. For example, failure in working memory may result in number displacement. Preparatory set is a goal-directed process and is attention to a future task, utilizing information from working memory. If this information is incorrect or the goal-directed behavior is not properly executed, an error may occur. Lastly, inhibitory control suppresses any internal or external influences that may interfere with task(s) at hand, and failure in this domain may result in unwanted and incorrect information being integrated into the final response. As this test was designed with positioning to elicit these errors, this may also illustrate failure in the inhibitory control system, as these error primes are not being properly ignored. Conversely, these errors may reflect activations of still intact systems. Prior research with the Deese-Roediger-McDermott Task suggests that related intrusions reflect activation of semantic memory networks in the brain, and arguably represent an adaptive process (Pardilla-Delgado & Payne, 2017). These errors may demonstrate activation of intact networks, which would bode well in the context of a neurodegenerative process.

With performance on cognitive tests, it is also crucial to consider intraindividual variability, or short-term variations in behavior that are not reflective of systemic or durable changes (Costa et al., 2019). This variance can occur over time (referred to as inconsistency) or across domains at one given time (referred to as dispersion) (Costa et al., 2019). Variable performance on cognitive testing may be a normative response to test conditions or exposure such as fatigue or practice effects, which may contribute to variability in this study's data. Alternatively, research has suggested that intraindividual variability may be sensitive to subtle changes and signal a neurodegenerative process, which may also be occurring in these data (Costa et al., 2019; Hultsch et al., 2000). An

individual with a prodromal neurodegenerative process may obtain the same score on evaluations from yearly assessments but have qualitatively different performances that are not captured by traditional achievement scores. For example, an individual could obtain the same score on a task with dichotomously scored items (i.e., 0 for incorrect responses, 1 for correct responses), but vary greatly in the errors they make, or how far or close they were from the correct answer. Capturing the subtle variability in an individual's performance through process approach data collection can increase diagnostic sensitivity and specificity.

5.3 Limitations

In the context of these significant findings, it is imperative to consider the limitations. Firstly, there are no base rates of performance or error frequencies for the BDT in normal aging individuals. It has been demonstrated that neurologically normal individuals show abnormal performance on neuropsychological testing, and the percentage of abnormal scores is contingent on external variables (i.e., cutoff scores, how many tests are included in the battery) (Schretlen et al., 2008). For the Backwards Digit Task, it is unknown how healthy adults with no subjective cognitive complaints perform on this test. Consequently, there is no normal sample to compare against our clinical groups. The analyses for some subgroups in this current investigation (i.e., cognitively normal, subtle cognitive impairment, and amnestic mild cognitive impairment) may or may not be significant when compared to an independent sample of healthy adults. Furthermore, there are several limitations related to this investigation's sample and data. The sample utilized in this study is well-educated (14.74 ± 2.65), and predominately female (72.1%) and White, as is the case for most cognitive aging study samples.

Although there were no differences in education and gender across clinical groups, the homogeneity of my sample limits the generalizability of my findings, as these results occur in the context of my sample's demographics. Additionally, the source for these data were from a medical clinic. That is, this sample is comprised of individuals who sought medical care for subjective cognitive complaints. By definition, these individuals had the support and resources to access health care services, and therefore are more likely to be in better health and from a higher socioeconomic class (Beatty et al., 2003; Larson & Halfon, 2010).

In this study, comprehensive Jak/Bondi criteria was used for MCI classification and Edmonds criteria was used for subtle cognitive impairment (Edmonds et al., 2015; Jak et al., 2009). Due to small sample sizes, mixed MCI and dysexecutive MCI had to be combined to form one subgroup. Although these groups have demonstrated similar performances on testing, this combined subgroup introduces a new source of variability to the data and may be more heterogenous than prior research suggests. It is possible that the significant findings found in this group were being driven by individuals with mixed MCI *or* dysexecutive MCI. The mixed MCI subgroup is arguably more impaired than the dysexecutive MCI group, due to the multi-domain nature of their impairment. Furthermore, the other clinical groups may not be as homogenous as assumed. Individuals within the amnestic MCI group show impairment in memory, but the degree to which they demonstrate this deficit may significantly vary within the group. Additionally, (aside from exclusion criteria) information regarding medical conditions and comorbidities was not collected. Participants may have health conditions such as

hypertension or sleep apnea that can contribute to cognitive dysfunction (Birns & Kalra, 2008; Gagnon et al., 2014).

Central limit theorem states that a sample mean distribution will assume a normal distribution if the sample size is large enough (i.e., equal to or greater than 30) (Kwak & Kim, 2017). As previously mentioned, one of the assumptions of OLS is that the residuals are normally distributed. OLS is generally robust to this assumption *if* central limit theorem is met (Castano et al., 1981). The subtle cognitive impairment group was small (i.e., below 30), which may have resulted in low statistical power. This group may have had significant differences in comparison to the other clinical groups that were not identified in this study due to low statistical power.

Lastly, there are limitations associated with the data collected for this study. As previously discussed, scores on neuropsychological tests can vary over time and across domains. Additionally, various exogenous factors can impact performance on cognitive testing, such as fatigue (Schultz et al., 2018). These data reflect performance on one task at one time within a 2 to 3 minute period. Consequently, these data may not capture normal variability seen in testing and within/across an individual's scores. Furthermore, they may be an underrepresentation of an individual's ability. The data used in this investigation was from a retrospective data sample, and therefore the procedures and collected variables were unalterable.

5.4 Potential Implications and Recommendations for Future Research

The results from this study contribute to current literature examining testing performance in different types of MCI. Furthermore, these results demonstrate the clinical and diagnostic utility of item level and process approach data for individuals with

mild cognitive impairment, specifically those with mixed/dysexecutive MCI. Individuals with dysexecutive MCI have shown increased vascular comorbidities, and this population may see more benefit from cardiovascular health recommendations (Libon et al., 2010; Sudo et al., 2012). Traditional digit span tasks are traditionally scored dichotomously (either 1 for a perfect sequence or 0 for any amount of error), which limits information collected from testing. Using sequencing difficulty (also referred to as trial accuracy or difficulty) as used in this study, can help highlight variability in performances and potential differences between clinical groups. Additionally, looking at serial-order vs. any-order may lend insight into overlapping but separate cognitive processes (i.e., auditory span and rote, immediate attention vs. executive attention).

In this study, an effect of education was seen on the first and last two trials of the BDT 5-span block. Education may contribute to cognitive reserve and be acting as a protective factor, helping with task switching and ameliorating the effects of cognitive fatigue. Education, along with other factors known to contribute to cognitive reserve (e.g., occupational exposure and leisure activities), should be examined in research to document their potential protective effects (Stern, 2009). Likewise, modifiable factors (such as leisure activities) that contribute to cognitive reserve should be recommended in clinical settings given their demonstrated protective effects.

Future research should address the discussed limitations, replicating this methodology with a larger, more representative sample, comprised of diagnostically homogenous subgroups. Furthermore, future work should incorporate or control for medical status and comorbidities, as these could contribute to performance on neuropsychological measures and introduce more variability into the data. Researchers

may be interested in looking at score discrepancies between trials within participants. This approach would afford a more nuanced examination of test performance patterns. Additionally, the relationship between test performance and neuroanatomical markers and biomarkers should be examined to identify potential signals of neurodegenerative risks or processes.

Appendix

Significant Interactions and Power Analyses

Several interactions were found between age, education, gender, and the clinical groups across various serial-order and any-order trial accuracy scores. The effect sizes (f^2) of interactions were calculated by hand by dividing their added variance (ΔR^2) over the total unexplained model variance (i.e., $1 - R^2$) (Selya et al., 2012). A post-hoc power analysis was conducted using G*Power (Version 3.1) (Erdfelder et al., 1996).

The relationship between age and trial 17 serial-order trial accuracy score was dependent upon membership in subtle MCI group ($\Delta R^2 = .038$, $p = .019$, $f^2 = .049$, power = .688). The relationship between education and trial 18 serial-order trial accuracy scores was dependent upon membership in subtle MCI group ($\Delta R^2 = .038$, $p = .016$, $f^2 = .044$, power = .705). The relationship between education and trial 19 serial-order trial accuracy scores was dependent upon membership in mixed/dysexecutive MCI group ($\Delta R^2 = .041$, $p = .016$, $f^2 = .047$, power = .704). Additionally, there was an interaction between education, sex, age, and membership in the mixed/dysexecutive MCI group on trial 19 serial-order trial accuracy scores ($\Delta R^2 = .030$, $p = .039$, $f^2 = .034$, power = .565). The relationship between education and trial 19 serial-order trial accuracy scores was dependent upon membership in mixed/dysexecutive MCI group ($\Delta R^2 = .039$, $p = .016$, $f^2 = .047$, power = .707). There was an interaction between education, sex, and age on trial 21 serial-order trial accuracy scores ($\Delta R^2 = .033$, $p = .021$, $f^2 = .043$, power = .671). The relationship between education and trial 21 serial-order trial accuracy scores was dependent upon membership in mixed/dysexecutive MCI group ($\Delta R^2 = .039$, $p = .011$, $f^2 = .051$, power = .743).

The relationship between age and trial 15 any-order trial accuracy scores was dependent upon membership in mixed/dysexecutive MCI group ($\Delta R^2 = .039$, $p = .016$, $f^2 = .046$, power = .702). There was an interaction between education, sex, and age on trial 16 any-order trial accuracy scores ($\Delta R^2 = .035$, $p = .025$, $f^2 = .039$, power = .630). There was an interaction between education, age, and membership in the mixed/dysexecutive MCI group on trial 19 any-order trial accuracy scores ($\Delta R^2 = .033$, $p = .036$, $f^2 = .035$, power = .584). Additionally, there was an interaction between education, sex, age, and membership in the mixed/dysexecutive MCI group on trial 19 any-order trial accuracy scores ($\Delta R^2 = .074$, $p = .001$, $f^2 = .083$, power = .914). The relationship between education and trial 20 any-order trial accuracy scores was dependent upon membership in mixed/dysexecutive MCI group ($\Delta R^2 = .033$, $p = .034$, $f^2 = .035$, power = .586). There was an interaction between education, sex, and age on trial 21 any-order trial accuracy scores ($\Delta R^2 = .037$, $p = .024$, $f^2 = .040$, power = .639).

Table 1.

Demographic composition of mild cognitive impairment subtype groups.

MCI Subtype	N	Age	Education	% Female
Cognitively Normal	53	74.57 ± 6.82	15.08 ± 2.55	69.8%
Subtle	18	77.94 ± 8.36	14.67 ± 2.72	61.1%
Amnestic	30	74.5 ± 5.93	13.9 ± 2.87	76.7%
Mixed/Dysexecutive	35	75 ± 5.8	15 ± 2.52	77.1%
Total	136	75.11 ± 6.64	14.74 ± 2.65	72.1%

Table 2a.

