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Everyday Working Memory: The Ecological Validity of Three Working Memory Tests

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Everyday Working Memory: The Ecological Validity of Three Working Memory Tests

by

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A research project submitted in partial fulfilment of the requirements for the degree of Master of Arts by Coursework and Research Report in the field of Social and Psychological Research in the Faculty of Humanities, University of the Witwatersrand, Johannesburg, March 2024.

Declaration

I declare that this research project is my own, unaided work. It has not been submitted before for any other degree or examination at this or any other university.

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Abstract

Working memory plays a crucial role in adaptive functioning, yet the ability of traditional working memory tests to predict real-life challenges remains uncertain. Despite their everyday use in laboratory settings, there needs to be more research on the ecological validity of the *n*-back test, Symbol Span subtest, and Digit Span subtest in capturing everyday life problems related to working memory. This gap is especially noticeable in South Africa, where cultural and contextual factors may influence working memory performance and its impact on daily functioning. This study aimed to address this research gap by assessing the ecological validity of three working memory tests, the *n*-back test, the Symbol Span subtest, and the Digit Span subtest, in predicting everyday life problems related to working memory. Sixty-nine bilingual and multilingual young adults aged 18 to 25 completed a demographic questionnaire, the Working Memory Questionnaire (WMQ), and the three working memory tests. The data was analysed using descriptive statistics, correlation analyses, and ordinal logistic regression analyses. Significant correlations were found between various working memory tests and specific working memory questions, providing valuable insights into the relationships between these variables. These findings contribute to the understanding of working memory assessment and have implications for everyday functioning, particularly in educational settings, highlighting the relevance of working memory in cognitive processes.

Keywords: Digit Span subtest, ecological validity, *n*-back test, Symbol Span subtest, working memory

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Chapter 1: Literature and Theoretical Review

Introduction

Among the main issues in clinical neuropsychology is the ecological validity of psychometric measures of cognition. Although conventional measures of working memory are beneficial, many were created for research purposes rather than for tapping functioning in real-life settings. Numerous people need help with the everyday functioning of working memory despite performing within normal limits on traditional, laboratory-based tests, such as the *n*-back test (Eslinger & Damasio, 1985; Shallice & Burgess, 1991). The disparity has been attributed partly to the unstructured, open-ended nature of daily life events as opposed to the highly structured neuropsychological tests in which patients are often required to identify a solution to a given issue (Lezak, 1995).

Early detection of working memory difficulties is essential to ensuring that children with such issues can reach their full developmental potential (Fewell & Littlefair, 2016). Given its vital role in learning, assessing this capacity is important from preschool to university. It is essential for many complex school activities, including mental arithmetic, word problems, reading comprehension, and basic tasks such as copying from the board and navigating around the school (Alloway & Copello, 2013). Thus, academic success correlates with working memory ability (Alloway et al., 2005; Gathercole et al., 2004). For these reasons, working memory assessments must be able to tap the functioning of this ability in everyday settings.
Similarly, exploring working memory deficits in university students holds significant relevance, as these challenges extend beyond controlled laboratory environments to real-life settings, including educational institutions. This exploration is particularly pertinent in the context of South Africa, a developing nation with limited financial and psychological resources. In such resource-constrained settings, strategic allocation of resources towards tools and interventions becomes crucial to optimise the cognitive potential of the population. Recognising the impact of working memory on academic success, especially among university students, underscores the importance of identifying and addressing these cognitive challenges, aligning with the broader goal of fostering enhanced cognitive abilities within the academic landscape.

Consequently, this study examined the ecological validity of laboratory-based working memory tests, specifically the *n*-back test, and two diagnostic clinical neuropsychological tests, the Symbol Span and Digit Span subtest, with a sample of South African university students.

By exploring the relationship of these tests with everyday working memory errors, the study aims to bridge the knowledge gap regarding their effectiveness in predicting working memory-related problems in real-life scenarios.

Literature Review and Theoretical Framework

In addition to the rationale provided in the introduction, this section of the literature review explores the theoretical and empirical evidence related to the measures used in this study and the assessment of ecological validity in predicting everyday life problems in working memory. To accomplish this, the chapter begins by examining the conceptualisation of working memory and how it fits within executive functions more broadly. The review then discusses two relevant theoretical models of working memory, namely Baddeley's Multicomponent Model (1992) and Cowan's Embedded-Processes Model (1999). These models provide a theoretical framework for understanding working memory and its components. Following the conceptualisation of working memory and the exploration of the theoretical models, the review proceeds to discuss the theoretical and empirical evidence concerning the predictive nature and relationship between laboratory-based working memory test (the *n*-back test) and the clinical tests (the Symbol Span subtest, and the Digit Span subtest) and everyday life problems. It will then explain the ecological validity of working memory tests and their measures internationally and in South Africa.

Conceptualisation of Executive Functions and Working Memory

Executive functioning refers to a broader set of higher-order cognitive processes that control and regulate thoughts, actions, and emotions. They are higher-order cognitive functions that coordinate and manage other cognitive processes to achieve goals effectively (Cristofori et al., 2019). Although executive functions comprise many components, the following are considered the primary elements: inhibition, shifting, conflict management, updating, and monitoring (Cristofori et al., 2019). Inhibition is the deliberate restraint of habitual, automated responses (Zuber et al., 2019). This component enables individuals engaged in tasks to override or restrain responses that may be irrelevant to these tasks (Zuber et al., 2019). Shifting is the ability to flexibly move between objectives or perspectives when problem-solving (Zuber et al., 2019). This component enables individuals to disengage from an irrelevant objective/perspective so that they engage in a relevant objective/perspective.

Conflict monitoring refers to the cognitive process of detecting and managing discrepancies or conflicts in information, typically arising from competing stimuli, responses,

or goals. It is a critical component of cognitive control and executive functions, involving the continuous evaluation of ongoing tasks to identify and address instances of incongruence or interference (Abutalebi et al., 2011). Updating and monitoring refer to the ability to assimilate and maintain new and relevant information, allowing for replacing old information that is no longer relevant (Zuber et al., 2019).