Backwards Digit Span Error Type Definitions

Error Type	Definition	Further Classification
Anticipation	A number occurs *earlier* in the sequence than it should.	These errors are further classified by the distance (i.e., number of positions) it was displaced.
Postponement	A number occurs *later* in the sequence than it should.	
Capture	A previous number is pulled into the current response to make a consecutive string of digits.	Between-trial: A number from the preceding two trials is pulled into the current response.
		Within-trial: A number from the same trial is pulled into the current response.
		Forward: The numbers provided are in ascending order.
		Backward: The numbers provided are in descending order.
Perseveration	An inappropriate repetition of a number.	Between-trial: A number from the preceding two trials is pulled into the current response.
		Within-trial: A number within the same trial is repeated.

Table 2b.

Backwards Digit Span Error Type Examples. The examples provided are samples for an individual responding to item number 3.

BDT Items	*Correct Response*
1.) 8-2-3-1-6	1.) 6-1-3-2-8
2.) 4-8-7-9-1	2.) 1-9-7-8-4
3.) 2-5-4-6-9	3.) 9-6-4-5-2

Error Type	**Example**	**Explanation**
Anticipation	9 - 5 - 6 - 4 - 2	The number occurs *earlier* in the sequence than it should. These errors are further classified by the distance (i.e., number of positions) it was displaced. It is in position 2 when it should be in position 4. It was displaced 2 spots, making this an anticipation -2 error.
Postponement	9 - 6 - 4 - 2 - 5	The number occurs *later* in the sequence than it should. These errors are further classified by the distance (i.e., number of positions) it was displaced. It is in position 5 when it should be in position 4. It was displaced 1 spot, making this a postponement -1 error.
Between-trial Forward Capture	9 - 3 - 4 - 5 - 2	The number 3 is pulled from trial 1 (making it a between-trial error) into the current trial to create a consecutive set of numbers (highlighted in gray, making it a capture error). The numbers are in ascending order, making it a forward error.
Within-trial Backward Capture	9 - 6 - 5 - 4 - 2	The number 4 is repositioned within the trial (making it a within-trial error) to create a consecutive set of numbers (highlighted in gray, making it a capture error). The numbers are in descending order, making it a backward error.
Between-trial Perseveration	9 - 8 - 6 - 4 - 2	A number (i.e., 8) from the preceding two trials is pulled into the current response.
Within-trial Perseveration	9 - 6 - 5 - 5 - 2	A number (i.e., 5) within the same trial is repeated.

Table 3.

Backwards Digit Span Error Type Descriptive Statistics Across Groups.

Error Type	Cognitively Normal	Subtle	Amnestic	Mixed/ Dysexecutive	Total
Anticipation	2.64 (2.06)	2.78 (2.16)	3.30 (2.51)	5.60 (3.12)	3.57 (2.74)
Postponement	1.83 (1.44)	2.11 (1.57)	2.53 (2.24)	3.97 (2.61)	2.57 (2.16)
Capture	1.66 (1.40)	2.00 (1.53)	2.27 (1.84)	3.14 (1.67)	2.22 (1.68)
Perseveration	1.09 (1.13)	1.06 (1.30)	1.20 (.96)	1.54 (1.50)	1.23 (1.23)

Table 4a

Regression Predicting Trial 15 Serial-Order Sequencing Difficulty from Demographic Variables and Clinical Group Membership

Step and Predictor Variable	R^2	ΔR^2	*b*	sr^2
Step 1	.076*	.076*		
Age (Centered)			0.33	0.01
Education (Centered)			2.29*	0.06
Gender†			-4.66	0.01
Step 2	.187*	.111*		
Age (Centered)			0.23	0.00
Education (Centered)			2.31*	0.06
Gender†			-2.69	0.00
D1†			7.66	0.01
D2†			-4.68	0.01
D3†			-16.28*	0.07

**p* < .05. (*2-tailed)*

†Dummy coded variables:

Gender: Comparing to males

D1: Comparing cognitively normal to subtle cognitive impairment

D2: Comparing cognitively normal to amnestic MCI

D3: Comparing cognitively normal to mixed/dysexecutive MCI

Table 4b

Regression Predicting Trial 15 Serial-Order Sequencing Difficulty from Demographic Variables and Clinical Group Membership

Step and Predictor Variable	R^2	ΔR^2	*b*	sr^2
Step 1	.076*	.076*		
Age (Centered)			0.33	0.01
Education (Centered)			2.29*	0.06
Gender†			-4.66	0.01
Step 2	.177*	.101*		
Age (Centered)			0.29	0.01
Education (Centered)			2.29*	0.06
Gender†			-3.10	0.00
D5†			-6.55	0.01
D6†			-18.16*	0.10

**p* < .05. (*2-tailed)*

†Dummy coded variables:

Gender: Comparing to males

D5: Comparing subtle cognitive impairment to amnestic MCI

D6: Comparing subtle cognitive impairment to mixed/dysexecutive MCI

Table 4c

Regression Predicting Trial 15 Serial-Order Sequencing Difficulty from Demographic Variables and Clinical Group Membership

Step and Predictor Variable	R^2	ΔR^2	*b*	sr^2
Step 1	.076*	.076*		
Age (Centered)			0.33	0.01
Education (Centered)			2.29*	0.06
Gender†			-4.66	0.01
Step 2	.165*	.090*		
Age (Centered)			0.33	0.01
Education (Centered)			2.46*	0.07
Gender†			-3.48	0.00
D9†			-16.24*	0.09

*$p < .05$. (*2-tailed)*

†Dummy coded variables:

Gender: Comparing to males

D9: Comparing amnestic MCI to mixed/dysexecutive MCI

Table 5a

Regression Predicting Trial 16 Serial-Order Sequencing Difficulty from Demographic Variables and Clinical Group Membership

Step and Predictor Variable	R^2	ΔR^2	*b*	sr^2
Step 1	.014	.014		
Age (Centered)			0.02	0.00
Education (Centered)			1.04	0.01
Gender†			-2.19	0.00
Step 2	.112*	.098*		
Age (Centered)			0.02	0.00
Education (Centered)			1.09	0.01
Gender†			-0.91	0.00
D1†			-4.57	0.00
D2†			-5.97	0.01
D3†			5.28*	0.10

**p* < .05. (*2-tailed)*

†Dummy coded variables:

Gender: Comparing to males

D1: Comparing cognitively normal to subtle cognitive impairment

D2: Comparing cognitively normal to amnestic MCI

D3: Comparing cognitively normal to mixed/dysexecutive MCI

Table 5b

Regression Predicting Trial 16 Serial-Order Sequencing Difficulty from Demographic Variables and Clinical Group Membership

Step and Predictor Variable	R^2	ΔR^2	*b*	sr^2
Step 1	.014	.014		
Age (Centered)			0.02	0.00
Education (Centered)			1.04	0.01
Gender†			-2.19	0.00
Step 2	.109*	.094*		
Age (Centered)			-0.01	0.00
Education (Centered)			1.10	0.01
Gender†			-0.66	0.00
D5†			-4.85	0.01
D6†			-18.53*	0.09

*$p < .05$. (*2-tailed)*

†Dummy coded variables:

Gender: Comparing to males

D5: Comparing subtle cognitive impairment to amnestic MCI

D6: Comparing subtle cognitive impairment to mixed/dysexecutive MCI

Table 5c

Regression Predicting Trial 16 Serial-Order Sequencing Difficulty from Demographic Variables and Clinical Group Membership

Step and Predictor Variable	R^2	ΔR^2	*b*	sr^2
Step 1	.014	.014		
Age (Centered)			0.02	0.00
Education (Centered)			1.04	0.01
Gender†			-2.19	0.00
Step 2	.103*	.089*		
Age (Centered)			0.02	0.00
Education (Centered)			1.22	0.02
Gender†			-0.95	0.00
D9†			-17.10*	0.09

*$p < .05$. (*2-tailed)*

†Dummy coded variables:

Gender: Comparing to males

D9: Comparing amnestic MCI to mixed/dysexecutive MCI

Table 6a

Regression Predicting Trial 17 Serial-Order Sequencing Difficulty from Demographic Variables and Clinical Group Membership

Step and Predictor Variable	R^2	ΔR^2	*b*	sr^2
Step 1	.029	.029		
Age (Centered)			0.20	0.00
Education (Centered)			0.85	0.01
Gender†			-7.52	0.02
Step 2	.115*	.086*		
Age (Centered)			0.16	0.00
Education (Centered)			1.05	0.01
Gender†			-6.05	0.01
D1†			6.08	0.01
D2†			1.92	0.00
D3†			-14.42*	0.05

**p* < .05. (*2-tailed)*

†Dummy coded variables:

Gender: Comparing to males

D1: Comparing cognitively normal to subtle cognitive impairment

D2: Comparing cognitively normal to amnestic MCI

D3: Comparing cognitively normal to mixed/dysexecutive MCI

Table 6b

Regression Predicting Trial 17 Serial-Order Sequencing Difficulty from Demographic Variables and Clinical Group Membership

Step and Predictor Variable	R^2	ΔR^2	*b*	sr^2
Step 1	.029	.029		
Age (Centered)			0.20	0.00
Education (Centered)			0.85	0.01
Gender†			-7.52	0.02
Step 2	.109*	.080*		
Age (Centered)			0.20	0.00
Education (Centered)			1.03	0.01
Gender†			-6.38	0.01
D5†			0.43	0.00
D6†			-15.91*	0.07

*$p < .05$. (*2-tailed)*

†Dummy coded variables:

Gender: Comparing to males

D5: Comparing subtle cognitive impairment to amnestic MCI

D6: Comparing subtle cognitive impairment to mixed/dysexecutive MCI

Table 6c

Regression Predicting Trial 17 Serial-Order Sequencing Difficulty from Demographic Variables and Clinical Group Membership

Step and Predictor Variable	R^2	ΔR^2	*b*	sr^2
Step 1	.029	.029		
Age (Centered)			0.20	0.00
Education (Centered)			0.85	0.01
Gender†			-7.52	0.02
Step 2	.109*	.080*		
Age (Centered)			0.20	0.00
Education (Centered)			1.02	0.01
Gender†			-6.35	0.01
D9†			-16.04*	0.08

*$p < .05$. (*2-tailed)*

†Dummy coded variables:

Gender: Comparing to males

D9: Comparing amnestic MCI to mixed/dysexecutive MCI

Table 7a

Regression Predicting Trial 18 Serial-Order Sequencing Difficulty from Demographic Variables and Clinical Group Membership

Step and Predictor Variable	R^2	ΔR^2	*b*	sr^2
Step 1	.021	.021		
Age (Centered)			-0.14	0.00
Education (Centered)			0.89	0.01
Gender†			-5.15	0.01
Step 2	.146*	.125*		
Age (Centered)			-0.15	0.00
Education (Centered)			0.95	0.01
Gender†			-3.50	0.00
D1†			-3.55	0.00
D2†			-6.80	0.01
D3†			-23.19*	0.12

**p* < .05. (*2-tailed)*

†Dummy coded variables:

Gender: Comparing to males

D1: Comparing cognitively normal to subtle cognitive impairment

D2: Comparing cognitively normal to amnestic MCI

D3: Comparing cognitively normal to mixed/dysexecutive MCI

Table 7b

Regression Predicting Trial 18 Serial-Order Sequencing Difficulty from Demographic Variables and Clinical Group Membership