Among these executive function components, updating and monitoring are component processes of working memory, signifying the latter's role as a core component of executive function (Baddeley, 2000; Miyake et al., 2000). Working memory is theoretically conceptualised as a cognitive system that temporarily stores and manipulates information necessary for complex cognitive tasks. It acts as a mental workspace where information is actively held and processed (Baddeley, 2020). It is closely intertwined with executive function as it supports several executive processes, such as inhibition and shifting, and includes updating and monitoring (Cristofori et al., 2019).

Since working memory enables individuals to hold and manipulate relevant information in their minds, it allows them to inhibit or suppress irrelevant information or responses. It provides the capacity for cognitive flexibility by allowing individuals to shift between different task demands or perspectives (Chai et al., 2018).

Literature highlights the role of working memory in supporting the updating and monitoring of information, involving the retention of new information while integrating it with existing knowledge (Chai et al., 2018). This complex relationship is further explored by emphasising the interconnected nature of updating and monitoring within working memory. While some researchers propose a separation, treating updating and monitoring as processes supported by working memory (Cowan, 2008), an alternative viewpoint sees them as inherent components of working memory (Baddeley, 1992). This ongoing debate prompts a nuanced exploration of the relationship between working memory, updating, and monitoring, offering differing perspectives on whether these cognitive processes are distinct or integral within the construct of working memory (Chai et al., 2018). This intricate connection between working memory and executive functions is echoed in the literature, where terms like updating monitoring and working memory are frequently used interchangeably.

Exploring working memory models: Baddeley's (1992) Multicomponent Model and Cowan's Embedded-Processes Model (1999)

There are many different theoretical conceptualisations of working memory; however, this research paper focuses on two of the most prominent models of working memory amongst

multiple competing theories. The first model, the Multicomponent Model of Working Memory, was introduced by Baddeley (1992) – building upon the earlier model of working memory by Baddeley and Hitch (1974) - to expand and refine the original working memory model to incorporate the concept of the episodic buffer. The second model, Cowan's Embedded-Processes Model (1999), emerged later and presents a compelling alternative perspective on the structure and functioning of working memory. The following sections will establish the connection between these theories and the specific working memory measures employed in the study.

The term 'working memory' emerged from the prior concept of 'short-term memory' (Baddeley, 2017). Baddeley and Hitch (1974) discovered that working memory was a multicomponent system rather than a single unitary store, as initially hypothesised, from a series of investigations on language comprehension and long-term memory. According to later versions of their model, this multicomponent system comprises four parts: a visuospatial sketchpad, a phonological loop, an episodic buffer, and a central executive (Baddeley, 2017). The visuospatial sketchpad (short-term visuospatial memory) is a passive store that integrates spatial and visual kinaesthetic information into cohesive representations that can be held briefly (Baddeley, 2017). It comprises two parts, the visual cache, which stores shape and colour information, and the inner scribe, which processes spatial and movement information (Logie, 1995). The phonological loop, also a passive store, is similarly made up of two parts: a phonological store, which stores acoustic or speech-based information for one or two seconds, and an articulatory control process, like inner speech. The purpose of the phonological loop system is to store verbal information, typically termed short-term verbal memory (Baddeley, 1992). It is the most developed and researched component of working memory, having been studied using phonological similarity, word length, and suppression effects (e.g., Baddeley et al., 2018; Jalbert et al., 2011). However, it is only one part of working memory (Baddeley, 2012). Its advantage is that it can provide temporary sequential storage rapidly and efficiently while requiring little attention (Baddeley, 2012). The newest component of the model, the episodic buffer organises information into meaningful episodes and acts as an intermediary between the subsidiary and long-term memory (Baddeley, 2017). The central executive is the most complex component of this model. It is responsible for processing information, engaging in active tasks, and integrating information from other brain networks, such as specifying task goals and initiating and terminating cognitive routines (Baddeley, 2017). The central executive controls the visual sketchpad, episodic buffer, and phonological loop, which work together to process data for ongoing tasks (Yang, 2017).

Working and short-term verbal memory are commonly measured by the Digit Span test in research and clinical settings (e.g., Perna et al., 2018) and used in the current study. This test is a subtest of the Wechsler Adult Intelligence Scale – Fourth Edition (Wechsler, 2014). Participants are asked to repeat a series of spoken digits either in the order they were given (Forward Span), in the reverse order (Backwards Span), or numerical order (Sequencing; Blackburn & Harold, 1957). Digits Forward is widely employed to measure the Multicomponent Model's (Baddeley, 1992) phonological loop. Forward Span activities rely on either the articulatory loop or visual sketchpad, with no requirement for involvement from the central executive system.

In contrast, Backward Span and Sequencing tasks demand the use of the central executive system and those provided by the subsidiary storage systems because of the increased attentional demands and control procedures required in remembering and re-ordering information (Rosenthal et al., 2006). Less commonly used than the Digit Span task but a popular measure, the Symbol Span subtest (Wechsler Memory Scale - Fourth Edition; Wechsler, 2009) tapped visuospatial short-term and working memory and was employed in the current study. Participants are shown cards with one to four abstract symbols in a row in this subtest. They are expected to recall the design or designs, as well as the order of the design from left to right. Participants are then instructed to select the correct matching design foils and to do so in the correct sequence. In this way, the subtest assesses immediate memory for the designs and memory for the location or ordering of the designs.