Step and Predictor Variable	R^2	ΔR^2	*b*	sr^2
Step 1	.021	.021		
Age (Centered)			-0.14	0.00
Education (Centered)			0.89	0.01
Gender†			-5.15	0.01
Step 2	.144*	.124*		
Age (Centered)			-0.18	0.00
Education (Centered)			0.96	0.01
Gender†			-3.31	0.00
D5†			-5.94	0.01
D6†			-22.31*	0.12

*$p < .05$. (*2-tailed)*

†Dummy coded variables:

Gender: Comparing to males

D5: Comparing subtle cognitive impairment to amnestic MCI

D6: Comparing subtle cognitive impairment to mixed/dysexecutive MCI

Table 7c

Regression Predicting Trial 18 Serial-Order Sequencing Difficulty from Demographic Variables and Clinical Group Membership

Step and Predictor Variable	R^2	ΔR^2	*b*	sr^2
Step 1	.021	.021		
Age (Centered)			-0.14	0.00
Education (Centered)			0.89	0.01
Gender†			-5.15	0.01
Step 2	.137*	.116*		
Age (Centered)			-0.15	0.00
Education (Centered)			1.11	0.01
Gender†			-3.66	0.00
D9†			-20.58*	0.12

*$p < .05$. (*2-tailed)*

†Dummy coded variables:

Gender: Comparing to males

D9: Comparing amnestic MCI to mixed/dysexecutive MCI

Table 8a

Regression Predicting Trial 19 Serial-Order Sequencing Difficulty from Demographic Variables and Clinical Group Membership

Step and Predictor Variable	R^2	ΔR^2	*b*	sr^2
Step 1	.018	.018		
Age (Centered)			0.08	0.00
Education (Centered)			1.34	0.02
Gender†			1.60	0.00
Step 2	.079*	.060*		
Age (Centered)			0.10	0.00
Education (Centered)			1.35	0.02
Gender†			2.48	0.00
D1†			-6.34	0.01
D2†			-6.24	0.01
D3†			-16.07*	0.06

**p* < .05. (*2-tailed)*

†Dummy coded variables:

Gender: Comparing to males

D1: Comparing cognitively normal to subtle cognitive impairment

D2: Comparing cognitively normal to amnestic MCI

D3: Comparing cognitively normal to mixed/dysexecutive MCI

Table 8b

Regression Predicting Trial 19 Serial-Order Sequencing Difficulty from Demographic Variables and Clinical Group Membership

Step and Predictor Variable	R^2	ΔR^2	*b*	sr^2
Step 1	.018	.018		
Age (Centered)			0.08	0.00
Education (Centered)			1.34	0.02
Gender†			1.60	0.00
Step 2	.073*	.054*		
Age (Centered)			0.05	0.00
Education (Centered)			1.37	0.02
Gender†			2.82	0.00
D5†			-4.69	0.00
D6†			-14.52*	0.05

*$p < .05$. (*2-tailed)*

†Dummy coded variables:

Gender: Comparing to males

D5: Comparing subtle cognitive impairment to amnestic MCI

D6: Comparing subtle cognitive impairment to mixed/dysexecutive MCI

Table 8c

Regression Predicting Trial 19 Serial-Order Sequencing Difficulty from Demographic Variables and Clinical Group Membership

Step and Predictor Variable	R^2	ΔR^2	*b*	sr^2
Step 1	.018	.018		
Age (Centered)			0.08	0.00
Education (Centered)			1.34	0.02
Gender†			1.60	0.00
Step 2	.068*	.050*		
Age (Centered)			0.08	0.00
Education (Centered)			1.49	0.02
Gender†			2.55	0.00
D9†			-13.14*	0.05

*$p < .05$. (*2-tailed)*

†Dummy coded variables:

Gender: Comparing to males

D9: Comparing amnestic MCI to mixed/dysexecutive MCI

Table 9a

Regression Predicting Trial 20 Serial-Order Sequencing Difficulty from Demographic Variables and Clinical Group Membership

Step and Predictor Variable	R^2	ΔR^2	*b*	sr^2
Step 1	.048	.048		
Age (Centered)			0.04	0.00
Education (Centered)			1.73*	0.03
Gender†			-6.17	0.01
Step 2	.128*	.080*		
Age (Centered)			-0.02	0.00
Education (Centered)			1.77*	0.03
Gender†			-4.52	0.01
D1†			3.37	0.00
D2†			-4.86	0.00
D3†			-16.49*	0.06

**p* < .05. (*2-tailed)*

†Dummy coded variables:

Gender: Comparing to males

D1: Comparing cognitively normal to subtle cognitive impairment

D2: Comparing cognitively normal to amnestic MCI

D3: Comparing cognitively normal to mixed/dysexecutive MCI

Table 9b

Regression Predicting Trial 20 Serial-Order Sequencing Difficulty from Demographic Variables and Clinical Group Membership

Step and Predictor Variable	R^2	ΔR^2	*b*	sr^2
Step 1	.048	.048		
Age (Centered)			0.04	0.00
Education (Centered)			1.73*	0.03
Gender†			-6.17	0.01
Step 2	.126*	.079*		
Age (Centered)			0.01	0.00
Education (Centered)			1.76*	0.03
Gender†			-4.71	0.01
D5†			-5.68	0.01
D6†			-17.31*	0.08

**p* < .05. (*2-tailed)*

†Dummy coded variables:

Gender: Comparing to males

D5: Comparing subtle cognitive impairment to amnestic MCI

D6: Comparing subtle cognitive impairment to mixed/dysexecutive MCI

Table 9c

Regression Predicting Trial 20 Serial-Order Sequencing Difficulty from Demographic Variables and Clinical Group Membership

Step and Predictor Variable	R^2	ΔR^2	*b*	sr^2
Step 1	.048	.048		
Age (Centered)			0.04	0.00
Education (Centered)			1.73*	0.03
Gender†			-6.17	0.01
Step 2	.119*	.071*		
Age (Centered)			0.04	0.00
Education (Centered)			1.91*	0.04
Gender†			-5.04	0.01
D9†			-15.65*	0.07

*$p < .05$. (*2-tailed)*

†Dummy coded variables:

Gender: Comparing to males

D9: Comparing amnestic MCI to mixed/dysexecutive MCI

Table 10a

Regression Predicting Trial 21 Serial-Order Sequencing Difficulty from Demographic Variables and Clinical Group Membership

Step and Predictor Variable	R^2	ΔR^2	*b*	sr^2
Step 1	.055	.055		
Age (Centered)			0.05	0.00
Education (Centered)			2.07*	0.04
Gender†			-5.47	0.01
Step 2	.202*	.148*		
Age (Centered)			0.11	0.00
Education (Centered)			2.41*	0.05
Gender†			-4.30	0.01
D1†			-4.65	0.00
D2†			2.89	0.00
D3†			-22.74*	0.11

**p* < .05. (*2-tailed)*

†Dummy coded variables:

Gender: Comparing to males

D1: Comparing cognitively normal to subtle cognitive impairment

D2: Comparing cognitively normal to amnestic MCI

D3: Comparing cognitively normal to mixed/dysexecutive MCI

Table 10b

Regression Predicting Trial 21 Serial-Order Sequencing Difficulty from Demographic Variables and Clinical Group Membership

Step and Predictor Variable	R^2	ΔR^2	*b*	sr^2
Step 1	.055	.055		
Age (Centered)			0.05	0.00
Education (Centered)			2.07*	0.04
Gender†			-5.47	0.01
Step 2	.199*	.145*		
Age (Centered)			0.07	0.00
Education (Centered)			2.42*	0.05
Gender†			-4.05	0.00
D5†			4.03	0.00
D6†			-21.60*	0.11

*$p < .05$. (*2-tailed)*

†Dummy coded variables:

Gender: Comparing to males

D5: Comparing subtle cognitive impairment to amnestic MCI

D6: Comparing subtle cognitive impairment to mixed/dysexecutive MCI

Table 10c

Regression Predicting Trial 21 Serial-Order Sequencing Difficulty from Demographic Variables and Clinical Group Membership

Step and Predictor Variable	R^2	ΔR^2	*b*	sr^2
Step 1	.055	.055		
Age (Centered)			0.05	0.00
Education (Centered)			2.07*	0.04
Gender†			-5.47	0.01
Step 2	.196*	.141*		
Age (Centered)			0.05	0.00
Education (Centered)			2.32*	0.05
Gender†			-3.81	0.00
D9†			-22.78*	0.14

*$p < .05$. (*2-tailed)*

†Dummy coded variables:

Gender: Comparing to males

D9: Comparing amnestic MCI to mixed/dysexecutive MCI

Table 11a

Regression Predicting Trial 15 Any-Order Sequencing Difficulty from Demographic Variables and Clinical Group Membership

Step and Predictor Variable	R^2	ΔR^2	*b*	sr^2
Step 1	.050	.050		
Age (Centered)			0.22	0.02
Education (Centered)			0.45	0.01
Gender†			-3.39	0.02
Step 2	.119*	.069*		
Age (Centered)			0.18	0.01
Education (Centered)			0.47	0.01
Gender†			-2.72	0.01
D1†			3.14	0.01
D2†			-1.01	0.00
D3†			-5.22*	0.04

**p* < .05. (*2-tailed)*

†Dummy coded variables:

Gender: Comparing to males

D1: Comparing cognitively normal to subtle cognitive impairment

D2: Comparing cognitively normal to amnestic MCI

D3: Comparing cognitively normal to mixed/dysexecutive MCI

Table 11b

Regression Predicting Trial 15 Any-Order Sequencing Difficulty from Demographic Variables and Clinical Group Membership

Step and Predictor Variable	R^2	ΔR^2	*b*	sr^2
Step 1	.050	.050		
Age (Centered)			0.22	0.02
Education (Centered)			0.45	0.01
Gender†			-3.39	0.02
Step 2	.110*	.060*		
Age (Centered)			0.21	0.02
Education (Centered)			0.47	0.01
Gender†			-2.89	0.02
D5†			-1.77	0.00
D6†			-5.99*	0.06

**p* < .05. (*2-tailed)*

†Dummy coded variables:

Gender: Comparing to males

D5: Comparing subtle cognitive impairment to amnestic MCI

D6: Comparing subtle cognitive impairment to mixed/dysexecutive MCI

Table 11c

Regression Predicting Trial 15 Any-Order Sequencing Difficulty from Demographic Variables and Clinical Group Membership

Step and Predictor Variable	R^2	ΔR^2	*b*	sr^2
Step 1	.050	.050		
Age (Centered)			0.22	0.02
Education (Centered)			0.45	0.01
Gender†			-3.39	0.02
Step 2	.105*	.055*		
Age (Centered)			0.22	0.02
Education (Centered)			0.51	0.02
Gender†			-2.99	0.02
D9†			-5.47*	0.06

*$p < .05$. (*2-tailed)*

†Dummy coded variables:

Gender: Comparing to males

D9: Comparing amnestic MCI to mixed/dysexecutive MCI

Table 12a

Regression Predicting Trial 17 Any-Order Sequencing Difficulty from Demographic Variables and Clinical Group Membership