The second working memory model addressed in this study is Cowan's (1999) Embedded Processes Model. According to this model, working memory is not a separate cognitive system, as proposed by Baddeley (1992), but rather an activated part of long-term memory. Cowan's (1999) model regards working memory as the "focus of attention. The "focus of attention" aspect highlights the dynamic nature of working memory, capturing the immediate contents that are currently activated and subject to active cognitive processes. By understanding working memory as the "focus of attention," Cowan's (1999) model underscores the interactive nature of cognitive systems, offering a nuanced perspective on how attention and long-term memory collaboratively contribute to the ongoing cognitive processes within working memory. This model thus integrates working memory, long-term memory, and attention (voluntary and involuntary; Cowan, 1999). Working memory is represented as a two-phase process in the embedded-processes model, with the activated portion of long-term memory holding relevant features temporarily, including newly learned information, and the focus of attention holding several integrated items within it (Cowan et al., 2020).

The embedded processes model was included as the *n*-back test often operationalises it, another of the working memory tests used in the current study (Kirchner, 1958). The *n*-back test is a running working memory test that taps the process of updating or modifying a schema representation's current state to accommodate new knowledge (Kane et al., 2007; Morris & Jones, 1990). For this task, participants must determine whether the digit on the screen was the same as the one presented '*n*' trials ago. The *n* can indicate one, two, or three digits past the displayed one. The complexity of the task and the demand for working memory increase as the number rises as it requires the participant to continually update information in working memory to accommodate the new information (Morris & Jones, 1990; Verhaeghen & Basak, 2005). Access rates from working memory for *n*=2 and *n*=3 seem the same, while access speeds for *n*=1 are significantly faster than for *n*=2 or *n*=3 (McElree, 2001). According to the interpretation, only one element can be held in the focus of attention at any time. When *n* is more significant than one, the target must be retrieved from outside this attentional focus and moved into it for processing, supporting Cowan's (1999) model (Verhaeghen & Basak, 2005). According to Cowan's embedded processes working memory model (Cowan, 1999), the Digit Span and *n*-back tasks also focus on different cognitive processes, with *n*-back requiring only retrieval from the central focus of attention and span tasks requiring processing of items in both the focus of attention and activated long-term memory. A study conducted by Ivanova et al. (2017) showed that, although *n*-back tasks appear to be comparable to conventional working memory span measures and index abilities related to executive functions, they tap into distinct cognition domains. This evidence has important practical implications because these tasks cannot be used interchangeably as working memory indicators. After all, they draw on various aspects of this process. The *n*-back tasks' unstable psychometric properties and lack of construct validity have also been criticised (DeDe et al., 2014; Jaeggi et al., 2010). Although the *n*-back test is used widely in research, there are suggestions that it may not be a pure test of working memory but instead a test of processing speed, as it seems to focus on how quickly we process information rather than how much information can be held in working memory (Miller et al., 2009). A secondary aim of the current study was therefore to determine whether the *n*-back test correlates with the other two measures of working memory (i.e., Digit Span and Symbol Span).

While Cowan's Embedded Processes Model (1999) and Baddeley's Multicomponent Model (1992) have been used to explain the theoretical bases of the working memory tests used in the current study, they are fundamentally different in their assumptions. The Multicomponent Model's (Baddeley, 1992) fundamental premise is that the memory subsystems (i.e.,

phonological loop, visuospatial sketchpad, and episodic buffer) subject to the central executive system are structurally distinct, hence the name 'multicomponent' model (Gruszka & Orzechowski, 2016). Cowan (1999), in contrast, incorporates the activated long-term memory as a central component, underscoring the significance of long-term memory in working memory processes. The focus of attention, a subset within activated long-term memory, represents the current contents actively involved in ongoing cognitive activities. Cowan's (1999) reinterpretation of evidence for distinct subsystems, often supported by Baddeley's (1992) model, suggests a more unified system. Cowan attributes the observed interference in concurrent tasks, seen as evidence for distinct subsystems by Baddeley, to the interference within active information. This reinterpretation posits interference as a mechanism contributing to information loss in working memory (Glass et al., 1985), offering an alternative perspective on the nature of working memory processes.

There are many different working memory measures based on these working memory models, such as the Digit Span subtest, and most of them claim to measure the same construct (i.e., working memory). However, their ability to tap working memory functioning in everyday life needs to be clarified and formed the primary focus of the current study.

Ecological validity and its role in the measurement of cognitive constructs

Ecological validity refers to the application and generalisability of experimental results to the real world (Kihlstrom, 2021). As Burgess et al. (2006) outlined, ecological validity encompasses two key components: representativeness and generalisability. Representativeness refers to how a clinical test mirrors real-world situations beyond the laboratory in form and context. Conversely, generalisability pertains to how effectively poor performance on a test can predict challenges in real-world scenarios (Vallat-Azouvi et al., 2012). Developing ecologically valid neuropsychological assessments is crucial for comprehensively evaluating individuals' everyday difficulties with working memory. These assessments are pivotal in objectively measuring interventions' impact and supporting clinicians' decision-making (Vallat-Azouvi et al., 2012).

Diagnostic tests like the Digit Span and Symbol Search (Wechsler, 2008) are developed, standardised, and administered under rigorous testing conditions. These conditions are very different from the unstructured, unpredictable contexts that we function in in everyday life. Therefore, the current study aims to assess whether these tests also tap everyday life working memory problems. Researchers studying ecological validity emphasise the need for the data collection technique to be akin to fundamental tasks performed in an open environment by

emphasising realness. The test findings must reflect and forecast real-world phenomena for the neuropsychological measure to tap the constructs they claim to measure (Chaytor & Schmitter-Edgecombe, 2003). Aside from the debate over whether current indices found on commonly used paper-and-pencil neuropsychological tests provide enough detail to predict the potential everyday difficulties that people are likely to face (Wilson, 1993), there has been little research into the extent to which neuropsychological testing is ecologically valid (Nussbaum et al., 1995). Only a few cognitive measures have been developed with the specific goal of tapping into everyday problems with working memory (Parsons, 2015), which is the aim of the current study. Furthermore, standard neurocognitive batteries focus on isolated aspects of neuropsychological ability, which may not accurately reflect distinct cognitive domains (Parsons et al., 2004; Wilson, 1993).