Step and Predictor Variable	R^2	ΔR^2	*b*	sr^2
Step 1	.036	.036		
Age (Centered)			0.04	0.00
Education (Centered)			0.10	0.00
Gender†			-4.90*	0.03
Step 2	.100*	.064*		
Age (Centered)			0.01	0.00
Education (Centered)			0.08	0.00
Gender†			-4.19	0.02
D1†			1.18	0.00
D2†			-3.18	0.01
D3†			-6.78*	0.05

*$p < .05$. (*2-tailed)*

†Dummy coded variables:

Gender: Comparing to males

D1: Comparing cognitively normal to subtle cognitive impairment

D2: Comparing cognitively normal to amnestic MCI

D3: Comparing cognitively normal to mixed/dysexecutive MCI

Table 12b

Regression Predicting Trial 17 Any-Order Sequencing Difficulty from Demographic Variables and Clinical Group Membership

Step and Predictor Variable	R^2	ΔR^2	*b*	sr^2
Step 1	.036	.036		
Age (Centered)			0.04	0.00
Education (Centered)			0.10	0.00
Gender†			-4.90*	0.03
Step 2	.099*	.064*		
Age (Centered)			0.02	0.00
Education (Centered)			0.08	0.00
Gender†			-4.26	0.03
D5†			-3.47	0.01
D6†			-7.06*	0.06

*$p < .05$. (*2-tailed)*

†Dummy coded variables:

Gender: Comparing to males

D5: Comparing subtle cognitive impairment to amnestic MCI

D6: Comparing subtle cognitive impairment to mixed/dysexecutive MCI

Table 12c

Regression Predicting Trial 17 Any-Order Sequencing Difficulty from Demographic Variables and Clinical Group Membership

Step and Predictor Variable	R^2	ΔR^2	*b*	sr^2
Step 1	.036	.036		
Age (Centered)			0.04	0.00
Education (Centered)			0.10	0.00
Gender†			-4.90*	0.03
Step 2	.086*	.050*		
Age (Centered)			0.04	0.00
Education (Centered)			0.16	0.00
Gender†			-4.46*	0.03
D9†			-6.05*	0.05

*$p < .05$. (*2-tailed)*

†Dummy coded variables:

Gender: Comparing to males

D9: Comparing amnestic MCI to mixed/dysexecutive MCI

Table 13a

Regression Predicting Capture Error Frequency from Demographic Variables and Clinical Group Membership

Step and Predictor Variable	R^2	ΔR^2	*b*	sr^2
Step 1	.048	.048		
Age (Centered)			0.01	0.00
Education (Centered)			-0.09	0.02
Gender†			0.49	0.02
Step 2	.165*	.117*		
Age (Centered)			0.01	0.00
Education (Centered)			-0.10	0.02
Gender†			0.39	0.01
D1†			0.30	0.00
D2†			0.47	0.01
D3†			1.44*	0.11

**p* < .05. (*2-tailed)*

†Dummy coded variables:

Gender: Comparing to males

D1: Comparing cognitively normal to subtle cognitive impairment

D2: Comparing cognitively normal to amnestic MCI

D3: Comparing cognitively normal to mixed/dysexecutive MCI

Table 13b

Regression Predicting Capture Error Frequency from Demographic Variables and Clinical Group Membership

Step and Predictor Variable	R^2	ΔR^2	*b*	sr^2
Step 1	.048	.048		
Age (Centered)			0.01	0.00
Education (Centered)			-0.09	0.02
Gender†			0.49	0.02
Step 2	.162*	.114*		
Age (Centered)			0.01	0.00
Education (Centered)			-0.10	0.02
Gender†			0.37	0.01
D5†			0.39	0.01
D6†			1.37*	0.11

*$p < .05$. (*2-tailed)*

†Dummy coded variables:

Gender: Comparing to males

D5: Comparing subtle cognitive impairment to amnestic MCI

D6: Comparing subtle cognitive impairment to mixed/dysexecutive MCI

Table 13c

Regression Predicting Capture Error Frequency from Demographic Variables and Clinical Group Membership

Step and Predictor Variable	R^2	ΔR^2	*b*	sr^2
Step 1	.048	.048		
Age (Centered)			0.01	0.00
Education (Centered)			-0.09	0.02
Gender†			0.49	0.02
Step 2	.154*	.106*		
Age (Centered)			0.01	0.00
Education (Centered)			-0.11	0.03
Gender†			0.40	0.01
D9†			1.25*	0.11

*$p < .05$. (*2-tailed)*

†Dummy coded variables:

Gender: Comparing to males

D9: Comparing amnestic MCI to mixed/dysexecutive MCI

Table 14a

Regression Predicting Anticipation Error Frequency from Demographic Variables and Clinical Group Membership

Step and Predictor Variable	R^2	ΔR^2	*b*	sr^2
Step 1	.065*	.065*		
Age (Centered)			-0.02	0.00
Education (Centered)			-0.23*	0.05
Gender†			0.68	0.01
Step 2	.265*	.200*		
Age (Centered)			-0.02	0.00
Education (Centered)			-0.25*	0.05
Gender†			0.47	0.01
D1†			0.13	0.00
D2†			0.33	0.00
D3†			2.91*	0.18

**p* < .05. (*2-tailed)*

†Dummy coded variables:

Gender: Comparing to males

D1: Comparing cognitively normal to subtle cognitive impairment

D2: Comparing cognitively normal to amnestic MCI

D3: Comparing cognitively normal to mixed/dysexecutive MCI

Table 14b

Regression Predicting Anticipation Error Frequency from Demographic Variables and Clinical Group Membership

Step and Predictor Variable	R^2	ΔR^2	*b*	sr^2
Step 1	.065*	.065*		
Age (Centered)			-0.02	0.00
Education (Centered)			-0.23*	0.05
Gender†			0.68	0.01
Step 2	.265*	.200*		
Age (Centered)			-0.02	0.00
Education (Centered)			-0.25*	0.05
Gender†			0.46	0.01
D5†			0.30	0.00
D6†			2.88*	0.19

**p* < .05. (*2-tailed)*

†Dummy coded variables:

Gender: Comparing to males

D5: Comparing subtle cognitive impairment to amnestic MCI

D6: Comparing subtle cognitive impairment to mixed/dysexecutive MCI

Table 14c

Regression Predicting Anticipation Error Frequency from Demographic Variables and Clinical Group Membership

Step and Predictor Variable	R^2	ΔR^2	*b*	sr^2
Step 1	.065*	.065*		
Age (Centered)			-0.02	0.00
Education (Centered)			-0.23*	0.05
Gender†			0.68	0.01
Step 2	.263*	.198*		
Age (Centered)			-0.02	0.00
Education (Centered)			-0.26*	0.06
Gender†			0.48	0.01
D9†			2.79*	0.20

*$p < .05$. (*2-tailed)*

†Dummy coded variables:

Gender: Comparing to males

D9: Comparing amnestic MCI to mixed/dysexecutive MCI

Table 15a

Regression Predicting Postponement Error Frequency from Demographic Variables and Clinical Group Membership

Step and Predictor Variable	R^2	ΔR^2	*b*	sr^2
Step 1	.036	.036		
Age (Centered)			0.00	0.00
Education (Centered)			-0.14	0.03
Gender†			0.30	0.00
Step 2	.197*	.161*		
Age (Centered)			0.00	0.00
Education (Centered)			-0.15*	0.03
Gender†			0.14	0.00
D1†			0.23	0.00
D2†			0.52	0.01
D3†			2.12*	0.15

**p* < .05. (*2-tailed)*

†Dummy coded variables:

Gender: Comparing to males

D1: Comparing cognitively normal to subtle cognitive impairment

D2: Comparing cognitively normal to amnestic MCI

D3: Comparing cognitively normal to mixed/dysexecutive MCI

Table 15b

Regression Predicting Postponement Error Frequency from Demographic Variables and Clinical Group Membership

Step and Predictor Variable	R^2	ΔR^2	*b*	sr^2
Step 1	.036	.036		
Age (Centered)			0.00	0.00
Education (Centered)			-0.14	0.03
Gender†			0.30	0.00
Step 2	.196*	.159*		
Age (Centered)			0.00	0.00
Education (Centered)			-0.15*	0.03
Gender†			0.13	0.00
D5†			0.46	0.01
D6†			2.06*	0.16

*$p < .05$. (*2-tailed)*

†Dummy coded variables:

Gender: Comparing to males

D5: Comparing subtle cognitive impairment to amnestic MCI

D6: Comparing subtle cognitive impairment to mixed/dysexecutive MCI

Table 15c

Regression Predicting Postponement Error Frequency from Demographic Variables and Clinical Group Membership

Step and Predictor Variable	R^2	ΔR^2	*b*	sr^2
Step 1	.036	.036		
Age (Centered)			0.00	0.00
Education (Centered)			-0.14	0.03
Gender†			0.30	0.00
Step 2	.189*	.153*		
Age (Centered)			0.00	0.00
Education (Centered)			-0.16*	0.04
Gender†			0.16	0.00
D9†			1.93*	0.15

*$p < .05$. (*2-tailed)*

†Dummy coded variables:

Gender: Comparing to males

D9: Comparing amnestic MCI to mixed/dysexecutive MCI

Figure 1.

Figure from Sperling et al., 2011 delineating cognitive decline trajectories in individuals experiencing healthy aging, mild cognitive decline, and dementia.