Working memory tests illuminate distinctions in attention control, or executive attention, crucial for maintaining engaged and accessible knowledge amidst distractions (Engle & Kane, 2004). Individual differences in working memory capacity reflect the ability to control attention during goal-directed activities, allowing those with greater capacity to concentrate on relevant information, integrate new data, and suppress irrelevant information (Martin et al., 2019). This perspective highlights the importance of valid measurements of working memory.

The Ecological Validity of the Three Working Memory Tests Used in the Current Study

Given the importance of working memory for everyday functioning, there is a solid basis for investigating the ecological validity of existing working memory assessments in predicting everyday problems with working memory. As mentioned earlier, these assessments tap different aspects of working memory capacity and correlate significantly with various cognitive tasks and real-world outcomes (Titz et al., 2014).

The theoretical models provide a foundation for understanding the cognitive processes and mechanisms underlying working memory. Moreover, they emphasise the importance of attentional control, the limited capacity of working memory, and the role of different components in facilitating various cognitive tasks (Oberauer, 2019). By integrating these theoretical models, researchers can understand how working memory assessments tap into different aspects of working memory functioning.

Theoretical models and empirical evidence suggest that working memory capacity is closely linked to the ability to cope well with various everyday life problems (Glisky, 2007). Individuals with a fully functional working memory capacity are likely to have enhanced cognitive functioning and perform better in tasks that require active information maintenance,

manipulation, and updating (Glisky, 2007). They are more capable of organising and remembering appointments, multitasking effectively, managing time, and engaging in complex problem-solving and decision-making (Logie et al., 2010).

Working memory tests, such as the *n*-back test, Symbol Span subtest, and Digit Span subtest, have been studied to explore their predictive value for everyday problems related to poor working memory. These studies provide compelling evidence linking the capacity measured through these assessments to various real-world outcomes (Ripp et al., 2022). The empirical findings support the notion that performance on these working memory assessments reflects individuals' ability to cope with cognitive demands in their daily lives (Ripp et al., 2022).

The Digit Span and Symbol Span tasks originate from Baddeley and Hitch's (1974) multicomponent working memory model, emphasising the functional role of an immediate-memory system in temporarily storing limited information to support ongoing mental activity. Contrary to the notion that a working memory system exists solely for storing or rehearsing information, the ecological validity of these tests is highlighted by their alignment with real-world scenarios where individuals must manage and process multiple pieces of information simultaneously (Conway et al., 2005).

Furthermore, the relevance of working memory tests in real-world situations is augmented by considering Cowan's Embedded Processes model, particularly in explaining the updating focus of running memory tests like the *n*-back test (Miyake & Friedman, 2012). This theory suggests that the ecological validity of working memory tests extends to capturing the dynamic and evolving nature of memory processes during ongoing mental activities, providing a more comprehensive understanding of cognitive functioning in real-life scenarios.

Several studies have examined the relationship between Digit Span performance and everyday life problems related to working memory (Fitri et al., 2020). One study found that anesthetisation of the oro-motor structures significantly reduced performance in both backward digit span and rate of speech in neurotypical young adults, suggesting that sensory-motor feedback achieved via subvocal articulatory rehearsals contributes to working memory task performances (Gafoor et al., 2023). Another study developed a test protocol using monosyllabic word recognition and word span tests in Korean Speech Audiometry to measure auditory working memory in young adults with normal hearing. The results showed that word recognition scores and word recall span scores were highest in quiet conditions and lowest in noisy conditions and that the word span test outcomes for quiet-backward (and noise-forward)

conditions were highly associated with digit span scores on the Korean Wechsler Adult Intelligence Scale-IV (K-WAIS-IV; Lee & Lee, 2023)

Researchers have explored the impact of verbal working memory capacity on daily functioning, such as time management, organisation, and attentional control (Frith et al., 2021). These studies consistently demonstrate that individuals with higher Digit Span performance exhibit more effective daily functioning and adaptive behaviour.

Moreover, some research suggests that the Symbol Span may be more sensitive in detecting emergent cognitive impairment than analogous verbal working memory tests (Tang et al., 2021). It is theorised that the Symbol Span is more cognitively demanding than the Digit Span Backwards and Sequencing tasks, as the cognitive skills required for the Symbol Span are less automated, whereas recalling digits is routinely practiced in everyday life. This hypothesis is supported by studies in neuroscience (Moberly et al., 2018). Additionally, it is common for individuals to assign verbal labels to nonverbal visual stimuli (Vivanti et al., 2016), which suggests the recruitment of verbal cognitive operations in visuo-spatial tasks. This influence of verbal labels on the organisation of non-verbal shapes in memory implies that visual working memory (i.e., Symbol Span) test performance may be underpinned by a more extensive arrangement of neurocognitive operations.

While the Digit Span and Symbol Span subtests are frequently used for diagnostic purposes in clinical neuropsychology (e.g., Hale et al., 2002; Leung et al., 2011; Lumpkin & Sheerin, 2018; Young, Caron, et al., 2012), the *n*-back task (Gevins & Cutillo, 1993) is commonly used in neuroimaging and experimental research. This task helps study the brain networks or cognitive activities that underpin working memory (e.g., Lamichhane et al., 2020; Miró-Padilla et al., 2020). A study investigating the relationship between *n*-back test performance and everyday life problems found that individuals who performed poorly on the *n*-back test reported difficulties in organising and remembering appointments, multitasking, and managing time effectively. These results support the theoretical understanding of working memory as a critical cognitive function involved in everyday functioning (Smith et al., 2018). However, an exploration into the psychometric properties of the *n*-back task, aimed at understanding its relation to other working memory and executive function tasks while investigating its role as an individual difference measure, revealed ongoing debates about its classification as a 'pure' working memory measure (Cowan, 2001; Kane et al., 2007; Oberauer, 2005). The experiments provided evidence of weak concurrent validity between the *n*-back task and other cognitive measures. The observed weak correlations suggest a departure from the unitary nature of working memory and executive functions, as proposed by Miyake et al.

(2000), Salthouse et al. (2003), and Stuss et al. (2002). The lack of correlation with working memory span tasks may be attributed to the *n*-back task's reliance on familiarity- and recognition-based discrimination processes, in contrast to the active recall processes emphasised in working memory span tasks (Jaeggi et al., 2010). The mixed results regarding reliability in both this study and previous research pose challenges in drawing firm conclusions about the concurrent validity of the *n*-back task. This investigation underscores the *n*-back task's complexity and disentangling the involved processes proving nontrivial. While it may not serve as a reliable measure of individual differences in working memory capacity, the *n*-back task remains a valuable tool for experimental investigations into working memory processes, offering a simple and straightforward means to manipulate cognitive load (Jaeggi et al., 2010).

Individuals with enhanced working memory capacity possess a notable advantage in managing cognitive demands encountered in daily life. Their proficiency in storing and manipulating information contributes to more effective learning and overall cognitive performance (Alloway & Alloway, 2010; Engle & Kane, 2004; Jaeggi et al., 2008). A recent study sheds light on the broader implications of executive functions, including working memory and task monitoring, in everyday functioning (Quilez-Robres et al., 2021). This study expands on the established link between improved everyday functioning and executive functions, revealing that solid working memory and monitoring abilities are robustly associated with enhanced performance across different life domains. These findings underscore the significance of a well-functioning working memory system in navigating the complexities of daily tasks and responsibilities. The ecological validity of working memory assessments becomes crucial as it ensures that the cognitive processes measured in controlled settings apply to real-world scenarios, providing meaningful insights for individuals, particularly in academic and professional contexts.

Environmental cues are pivotal influencers on working memory performance, shaping cognitive outcomes. The setting in which cognitive tasks unfold affects an individual's ability to uphold and manipulate information in working memory. Variables such as ambient noise, lighting conditions, and environmental distractions can facilitate or impede cognitive processes. Optimal environmental conditions, marked by minimal distractions and a comfortable atmosphere, are conducive to enhanced working memory performance (Wright et al., 1995). Understanding the impact of environmental cues on working memory performance is crucial in developing assessment tools such as the Working Memory Questionnaire used in the current study.

The Working Memory Questionnaire

The Working Memory Questionnaire (Vallat-Azouvi, 2012) was developed through a three-step process. The initial step involved a thorough literature review, concentrating on studies that addressed complaints from individuals who experienced severe traumatic brain injury (TBI) and their close relatives. Additionally, the review considered standardised observations made by rehabilitation professionals, drawing insights from relevant sources.
The second step in the development process comprised informal interviews with patients who had previously participated in cognitive rehabilitation programs. These interviews provided valuable qualitative data regarding individuals' challenges with working memory difficulties.
The third step involved integrating theoretical models of working memory, mainly influenced by Baddeley's (1986) framework. This theoretical foundation extends the concept of working memory beyond short-term storage to include attention and executive control (Vallat-Azouvi, 2012).

The resulting WMQ encompasses three distinct domains. The first domain assesses short-term storage, briefly evaluating an individual's ability to retain information in short-term memory. The second domain explores attention, encompassing elements like distractibility, mental slowness, mental fatigue, and dual-task processing. The third domain delves into executive aspects of working memory and probing skills such as decision-making, planning, and shifting (Vallat-Azouvi, 2012). This development process ensures that the WMQ is comprehensive, drawing on both empirical evidence from the literature and theoretical models, and is well-positioned to offer valuable insights into the intricacies of working memory challenges.

The robustness of the WMQ was demonstrated through a study involving 313 healthy participants. Within this sample, the questionnaire exhibited strong internal validity. While no significant gender differences were observed, age and education duration had notable effects on working memory complaint scores. Younger participants (20–29 years) exhibited more complaints than individuals under 60, suggesting potential ongoing development of cognitive functions in early adulthood. This finding aligns with research in school-aged children, emphasising the continuous strengthening of executive functions throughout childhood and adolescence (Best & Miller, 2010). These results affirm the WMQ's effectiveness in capturing age and education-related variations in subjective working memory experiences.

Ecological Validity of Working Memory Tests in the South African Context

Studying working memory assessment in South Africa is relevant for several reasons. Within clinical neuropsychology, understanding the ecological validity of working memory assessment is crucial for accurately identifying individuals who may experience challenges in everyday functioning (Ziemnik & Suchy, 2019). As a culturally diverse country, South Africa requires assessment tools suitable for its population to ensure appropriate diagnosis and intervention. Additionally, within educational settings, working memory abilities are integral to various tasks, including mental arithmetic, reading comprehension, and problem-solving (Cowan, 2014). Academic success is correlated with working memory performance, emphasising the importance of assessing working memory in the South African educational context. By identifying students with working memory difficulties, educators can provide targeted support and interventions to optimise learning outcomes (Elliot et al., 2010).

Cultural and linguistic factors have also been explored in the Digit Span subtest. Studies have examined the influence of language proficiency, linguistic background, and cultural differences on Digit Span performance. The findings indicate that individuals from different linguistic backgrounds and proficiency levels may approach verbal working memory tasks differently, potentially affecting their performance on the Digit Span subtest. These empirical findings emphasise the importance of considering cultural and linguistic factors when interpreting Digit Span results, ensuring appropriate adaptations or norms are applied when necessary (Razani et al., 2007).

From a cognitive research perspective, studying working memory assessment in South Africa contributes to the broader understanding of working memory and its impact on cognitive functioning across different populations (Conway et al., 2007). By examining the ecological validity of working memory tests commonly used in research, such as the *n*-back test, the Symbol Span subtest, and the Digit Span subtest, researchers can shed light on their effectiveness in capturing individuals' working memory functioning in real-life situations within the South African context. Furthermore, the limited resources in developing countries like South Africa necessitate the identification of assessment tools that are feasible and culturally appropriate.