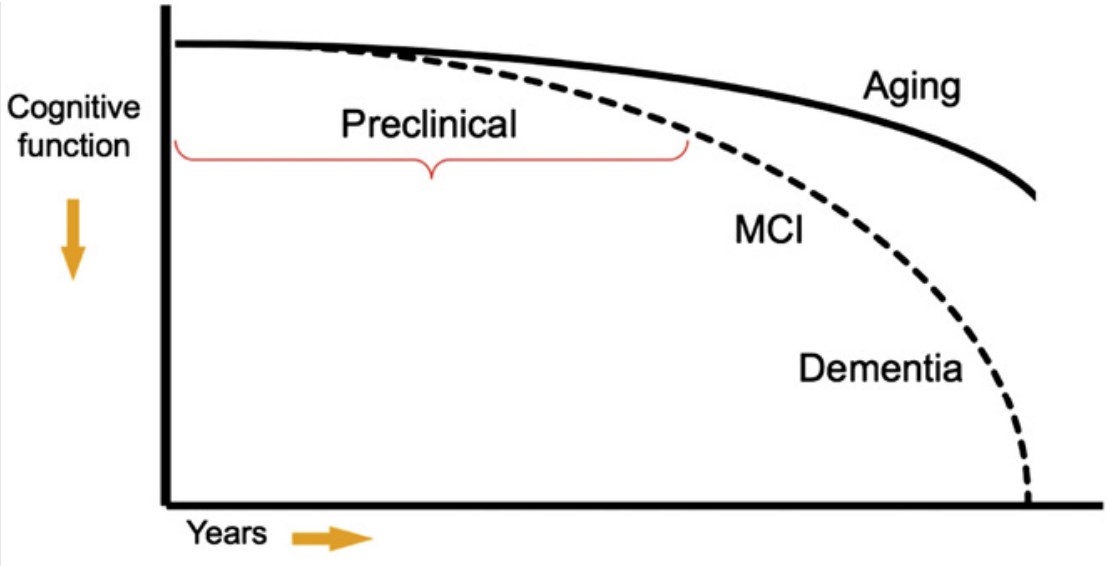
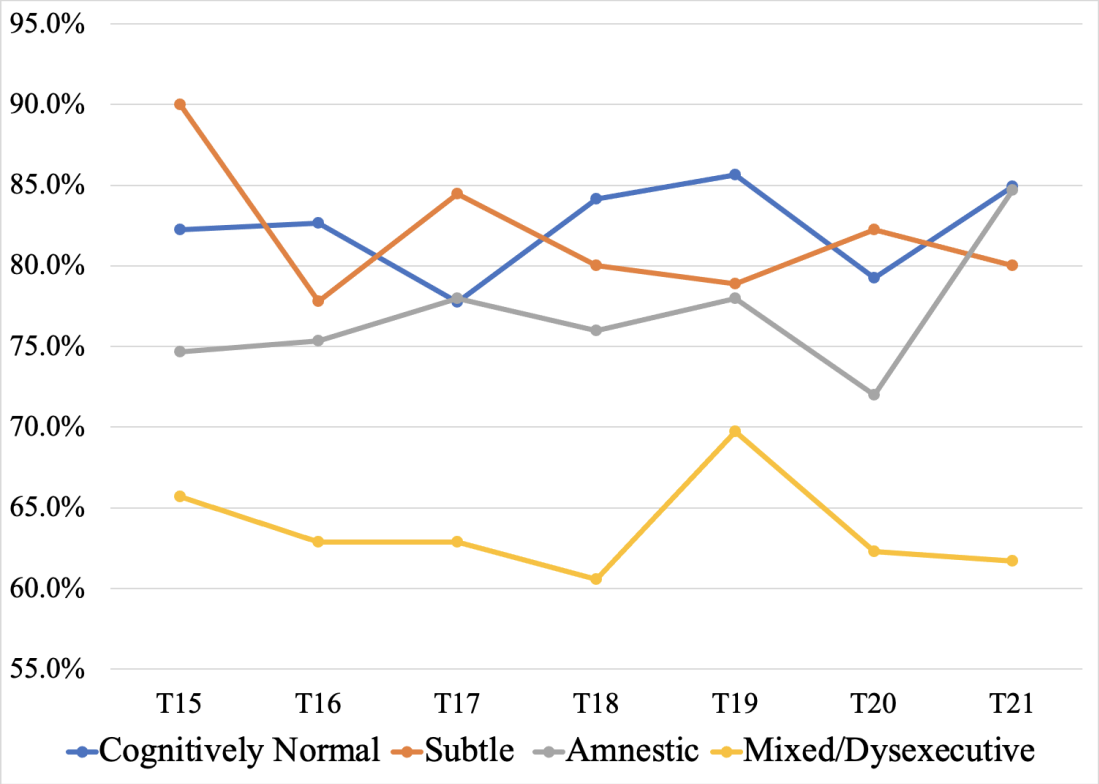


Figure 2.

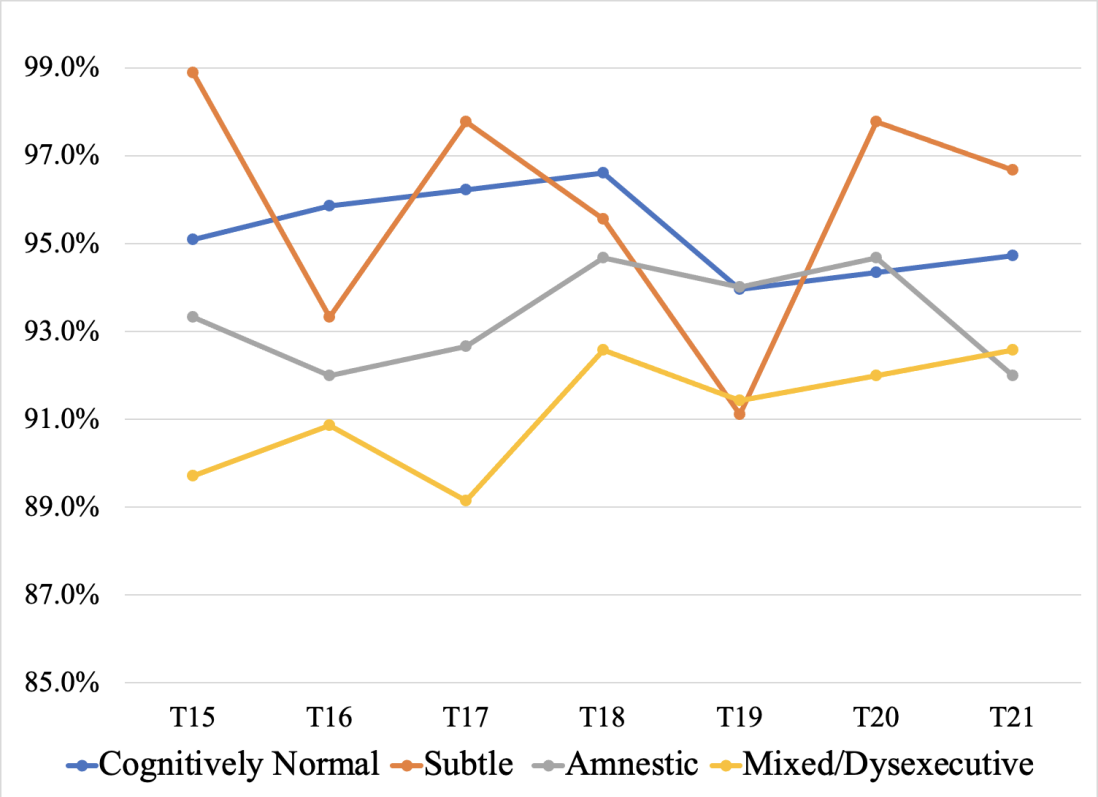
Serial-order accuracy by BDT 5-span trials across clinical groups.



Note. The mixed/dysexecutive MCI group had significantly lower serial-order accuracy than all the other groups on all trials. An effect of education was found on trials 15, 20, and 21, positively correlating with serial-order accuracy.

Figure 3.

Any-order accuracy by BDT 5-span trials across clinical groups.



Note. The mixed/dysexecutive MCI group had significantly lower serial-order accuracy than all the other groups on trial 15 and 17. An effect of gender was found on trial 17, with men having higher scores than women.

References

Ahmed, S., Brennan, L., Eppig, J., Price, C. C., Lamar, M., Delano-Wood, L., Bangen, K. J., Edmonds, E. C., Clark, L., Nation, D. A., Jak, A., Au, R., Swenson, R., Bondi, M. W., & Libon, D. J. (2016). Visuoconstructional impairment in subtypes of mild cognitive impairment. *Applied Neuropsychology: Adult*, *23*(1), 43–52. https://doi.org/10.1080/23279095.2014.1003067

Aiken, L. S., & West, S. G. (1991). *Multiple regression: Testing and interpreting interactions*. SAGE Publications, Inc.

Alagumalai, S., & Curtis, D. D. (2005). Classical Test Theory. In R. Maclean, R. Watanabe, R. Baker, Boediono, Y. C. Cheng, W. Duncan, J. Keeves, Z. Mansheng, C. Power, J. S. Rajput, K. H. Thaman, S. Alagumalai, D. D. Curtis, & N. Hungi (Eds.), *Applied Rasch Measurement: A Book of Exemplars: Papers in Honour of John P. Keeves* (Vol. 4, pp. 1–14). Springer Netherlands. https://doi.org/10.1007/1-4020-3076-2_1

Amato, M. P., & Goretti, B. (2016). Chapter 25—Cognitive Impairment in Multiple Sclerosis. In R. Arnon & A. Miller (Eds.), *Translational Neuroimmunology in Multiple Sclerosis* (pp. 365–384). Academic Press. https://doi.org/10.1016/B978-0-12-801914-6.00027-1

American Psychiatric Association (Ed.). (1994). *DSM-IV: Diagnostic and statistical manual of mental disorders* (4th ed.). Washington, DC: Author.

Ashendorf, L., Swenson, R., & Libon, D. (Eds.). (2013). *The Boston process approach to neuropsychological assessment: A practitioner's guide*. Oxford University Press.

Beatty, P. W., Hagglund, K. J., Neri, M. T., Dhont, K. R., Clark, M. J., & Hilton, S. A. (2003). Access to health care services among people with chronic or disabling conditions: Patterns and predictors. *Archives of Physical Medicine and Rehabilitation*, *84*(10), 1417–1425. https://doi.org/10.1016/S0003-9993(03)00268-5

Bezdicek, O., Ballarini, T., Albrecht, F., Libon, D. J., Lamar, M., Růžička, F., Roth, J., Hurlstone, M. J., Mueller, K., Schroeter, M. L., & Jech, R. (2021). Serial-order recall in working memory across the cognitive spectrum of Parkinson's disease and neuroimaging correlates. *Journal of Neuropsychology*, *15*(1), 88–111. https://doi.org/10.1111/jnp.12208

Bigler, E. D., & Stern, Y. (2015). Chapter 43—Traumatic brain injury and reserve. In J. Grafman & A. M. Salazar (Eds.), *Traumatic Brain Injury, Part II* (Vol. 128, pp. 691–710). Elsevier. https://doi.org/10.1016/B978-0-444-63521-1.00043-1

Binnewijzend, M. A. A., Schoonheim, M. M., Sanz-Arigita, E., Wink, A. M., van der Flier, W. M., Tolboom, N., Adriaanse, S. M., Damoiseaux, J. S., Scheltens, P., van Berckel, B. N. M., & Barkhof, F. (2012). Resting-state fMRI changes in Alzheimer's disease and mild cognitive impairment. *Neurobiology of Aging*, *33*(9), 2018–2028. https://doi.org/10.1016/j.neurobiolaging.2011.07.003

Binet, A. & Simon, T. (1905). Méthodes nouvelles pour le diagnostic du niveau intellectuel des anormaux [New methods for the diagnosis of intellectual level of subnormals]. *L'Année Psychologique, 11*, 191-244.

Birns, J., & Kalra, L. (2009). Cognitive function and hypertension. *Journal of Human Hypertension*, *23*(2), 86–96. https://doi.org/10.1038/jhh.2008.80

Bolton, T. L. (1892). The growth of memory in school children. *The American Journal of Psychology*, *4*(3), 362. https://doi.org/10.2307/1411616

Bopp, K. L., & Verhaeghen, P. (2005). Aging and verbal memory span: A meta-analysis. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *60*(5), 223–233. https://doi.org/10.1093/geronb/60.5.P223

Block, C. K., Johnson-Greene, D., Pliskin, N., & Boake, C. (2017). Discriminating cognitive screening and cognitive testing from neuropsychological assessment: Implications for professional practice. *The Clinical Neuropsychologist*, *31*(3), 487–500. https://doi.org/10.1080/13854046.2016.1267803

Bondi, M. W., Edmonds, E. C., Jak, A. J., Clark, L. R., Delano-Wood, L., McDonald, C. R., Nation, D. A., Libon, D. J., Au, R., Galasko, D., & Salmon, D. P. (2014). Neuropsychological criteria for mild cognitive impairment improves diagnostic precision, biomarker associations, and progression rates. *Journal of Alzheimer's disease: JAD*, *42*(1), 275–289. https://doi.org/10.3233/JAD-140276

Brooks, B. L., Sherman, E. M. S., & Strauss, E. (2009). NEPSY-II: A Developmental Neuropsychological Assessment, Second Edition. *Child Neuropsychology*, *16*(1), 80–101. https://doi.org/10.1080/09297040903146966

Cappelleri, J. C., Jason Lundy, J., & Hays, R. D. (2014). Overview of classical test theory and item response theory for the quantitative assessment of items in developing patient-reported outcomes measures. *Clinical Therapeutics*, *36*(5), 648–662. https://doi.org/10.1016/j.clinthera.2014.04.006

Castano, E., Weber, J., & Duckstein, L. (1981). Decisions Under Violation of Regression Normality. *Journal of the Water Resources Planning and Management Division*, *107*(2), 549–561. https://doi.org/10.1061/JWRDDC.0000227

Chan, R., Shum, D., Toulopoulou, T., & Chen, E. (2008). Assessment of executive functions: Review of instruments and identification of critical issues. *Archives of Clinical Neuropsychology*, *23*(2), 201–216. https://doi.org/10.1016/j.acn.2007.08.010

Chen, J.-H., Lin, K.-P., & Chen, Y.-C. (2009). Risk factors for dementia. *Journal of the Formosan Medical Association*, *108*(10), 754–764. https://doi.org/10.1016/S0929-6646(09)60402-2

Choi, H. J., Lee, D. Y., Seo, E. H., Jo, M. K., Sohn, B. K., Choe, Y. M., Byun, M. S., Kim, J. W., Kim, S. G., Yoon, J. C., Jhoo, J. H., Kim, K. W., & Woo, J. I. (2014). A Normative Study of the Digit Span in an Educationally Diverse Elderly Population. *Psychiatry Investigation*, *11*(1), 39. https://doi.org/10.4306/pi.2014.11.1.39

Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences* (2nd ed.). Routledge. https://doi.org/10.4324/9780203771587

Cohen, J., Cohen, P., West, S. G., & Aiken, L. S. (2003). *Applied Multiple Regression/Correlation Analysis for the Behavioral Sciences* (3rd ed.). Routledge. https://doi.org/10.4324/9780203774441

Collins, A., & Koechlin, E. (2012). Reasoning, learning, and creativity: Frontal lobe function and human decision-making. *PLoS Biology*, *10*(3), e1001293. https://doi.org/10.1371/journal.pbio.1001293

Costa, A. S., Dogan, I., Schulz, J. B., & Reetz, K. (2019). Going beyond the mean: Intraindividual variability of cognitive performance in prodromal and early neurodegenerative disorders. *The Clinical Neuropsychologist*, *33*(2), 369–389. https://doi.org/10.1080/13854046.2018.1533587

Deary, I. J., Bastin, M. E., Pattie, A., Clayden, J. D., Whalley, L. J., Starr, J. M., & Wardlaw, J. M. (2006). White matter integrity and cognition in childhood and old age. *Neurology*, *66*(4), 505–512. https://doi.org/10.1212/01.wnl.0000199954.81900.e2

Djordjevic, J., Jones-Gotman, M., De Sousa, K., & Chertkow, H. (2008). Olfaction in patients with mild cognitive impairment and Alzheimer's disease. *Neurobiology of Aging*, *29*(5), 693–706. https://doi.org/10.1016/j.neurobiolaging.2006.11.014

Eastwood, M. R., Lautenschlaeger, E., & Corbin, S. (1983). A comparison of clinical methods for assessing dementia. *Journal of the American Geriatrics Society*, *31*(6), 342–347. https://doi.org/10.1111/j.1532-5415.1983.tb05744.x

Ebbinghaus, H. *Memory: A Contribution to Experimental Psychology* (Ruger HA and Bussenius CE, Trans). New York: Dover, 1964 (Original work published in 1885).

Edmonds, E. C., Delano-Wood, L., Galasko, D. R., Salmon, D. P., & Bondi, M. W. (2014). Subjective cognitive complaints contribute to misdiagnosis of mild cognitive impairment. *Journal of the International Neuropsychological Society*, *20*(8), 836–847. https://doi.org/10.1017/S135561771400068X

Edmonds, E. C., Delano-Wood, L., Galasko, D. R., Salmon, D. P., & Bondi, M. W.

(2015). Subtle cognitive decline and biomarker staging in preclinical Alzheimer's Disease. *Journal of Alzheimer's Disease*, *47*(1), 231–242. https://doi.org/10.3233/JAD-150128

Emrani, S., Lamar, M., Price, C., Baliga, S., Wasserman, V., Matusz, E. F., Saunders, J., Gietka, V., Strate, J., Swenson, R., Baliga, G., & Libon, D. J. (2021). Neurocognitive constructs underlying executive control in statistically-determined mild cognitive impairment. *Journal of Alzheimer's Disease*, *82*(1), 5–16. https://doi.org/10.3233/JAD-201125

Emrani, S., Libon, D. J., Lamar, M., Price, C. C., Jefferson, A. L., Gifford, K. A., Hohman, T. J., Nation, D. A., Delano-Wood, L., Jak, A., Bangen, K. J., Bondi, M. W., Brickman, A. M., Manly, J., Swenson, R., & Au, R. (2018). Assessing working memory in mild cognitive impairment with serial order recall. *Journal of Alzheimer's Disease*, *61*(3), 917–928. https://doi.org/10.3233/JAD-170555

Eppig, J., Wambach, D., Nieves, C., Price, C. C., Lamar, M., Delano-Wood, L., Giovannetti, T., Bettcher, B. M., Penney, D. L., Swenson, R., Lippa, C., Kabasakalian, A., Bondi, M. W., & Libon, D. J. (2012). Dysexecutive functioning in mild cognitive impairment: derailment in temporal gradients. *Journal of the International Neuropsychological Society: JINS*, *18*(1), 20–28. https://doi.org/10.1017/S1355617711001238

Erdfelder, E., Faul, F., & Buchner, A. (1996). GPOWER: A general power analysis. *Behavior Research Methods, Instruments, & Computers*, *28*(1), 1–11.

Espinosa, A., Alegret, M., Valero, S., Vinyes-Junqué, G., Hernández, I., Mauleón, A.,

Rosende-Roca, M., Ruiz, A., López, O., Tárraga, L., & Boada, M. (2013). A longitudinal follow-up of 550 mild cognitive impairment patients: Evidence for large conversion to dementia rates and detection of major risk factors involved. *Journal of Alzheimer's Disease*, *34*(3), 769–780. https://doi.org/10.3233/JAD-122002

Ewers, M., Walsh, C., Trojanowski, J. Q., Shaw, L. M., Petersen, R. C., Jack, C. R., Feldman, H. H., Bokde, A. L. W., Alexander, G. E., Scheltens, P., Vellas, B., Dubois, B., Weiner, M., & Hampel, H. (2012). Prediction of conversion from mild cognitive impairment to Alzheimer's disease dementia based upon biomarkers and neuropsychological test performance. *Neurobiology of Aging*, *33*(7), 1203-1214.e2. https://doi.org/10.1016/j.neurobiolaging.2010.10.019

Fernandez-Miranda, J. C., Pathak, S., Engh, J., Jarbo, K., Verstynen, T., Yeh, F.-C., Wang, Y., Mintz, A., Boada, F., Schneider, W., & Friedlander, R. (2012). High-definition fiber tractography of the human brain. *Neurosurgery*, *71*(2), 430–453. https://doi.org/10.1227/NEU.0b013e3182592faa

Fuster, J. M. (2009). Cortex and memory: Emergence of a new paradigm. *Journal of Cognitive Neuroscience*, *21*(11), 2047–2072. https://doi.org/10.1162/jocn.2009.21280

Fuster, J. M. (2002). Frontal lobe and cognitive development. *Journal of Neurocytology*, *31*(3/5), 373–385. https://doi.org/10.1023/A:1024190429920

Fuster, J. M. (2015). *The prefrontal cortex* (Fifth edition). Academic Press.

Gagnon, K., Baril, A.-A., Gagnon, J.-F., Fortin, M., Décary, A., Lafond, C., Desautels, A., Montplaisir, J., & Gosselin, N. (2014). Cognitive impairment in obstructive sleep apnea. *Journal of Human Hypertension*, *62*(5), 233–240. https://doi.org/10.1016/j.patbio.2014.05.015

Ginsberg, T. B., Powell, L., Patel, A., Emrani, S., Chopra, A., Cavalieri, T., & Libon, D. J. (2017). Frailty phenotype and neuropsychological test performance: A preliminary analysis. *Journal of Osteopathic Medicine*, *117*(11), 683–687. https://doi.org/10.7556/jaoa.2017.134

Glynn, K., O'Callaghan, M., Hannigan, O., Bruce, I., Gibb, M., Coen, R., Green, E., Lawlor, B., & Robinson, D. (2021). Clinical utility of mild cognitive impairment subtypes and number of impaired cognitive domains at predicting progression to dementia: A 20-year retrospective study. *International Journal of Geriatric Psychiatry*, *36*(1), 31–37. https://doi.org/10.1002/gps.5385

Gómez-Pérez, E., & Ostrosky-Solís, F. (2006). Attention and Memory Evaluation Across the Life Span: Heterogeneous Effects of Age and Education. *Journal of Clinical and Experimental Neuropsychology*, *28*(4), 477–494. https://doi.org/10.1080/13803390590949296

Golomb, J., Kluger, A., & Ferris, S. H. (2004). Mild cognitive impairment: Historical development and summary of research. *Dialogues in Clinical Neuroscience*, *6*(4), 351–367. https://doi.org/10.31887/DCNS.2004.6.4/jgolomb

Gross, A. L., Rebok, G. W., Unverzagt, F. W., Willis, S. L., & Brandt, J. (2011). Word

list memory predicts everyday function and problem-solving in the elderly: Results from the ACTIVE cognitive intervention trial. *Aging, Neuropsychology, and Cognition*, *18*(2), 129–146. https://doi.org/10.1080/13825585.2010.516814

Guo, Y.-B., Gao, W.-J., Long, Z.-L., Cao, W.-F., Cui, D., Guo, Y.-X., Jiao, Q., Qiu, J.-F., Su, L.-Y., & Lu, G.-M. (2021). Shared and specific patterns of structural and functional thalamo-frontal disturbances in manic and euthymic pediatric bipolar disorder. *Brain Imaging and Behavior*, *15*(5), 2671–2680. https://doi.org/10.1007/s11682-021-00539-z

Hampstead, B. M., Libon, D. J., Moelter, S. T., Swirsky-Sacchetti, T., Scheffer, L., Platek, S. M., & Chute, D. (2010). Temporal order memory differences in Alzheimer's disease and vascular dementia. *Journal of Clinical and Experimental Neuropsychology*, *32*(6), 645–654. https://doi.org/10.1080/13803390903418918

Han, J. W., Kim, T. H., Lee, S. B., Park, J. H., Lee, J. J., Huh, Y., Park, J. E., Jhoo, J. H., Lee, D. Y., & Kim, K. W. (2012). Predictive validity and diagnostic stability of mild cognitive impairment subtypes. *Alzheimer's & Dementia*, *8*(6), 553–559. https://doi.org/10.1016/j.jalz.2011.08.007

Hester, R. L., Kinsella, G. J., & Ong, B. (2004). Effect of age on forward and backward span tasks. *Journal of the International Neuropsychological Society*, *10*, 475–481. https://doi.org/10.10170S1355617704104037

Hultsch, D. F., MacDonald, S. W. S., Hunter, M. A., Levy-Bencheton, J., & Strauss, E. (2000). Intraindividual variability in cognitive performance in older adults: Comparison of adults with mild dementia, adults with arthritis, and healthy adults. *Neuropsychology*, *14*(4), 588–598. https://doi.org/10.1037/0894-4105.14.4.588

Hurlstone, M. J., Hitch, G. J., & Baddeley, A. D. (2014). Memory for serial order across domains: An overview of the literature and directions for future research. *Psychological Bulletin*, *140*(2), 339–373. https://doi.org/10.1037/a0034221

Jacobs, J. (1886). The need of a society for experimental psychology. *Mind, 11*, 49-54.