Thus, examining the relationship between the *n*-back test, the Symbol Span subtest, and the Digit Span subtest is essential, as this contributes to a more comprehensive understanding of working memory and its relevance to everyday functioning. Considering cultural and linguistic factors in working memory assessment is crucial in the South African context, and adaptations to assessment tools may be necessary to improve ecological validity. By integrating

these assessments and exploring their relationship with real-world outcomes, researchers can enhance the ecological validity of working memory assessment and provide valuable insights for clinical and educational settings in South Africa.

Despite the significance of everyday working memory failures as measured in the WMQ, there needs to be more research into these failures (compared to experimental studies of laboratory tasks) due to the difficulties in documenting memory failures. Therefore, this study aims to investigate whether the three working memory tests; Digit Span, Symbol Span, and *n*-back test) predict everyday working memory errors as tapped by the WMQ and whether there is a significant relationship between these three working memory tests and working memory errors as tapped by the WMQ.

Rationale and Aims

Working memory, a critical component of cognitive functioning, has gained considerable attention in cognitive psychology and related fields. As a complex construct, the definition and measurement of working memory have led to diverse theoretical conceptualisations and a wide array of assessment tools (Baddeley, 1986; Miyake & Friedman, 2012). Notably, the *n*-back test, the Symbol Span subtest, and the Digit Span subtest have emerged as commonly utilised instruments in evaluating working memory (Gevins & Cutillo, 1993). However, the extent to which these tests effectively tap into the same cognitive constructs remains a subject of inquiry, raising questions about their comparability and applicability in predicting real-world working memory challenges.

This study addresses this gap by focusing on the ecological validity of three prominent working memory tests: the *n*-back test, the Symbol Span subtest, and the Digit Span subtest. Drawing on theoretical foundations from the literature, which underscores the multidimensional nature of working memory (Logie et al., 2010), this research aims to highlight the relationship between these laboratory-based assessments and real-world working memory errors. The investigation is guided by research questions, seeking to find significant associations between the *n*-back test, Digit Span, Symbol Span, and working memory errors measured by the WMQ.

This study acquires a unique significance in South Africa, where linguistic diversity and socio-economic factors play crucial roles in cognitive functioning (Razani et al., 2007; Ziemnik & Suchy, 2019). Previous literature has highlighted the potential impact of linguistic differences on verbal working memory tasks, emphasising the need for cultural sensitivity in assessment tools. By incorporating a culturally diverse sample of sixty-nine bilingual and

multilingual young adults (Mayers et al., 2009), this research explores working memory assessments in a context characterised by linguistic variation.

Research Questions

The study's primary aims were to examine the relationships between the *n*-back test, Digit Span, Symbol Span subtests, and working memory errors, and secondly, to investigate the predictive capabilities of these tests regarding everyday working memory challenges. The following research questions guided this study:

1. Is there a significant relationship between the *n*-back test, the Digit Span test, the Symbol Span test, and working memory errors as tapped by the WMQ?
2. Do the three WM tests (i.e., Digit Span, Symbol Span, and *n*-back test) predict everyday working memory errors as tapped by the WMQ?

The subsequent chapter provides a detailed discussion of the methods and materials utilised to explore the research questions outlined above.

Chapter 2: Methods

To address the research questions outlined in Chapter one, this study was part of a larger research project investigating the relationship between working memory and multilingualism in young adults (Protocol No: M210626). This chapter details the research paradigm, design, instruments, and procedures utilised in the study. Before initiating the research process, a pilot study was conducted with two participant volunteers to assess potential issues with the computer-based *n*-back task and the clarity of task instructions. Following the pilot study, no modifications were made to the research procedure.

Research Paradigm and Design

The study was situated within the post-positivist paradigm, as information was acquired through a post-positivist lens, rooted in careful observation and measurement of objective reality while acknowledging the biases and limitations inherent in such an approach (Ryan, 2006). The primary objective of this study was to evaluate the ecological validity of the *n*-back test, the Symbol Span test, and the Digit Span test in predicting everyday life problems in working memory. Therefore, a quantitative, non-experimental, ex post facto, correlational, cross-sectional research design was employed.

The study was non-experimental since the independent variables were not manipulated. The independent variables in this study were the *n*-back test score, the Digit Span test score, and the Symbol Span test score. The dependent variable was the working memory errors as measured by the WMQ. It was ex post facto because a sample with pre-existing qualities was used. The study's correlational nature enabled the exploration of potential relationships between the working memory tests and working memory errors. However, due to its inherent nature, this design could only establish the nature of the relationship between the variables. This research design was advantageous because of its ease of implementation and practicality.

Sample and Sampling Strategies

The sample used in this study was a non-probability, convenience sample of 72 students from the School of Human and Community Development at the University of the Witwatersrand. However, three participants were later excluded due to missing data on the *n*-back test, leaving 69 participants. The participants needed to be between 18 and 25 years of age and were required to be bilingual or multilingual as part of the more extensive study that focused on these qualities. However, this was not the focus of the current study. Since the sample consisted of university students, all participants were assumed to be 'test-wise' and both

questionnaire- and computer-literate. Furthermore, since all participants were studying courses in English, they were deemed sufficiently proficient in the language to complete the working memory assessments, which were presented in English. The exclusion criteria were monolingual young adults who had learning impairments. Descriptive statistics of the sample (e.g., age range, sex distribution) are presented in Chapter three.

Instruments

The following measures were employed: a demographic questionnaire, The Working Memory Questionnaire, the Digit Span subtest, the Symbol Span subtest, and the *n*-back test. These are each detailed below.

Demographic Questionnaire

Study data on the participants' gender, home languages, school languages, education level, educational past and current year of study, citizenship, number of languages spoken, their parents/primary caregivers' educational levels, current occupation, marital status, and number of primary caregivers were collected and managed using Research Electronic Data Capture (Redcap; Harris et al., 2019) hosted at the University of the Witwatersrand. Participants were also required to complete a Living Standards Measure (LSM) and Language Experience and Proficiency Questionnaire (LEAP-Q) for the more extensive study and, finally, the Working Memory Questionnaire on Redcap.