Jacobs, J. (1887). Experiments on "prehension." *Mind*, *12*, 75-79.

Jak, A. J., Bondi, M. W., Delano-Wood, L., Wierenga, C., Corey-Bloom, J., Salmon, D. P., & Delis, D. C. (2009). Quantification of five neuropsychological approaches to defining mild cognitive impairment. *The American journal of geriatric psychiatry: official journal of the American Association for Geriatric Psychiatry*, *17*(5), 368–375. https://doi.org/10.1097/JGP.0b013e31819431d5

John, E. R., Prichep, L. S., & Almas, M. (1992). Subtyping of psychiatric patients by cluster analysis of QEEG. *Brain Topography*, *4*(4), 321–326. https://doi.org/10.1007/BF01135569

Jorm, A. F., Anstey, K. J., Christensen, H., & Rodgers, B. (2004). Gender differences in cognitive abilities: The mediating role of health state and health habits. *Intelligence*, *32*(1), 7–23. https://doi.org/10.1016/j.intell.2003.08.001

Jutkowitz, E., Kane, R. L., Gaugler, J. E., MacLehose, R. F., Dowd, B., & Kuntz, K. M. (2017). Societal and family lifetime cost of dementia: Implications for policy. *Journal of the American Geriatrics Society*, *65*(10), 2169–2175. https://doi.org/10.1111/jgs.15043

Kalbe, E., Kessler, J., Calabrese, P., Smith, R., Passmore, A. P., Brand, M., & Bullock, R.

(2004). DemTect: A new, sensitive cognitive screening test to support the diagnosis of mild cognitive impairment and early dementia. *International Journal of Geriatric Psychiatry*, *19*(2), 136–143. https://doi.org/10.1002/gps.1042

Kaplan, E. (1988). The process approach to neuropsychological assessment. *Aphasiology*, *2*(3–4), 309–311. https://doi.org/10.1080/02687038808248930

Kessels, R. P. C., van den Berg, E., Ruis, C., & Brands, A. M. A. (2008). The Backward Span of the Corsi Block-Tapping Task and Its Association With the WAIS-III Digit Span. *Assessment*, *15*(4), 426–434. https://doi.org/10.1177/1073191108315611

Kida, J., Nemoto, K., Ikejima, C., Bun, S., Kakuma, T., Mizukami, K., & Asada, T. (2016). Impact of depressive symptoms on conversion from mild cognitive impairment subtypes to Alzheimer's disease: A Community-Based Longitudinal Study. *Journal of Alzheimer's Disease*, *51*(2), 405–415. https://doi.org/10.3233/JAD-150603

Kline, T. (2005). Classical test theory: Assumptions, equations, limitations, and item analyses. In *Psychological Testing: A Practical Approach to Design and Evaluation* (pp. 91–106). Sage Publications.

Kondo, D., Ota, K., Kasanuki, K., Fujishiro, H., Chiba, Y., Murayama, N., Sato, K., Hirayasu, Y., Arai, H., & Iseki, E. (2016). Characteristics of mild cognitive impairment tending to convert into Alzheimer's disease or dementia with Lewy bodies: A follow-up study in a memory clinic. *Journal of the Neurological Sciences*, *369*, 102–108. https://doi.org/10.1016/j.jns.2016.08.011

Kurt, P., Yener, G., & Oguz, M. (2011). Impaired digit span can predict further cognitive

decline in older people with subjective memory complaint: A preliminary result. *Aging & Mental Health*, *15*(3), 364–369. https://doi.org/10.1080/13607863.2010.536133

Kwak, S. G., & Kim, J. H. (2017). Central limit theorem: The cornerstone of modern statistics. *Korean Journal of Anesthesiology*, *70*(2), 144–156. https://doi.org/10.4097/kjae.2017.70.2.144

Lamar, M., Catani, M., Price, C. C., Heilman, K. M., & Libon, D. J. (2008). The impact of region-specific leukoaraiosis on working memory deficits in dementia. *Neuropsychologia*, *46*(10), 2597–2601. https://doi.org/10.1016/j.neuropsychologia.2008.04.007

Lamar, M., Podell, K., Carew, T. G., Cloud, B. S., Resh, R., Kennedy, C., Goldberg, E., Kaplan, E., & Libon, D. J. (1997). Perseverative behavior in Alzheimer's disease and subcortical ischemic vascular dementia. *Neuropsychology*, *11*(4), 523–534. https://doi.org/10.1037/0894-4105.11.4.523

Lamar, M., Price, C. C., Libon, D. J., Penney, D. L., Kaplan, E., Grossman, M., & Heilman, K. M. (2007). Alterations in working memory as a function of leukoaraiosis in dementia. *Neuropsychologia*, *45*(2), 245–254. https://doi.org/10.1016/j.neuropsychologia.2006.07.009

Landau, S. M., Harvey, D., Madison, C. M., Reiman, E. M., Foster, N. L., Aisen, P. S., Petersen, R. C., Shaw, L. M., Trojanowski, J. Q., Jack, C. R., Weiner, M. W., Jagust, W. J., & On behalf of the Alzheimer's Disease Neuroimaging Initiative.

(2010). Comparing predictors of conversion and decline in mild cognitive impairment. *Neurology*, *75*(3), 230–238. https://doi.org/10.1212/WNL.0b013e3181e8e8b8

Langa, K. M., & Levine, D. A. (2014). The diagnosis and management of mild cognitive impairment: A clinical review. *Journal of the American Medical Association*, *312*(23), 2551. https://doi.org/10.1001/jama.2014.13806

Larson, K., & Halfon, N. (2010). Family Income Gradients in the Health and Health Care Access of US Children. *Maternal and Child Health Journal*, *14*(3), 332–342. https://doi.org/10.1007/s10995-009-0477-y

Lesser, I. M., Miller, B. L., Swartz, J. R., Boone, K. B., Mehringer, C. M., & Mena, I. (1993). Brain imaging in late-life schizophrenia and related psychoses. *Schizophrenia Bulletin*, *19*(4), 773–782. https://doi.org/10.1093/schbul/19.4.773

Lezak, M. D. (Ed.). (2012). *Neuropsychological Assessment* (5th ed). Oxford University Press.

Li, B., Li, X., Stoet, G., & Lages, M. (2022). Processing Speed Predicts Mean Performance in Task-Switching but Not Task-Switching Cost. *Psychological Reports*. https://doi.org/10.1177/00332941211072228

Libon, D. J., Schwartzman, R. J., Eppig, J., Wambach, D., Brahin, E., Lee Peterlin, B., Alexander, G., & Kalanuria, A. (2010). Neuropsychological deficits associated with complex regional pain syndrome. *Journal of the International Neuropsychological Society*, *16*(3), 566–573. https://doi.org/10.1017/S1355617710000214

Libon, D. J., Xie, S. X., Eppig, J., Wicas, G., Lamar, M., Lippa, C., Bettcher, B. M., Price, C. C., Giovannetti, T., Swenson, R., & Wambach, D. M. (2010). The heterogeneity of mild cognitive impairment: A neuropsychological analysis. *Journal of the International Neuropsychological Society*, *16*(1), 84–93. https://doi.org/10.1017/S1355617709990993

Limongi, F., Siviero, P., Noale, M., Gesmundo, A., Crepaldi, G., & Maggi, S. (2017). Prevalence and conversion to dementia of Mild Cognitive Impairment in an elderly Italian population. *Aging Clinical and Experimental Research*, *29*(3), 361–370. https://doi.org/10.1007/s40520-017-0748-1

Loewenstein, D. A., D'Elia, L., Guterman, A., Eisdorfer, C., Wilkie, F., LaRue, A., Mintzer, J., & Duara, R. (1991). The occurrence of different intrusive errors in patients with Alzheimer's disease, multiple cerebral infarctions, and major depression. *Brain and Cognition*, *16*(1), 104–117. https://doi.org/10.1016/0278-2626(91)90088-P

Loewenstein, D. A., Wilkie, F., Eisdorfer, C., Guterman, A., Berkowitz, N., & Duara, R. (1989). An analysis of intrusive error types in Alzheimer's disease and related disorders. *Developmental Neuropsychology*, *5*(2–3), 115–126. https://doi.org/10.1080/87565648909540427

Loring, D. W. (Ed.). (1999). *INS dictionary of neuropsychology*. Oxford University Press.

Maioli, F., Coveri, M., Pagni, P., Chiandetti, C., Marchetti, C., Ciarrocchi, R., Ruggero, C., Nativio, V., Onesti, A., D'Anastasio, C., & Pedone, V. (2007). Conversion of

mild cognitive impairment to dementia in elderly subjects: A preliminary study in a memory and cognitive disorder unit. *Archives of Gerontology and Geriatrics, 44*, 233–241. https://doi.org/10.1016/j.archger.2007.01.032

Michaud, T. L., Su, D., Siahpush, M., & Murman, D. L. (2017). The risk of incident mild cognitive impairment and progression to dementia considering mild cognitive impairment subtypes. *Dementia and Geriatric Cognitive Disorders Extra*, *7*(1), 15–29. https://doi.org/10.1159/000452486

Moretti, L., Semenza, C., & Vallesi, A. (2018). General Slowing and Education Mediate Task Switching Performance Across the Life-Span. *Frontiers in Psychology, 9*, 630. https://doi.org/10.3389/fpsyg.2018.00630

Morrow, S. A., Rosehart, H., & Johnson, A. M. (2015). Diagnosis and Quantification of Cognitive Fatigue in Multiple Sclerosis. *Cognitive and Behavioral Neurology, 28*(1), 27–32. https://doi.org/10.1097/WNN.0000000000000050

Morris, L. S., Kundu, P., Dowell, N., Mechelmans, D. J., Favre, P., Irvine, M. A., Robbins, T. W., Daw, N., Bullmore, E. T., Harrison, N. A., & Voon, V. (2016). Fronto-striatal organization: Defining functional and microstructural substrates of behavioural flexibility. *Cortex, 74*, 118–133. https://doi.org/10.1016/j.cortex.2015.11.004

Murphy, K. R., Myors, B., & Wolach, A. (2014). *Statistical Power Analysis* (4th ed.). Routledge. https://doi.org/10.4324/9781315773155

Nasreddine, Z. S., Phillips, N. A., Bédirian, V., Charbonneau, S., Whitehead, V., Collin, I., Cummings, J. L., & Chertkow, H. (2005). The Montreal Cognitive Assessment, MoCA: A brief screening tool for mild cognitive impairment. *Journal of the*

American Geriatrics Society, *53*(4), 695–699. https://doi.org/10.1111/j.1532-5415.2005.53221.x

Oltra-Cucarella, J., Ferrer-Cascales, R., Alegret, M., Gasparini, R., Díaz-Ortiz, L. M., Ríos, R., Martínez-Nogueras, Á. L., Onandia, I., Pérez-Vicente, J. A., Cabello-Rodríguez, L., & Sánchez-SanSegundo, M. (2018). Risk of progression to Alzheimer's disease for different neuropsychological mild cognitive impairment subtypes: A hierarchical meta-analysis of longitudinal studies. *Psychology and Aging*, *33*(7), 1007–1021. https://doi.org/10.1037/pag0000294

Orsini, D. L., Van Gorp, W. G., & Boone, K. B. (2013). *The Neuropsychology Casebook.* Springer.