The Working Memory Questionnaire (Vallat-Azouvi et al., 2012)

The Working Memory Questionnaire (WMQ) is an open-access self-report measure that assesses three aspects of working memory: short-term memory, attention, and executive control. It consisted of 30 questions separated into three domains mentioned, comprising ten questions each. The questions, however, were presented in a preset, pseudo-random order, preventing questions from a specific domain from being presented one after the other to avoid response biases.

Each question was rated on a five-point Likert-type scale, with answers ranging from 1 ("not at all") to 5 ("extremely"). For each of the three domains, three sub-scores were generated (with a maximum score of 40 for each) and a total score (out of 120). Higher scores indicated more difficulties/complaints. The questionnaire has internal solid consistency in the sample (Cronbach's alpha = .88).

Working Memory Tests

Participants completed three working memory tests, namely the Digit Span subtest, the Symbol Span subtest, and the *n*-back test.

The Digit Span subtest (WAIS-IV; Wechsler, 2008a) measures verbal working memory. It is part of the Wechsler Adult Intelligence Scale – Fourth SA Edition (WAIS-IV SA), which was adopted and normed on South Africans (Wechsler, 2017). The test comprised Digit Span Forwards, Digit Span Backwards, and Digit Span Sequencing. These tasks involved the verbal presentation of digits to the participant at one-second intervals. When administering, the examiner dropped their tone on the last digit of each series to indicate that the participant could begin. The participant was requested to recall as many digits as possible in a particular order according to the specific task (described below). The total Digit Span scaled score was calculated from all three tasks. For each task, scoring ranged from zero to two. One point was given per trial (two points per item possible). The sum of the item scores was 16. A score of zero was given when the participant gave an incorrect response. The task was discontinued if the participant scored zero on both trials on an item. The test took approximately 15 minutes and had a Cronbach alpha of .69.

Digit Span Forward. The participants were read a sequence of numbers and asked to recall the numbers in the same order. Before beginning the tasks, two practice trials of what was required were administered to make sure the participants understood the requirements.

Digit Span Backwards. The participants were required to recall the numbers the researcher spoke in reverse order. The trials ranged from two to nine digits in length. In neurotypical subjects, ranging from ages 18-80+, a Cronbach alpha that ranges from .80 to .90 was found (Wechsler, 2017).

Digit Span Sequencing. The participants were required to sequence the numbers the researcher spoke in ascending order. The tasks increased in difficulty. This task has a high internal reliability that ranges from .70 to .90 (Wechsler, 2009).

The Symbol Span subtest (Wechsler, 2009) taps visuospatial working memory. Participants were presented with one to seven abstract symbols in a row on a page. They were asked to recall the symbol/s and the order of the design from left to right. The participants were then instructed to select the matching design foils in the correct sequence. It took approximately 15 minutes to complete the test. It has an internal consistency ranging from .76 to .92 (Wechsler, 2008a).

***n*-back Task (Gevins & Cutillo, 1993).** The *n*-back task is frequently employed in research to evaluate working memory load and executive functions such as attentional

switching and updating (Gajewski et al., 2018; Weicker et al., 2018). This study utilised a computerised version of the *n*-back task, where participants viewed digits presented sequentially on a 17-inch computer screen using Open Sesame software (version 3.3.11). The digits, ranging from one to six and eight to nine, were displayed in Arial font size 58, with a black background and white text, on a screen resolution of 1024 x 768 pixels. The task required participants to indicate whether the current digit matched the one presented '*n*' trials ago ('*n*' representing one, two, or three trials back). They responded by pressing the 'F' key for a match ('S' sticker marked for 'same') and the 'J' key for a non-match ('D' sticker marked for 'different') on the keyboard. The digit seven was excluded due to its two syllables.

The experiment consisted of three working memory load conditions (1-, 2-, and 3-back tasks), each with specific instructions on the screen and verbally reiterated. Participants progressed from the 1-back task to the 2-back task and finally the 3-back task. Before the main experiment, participants underwent a practice session comprising 37 trials distributed across the three load conditions, with performance thresholds for accuracy set at 85%, 75%, and 65% for the 1-, 2-, and 3-back conditions, respectively. Each practice round allowed up to three attempts to meet the accuracy criteria; failure resulted in the termination of the experiment.

During the experimental phase, participants were instructed to respond promptly and accurately. Digits were displayed for 500ms each, followed by a 250ms interstimulus interval denoted by a fixation cross. Each load condition comprised five blocks of 25 trials, followed by 10-second breaks to alleviate mental fatigue. Unlike the practice round, participants proceeded to the next block regardless of their accuracy in the previous one. The stimuli within each block were randomised, with a fixed proportion of targets (33%) and non-targets (67%). Recorded data included accuracy, average reaction time, correctness of responses, and types of errors for each load condition, along with an overall average. Participants could employ any strategy during the task (e.g., tapping or verbal rehearsal). Each experimental condition lasted approximately 15 minutes, resulting in a total duration of 45 minutes for assessment duration.

Procedure

Students who expressed interest in participating in the study first received a participant information sheet, including participation details (see Appendix A). After they confirmed their willingness to participate, they each received an email with a link to the survey. This constituted the first part of the data collection process, where participants completed the demographic questionnaire and the WMQ online, administered through the secure web application Redcap (Harris et al., 2019). Once the survey was completed, participants selected the most convenient

date and time. This constituted the second part of data collection, which involved face-to-face administration of the working memory assessments at the Neuroscience Research Laboratory, Department of Psychology, University of the Witwatersrand. All interviews were conducted one-on-one in a private room. The participants completed the Digit Span subtest, the Symbol Span subtest, and the *n*-back test. The assessments were carried out in a randomised order to prevent order effects and fatigue influence. The *n*-back test was the only computerised test.