Pardilla-Delgado, E., & Payne, J. D. (2017). The Deese-Roediger-McDermott (DRM) Task: A Simple Cognitive Paradigm to Investigate False Memories in the Laboratory. *Journal of Visualized Experiments*, *119*, 54793. https://doi.org/10.3791/54793

Parsons, T. D., Rizzo, A. R., Zaag, C. van der, McGee, J. S., & Buckwalter, J. G. (2005). Gender Differences and Cognition Among Older Adults. *Aging, Neuropsychology, and Cognition*, *12*(1), 78–88. https://doi.org/10.1080/13825580590925125

Petersen, R. C., Lopez, O., Armstrong, M. J., Getchius, T. S. D., Ganguli, M., Gloss, D., Gronseth, G. S., Marson, D., Pringsheim, T., Day, G. S., Sager, M., Stevens, J., & Rae-Grant, A. (2018). Practice guideline update summary: Mild cognitive impairment: Report of the Guideline Development, Dissemination, and

Implementation Subcommittee of the American Academy of Neurology. *Neurology*, *90*(3), 126–135. https://doi.org/10.1212/WNL.0000000000004826

Prince, M., Wimo, A., Guerchet, M., Ali, G-C., Wu, Y-T., & Prina, M. (2015). World Alzheimer Report 2015. The global impact of dementia. An analysis of prevalence, incidence, cost, and trends.

Rabin, L. A., Paolillo, E., & Barr, W. B. (2016). Stability in test-usage practices of clinical neuropsychologists in the United States and Canada over a 10-year period: A follow-up survey of INS and NAN members. *Archives of Clinical Neuropsychology*, *31*(3), 206–230. https://doi.org/10.1093/arclin/acw007

Ravaglia, G., Forti, P., Maioli, F., Martelli, M., Servadei, L., Brunetti, N., Pantieri, G., & Mariani, E. (2006). Conversion of mild cognitive impairment to dementia: Predictive role of mild cognitive impairment subtypes and vascular risk factors. *Dementia and Geriatric Cognitive Disorders*, *21*(1), 51–58. https://doi.org/10.1159/000089515

Reed, B. R., Jagust, W. J., & Coulter, L. (1993). Anosognosia in Alzheimer's disease: Relationships to depression, cognitive function, and cerebral perfusion. *Journal of Clinical and Experimental Neuropsychology*, *15*(2), 231–244. https://doi.org/10.1080/01688639308402560

Reisberg, B., Ferris, S. H., de Leon, M. J., & Crook, T. (1982). The Global Deterioration Scale for assessment of primary degenerative dementia. *American Journal of Psychiatry*, *139*(9), 1136–1139. https://doi.org/10.1176/ajp.139.9.1136

Reisberg, B., Ferris, S. H., de Leon, M. J., Franssen, E. S. E., Kluger, A., Mir, P.,

Borenstein, J., George, A. E., Shulman, E., Steinberg, G., & Cohen, J. (1988). Stage-specific behavioral, cognitive, and in vivo changes in community residing subjects with age-associated memory impairment and primary degenerative dementia of the Alzheimer type. *Drug Development Research*, *15*(2–3), 101–114. https://doi.org/10.1002/ddr.430150203

Restriction of Range. (2018). In B. B. Frey, *The SAGE Encyclopedia of Educational Research, Measurement, and Evaluation*. SAGE Publications, Inc. https://doi.org/10.4135/9781506326139.n595

Richardson, J. T. E. (2007). Measures of short-term memory: A historical review. *Cortex*, *43*(5), 635–650. https://doi.org/10.1016/S0010-9452(08)70493-3

Sato, T. (1996). Type I and Type II Error in Multiple Comparisons. *The Journal of Psychology*, *130*(3), 293–302. https://doi.org/10.1080/00223980.1996.9915010

Schretlen, D. J., Testa, S. M., Winicki, J. M., Pearlson, G. D., & Gordon, B. (2008). Frequency and bases of abnormal performance by healthy adults on neuropsychological testing. *Journal of the International Neuropsychological Society*, *14*(03), 436–445. https://doi.org/10.1017/S1355617708080387

Schoenberg, M. R., & Scott, J. G. (Eds.). (2011). *The little black book of neuropsychology: A syndrome-based approach*. Springer.

Schultz, I. Z., Sepehry, A. A., & Greer, S. C. (2018). Cognitive Impact of Fatigue in Forensic Neuropsychology Context. *Psychological Injury and Law*, *11*(2), 108–119. https://doi.org/10.1007/s12207-018-9324-z

Schwid, S. R., Tyler, C. M., Scheid, E. A., Weinstein, A., Goodman, A. D., & McDermott, M. P. (2003). Cognitive fatigue during a test requiring sustained

attention: A pilot study. *Multiple Sclerosis Journal*, *9*(5), 503–508. https://doi.org/10.1191/1352458503ms946oa

Selya, A. S., Rose, J. S., Dierker, L. C., Hedeker, D., & Mermelstein, R. J. (2012). A Practical Guide to Calculating Cohen's f^2, a Measure of Local Effect Size, from PROC MIXED. *Frontiers in Psychology*, *3*. https://doi.org/10.3389/fpsyg.2012.00111

Singh, D., Joska, J. A., Goodkin, K., Lopez, E., Myer, L., Paul, R. H., John, S., & Sunpath, H. (2010). Normative scores for a brief neuropsychological battery for the detection of HIV-associated neurocognitive disorder (HAND) among South Africans. *BMC Research Notes*, *3*(1), 28. https://doi.org/10.1186/1756-0500-3-28

Sperling, R.A., Aisen, P.S., Beckett, L.A., Bennett, D.A., Craft, S., Fagan, A.M., Iwatsubo, T., Jack, C.R., Kaye, J.A., Montine, T.J., Park, D.C., Reiman, E.M., Rowe, C.C., Siemers, E.R., Yaffe, K., Carrillo, M.C., Thies, B., Morrison-Bogorad, M., Wagster, M.V., & Phelps, C.H. (2011). Toward defining the preclinical stages of Alzheimer's disease: Recommendations from the National Institute on Aging and the Alzheimer's Association workgroup.

Stern, Y. (2002). What is cognitive reserve? Theory and research application of the reserve concept. *Journal of the International Neuropsychological Society*, *8*(3), 448–460. https://doi.org/10.1017/S1355617702813248

Stern, Y. (2009). Cognitive reserve. *Neuropsychologia*, *47*(10), 2015–2028. https://doi.org/10.1016/j.neuropsychologia.2009.03.004

Stuss, D. T., Shallice, T., Alexander, M. P., & Picton, T. W. (1995). A Multidisciplinary Approach to Anterior Attentional Functions. *Annals of the New York Academy of*

Sciences, *769*(1), 191–212. https://doi.org/10.1111/j.1749-6632.1995.tb38140.x

Sudo, F. K., Alves, C. E. O., Alves, G. S., Ericeira-Valente, L., Tiel, C., Moreira, D. M., Laks, J., & Engelhardt, E. (2012). Dysexecutive syndrome and cerebrovascular disease in non-amnestic mild cognitive impairment: A systematic review of the literature. *Dementia & Neuropsychologia*, *6*(3), 145–151. https://doi.org/10.1590/S1980-57642012DN06030006

Tabachnick, B.G. & Fidell, L.S. (2013). *Using Multivariate Statistics* (6th edition). Boston, MA: Pearson.

Tabert, M. H., Manly, J. J., Liu, X., Pelton, G. H., Rosenblum, S., Jacobs, M., Zamora, D., Goodkind, M., Bell, K., Stern, Y., & Devanand, D. P. (2006). Neuropsychological prediction of conversion to Alzheimer's disease in patients with mild cognitive impairment. *Archives of General Psychiatry*, *63*(8), 916. https://doi.org/10.1001/archpsyc.63.8.916

Thomas, K. R., Edmonds, E. C., Delano-Wood, L., & Bondi, M. W. (2017). Longitudinal trajectories of informant-reported daily functioning in empirically defined subtypes of mild cognitive impairment. *Journal of the International Neuropsychological Society: JINS*, *23*(6), 521–527. https://doi.org/10.1017/S1355617717000285

Traykov, L., Raoux, N., Latour, F., Gallo, L., Hanon, O., Baudic, S., Bayle, C., Wenisch, E., Remy, P., & Rigaud, A.-S. (2007). Executive functions deficit in mild cognitive impairment. *Cognitive and Behavioral Neurology*, *20*(4), 219–224. https://doi.org/10.1097/WNN.0b013e31815e6254

Vanderploeg, R. D. (Ed.). (2000). *Clinician's Guide to Neuropsychological Assessment* (2nd ed). Lawrence Erlbaum Associates.

Wambach, D., Lamar, M., Swenson, R., Penney, D. L., Kaplan, E., & Libon, D. J. (2011). Digit Span. In J. S. Kreutzer, J. DeLuca, & B. Caplan (Eds.), *Encyclopedia of Clinical Neuropsychology* (pp. 844–849). Springer New York. https://doi.org/10.1007/978-0-387-79948-3_1288

Woods, D. L., Kishiyama, M. M., Yund, E. W., Herron, T. J., Edwards, B., Poliva, O., Hink, R. F., & Reed, B. (2011). Improving digit span assessment of short-term verbal memory. *Journal of Clinical and Experimental Neuropsychology*, *33*(1), 101–111. https://doi.org/10.1080/13803395.2010.493149

World Health Organization (1993) *International Statistical Classification of Diseases and Related Health Problems (ICD-10)*. Geneva: WHO.

Yaffe, K., Petersen, R. C., Lindquist, K., Kramer, J., & Miller, B. (2006). Subtype of mild cognitive impairment and progression to dementia and death. *Dementia and Geriatric Cognitive Disorders*, *22*(4), 312–319. https://doi.org/10.1159/000095427

Zahodne, L. B., Manly, J. J., MacKay-Brandt, A., & Stern, Y. (2013). Cognitive declines precede and predict functional declines in aging and Alzheimer's disease. *PLoS ONE*, *8*(9), e73645. https://doi.org/10.1371/journal.pone.0073645