The working memory tests were administered as described in the Instruments section. As mentioned, all tasks were administered in English, and instructions were standardised for each task. Practice examples for the respective tasks confirmed that participants understood each task's instructions and objective, and participants were encouraged to ask questions if anything remained unclear. Overall, each interview lasted approximately 60 minutes. Participants received financial compensation of R150-00 to cover transportation costs to the Neuroscience Research Laboratory.

Ethical Considerations

Ethical clearance was obtained for this study from the Human Research Ethics Committee (HREC Non-Medical; Protocol No: MASPR/23/05; see Appendix C). Permission from the University Registrar, Head of School, and Heads of Departments were also obtained. As mentioned, before data collection, all participants received an online information sheet that provided a brief description of the study and additional information about the research process. Consent forms (Appendix B) were also made available through the Redcap platform, which stipulated that participation in the study was voluntary. Since all participants were above 18, consent could be legally obtained. All individuals who participated in the study received a once-off R150 compensation to cover transport expenses related to attending the data collection session. The tests in this study were not invasive and did not ask questions of a sensitive nature. Nevertheless, the anonymity of participants is essential. Since anonymity during data collection was not possible, given the face-to-face nature of the study, all information generated from data collection was subsequently anonymised to uphold the confidentiality of participants. The data collected was secured in a password-protected folder on a hard drive, which was locked in the laboratory, and only the researchers had access to participants' original demographic information. Consenting participants were made aware that the data collected throughout the research process contributed towards completing this research report and possibly disseminated through publications and conference papers. Individual feedback on performance was not

provided as the collected data was anonymous. Anonymised data may also be used for possible secondary analyses.

Data Analysis

Descriptive and inferential statistical techniques were used to analyse the data, using IBM SPSS Statistics, version 28.0.1.0. Descriptive statistics were generated for the sociodemographic characteristics of the sample and the working memory scores. After that, correlation and regression analyses were used to investigate relationships between crucial variables to address the three research questions. These analyses are discussed in the following chapter.

Chapter 3: Results

This study explored the ecological validity of working memory tests. The primary aim was to assess the ecological validity of the *n*-back test, the Symbol Span subtest, and the Digit Span subtest in predicting working memory's everyday problems. The preceding chapters provided the context in which the results are presented.

This chapter presents the study's findings using descriptive and inferential statistical techniques. Data analysis was conducted using IBM SPSS Statistics, version 28.0.1.0. Initially, descriptive statistics were generated to summarise the sociodemographic profile of the sample and the scores from the working memory measures. Subsequently, correlation analyses were undertaken to explore relationships among the variables, addressing the initial research question: Is there a significant relationship between the *n*-back test, the Digit Span test, the Symbol Span test, and everyday life working memory errors as measured by the WMQ? Finally, ordinal logistic regression analyses were done to determine whether the tests mentioned above can predict everyday life working memory errors as indicated by the WMQ, addressing the second research question. Throughout this process, the results of statistical analyses are presented in tables, emphasising key findings.

Descriptive Statistics

This section comprises three subsections. The first subsection details the characteristics of the data linked to each variable and outlines the methods utilised to determine the appropriateness of the data for parametric analysis. Prior to exploring the relationships among the key variables, it was essential to understand their distributions within the sample. The second subsection offers insights into the sociodemographic features of the sample. The final subsection presents the Digit Span, Symbol Span, and *n*-back variables, as specified below.

Assessing Data Suitability for Parametric Analysis

Data was assessed for parametric analysis using several methods. Three primary assumptions for parametric statistical analysis include random independent sampling, absence of extreme outliers, and approximately normal distribution of test scores. Although the sample was a convenience sample of volunteers, the order of the working memory tests was randomised, and each participant completed each test once. Raw scores were used for each of the analyses. The Digit Span subtest yielded continuous scores for each of its three conditions (Forward, Backward, and Sequencing), with a maximum possible score of 16 points for each condition and a cumulative maximum of 48 points.

Similarly, the Symbol Span subtest, providing continuous scores, had a potential maximum score of 50 points. Each *n*-back condition had a maximum possible score of 125 points. The WMQ assessed three aspects of working memory: short-term memory, attention, and executive control. It consisted of 30 questions separated into three domains mentioned above, which comprised 10 questions each. For each of the three domains, three sub-scores were generated, with a maximum score of 40 for each and a total score of 120. Raw scores from both latter subtests were used in the analyses. Concerning demographic variables, participants reported speaking at least two languages and a maximum of four. Lastly, the Socioeconomic Status (SES) scores obtained from the LSM questionnaire varied on an ordinal scale ranging from 1 (indicating the lowest) to 10 (indicating the highest).

Boxplots were generated for each variable to identify potential extreme outliers. The existence of outliers carries the risk of skewing the mean of a given variable toward more extreme values, a concern that becomes particularly pronounced with small sample sizes (Leys et al., 2019). However, it is essential to note that the presence of outliers in the data does not automatically imply their exclusion from the analysis (Oyeyemi et al., 2015). The Kolmogorov-Smirnov test (suitable for sample sizes ≥ 50; Mishra et al., 2019) was used to assess the distributions of the variables. Several variables returned a significant Kolmogorov-Smirnov test statistic, implying a non-normal distribution. Therefore, it was decided that non-parametric analyses were most appropriate.

Sociodemographic Profile of Sample

A consideration of the sociodemographic characteristics of the sample is essential in contextualising the findings reported here. For this reason, descriptive statistics were first used to explore the profile of the 69 participants in terms of biological sex (Table 1). Most participants were female (n = 62, 89.90%).

Table 1

Participants' Sociodemographic Profiles

Sex	Frequency	Percent (%)
Female	62	89.90
Male	7	10.10

Table 2 provides a summary of the descriptive statistics for age, socioeconomic status, and the number of languages spoken by the participants. These statistics offer valuable insights into the demographic profile of the sample population, which is essential for understanding the context of the study's findings.

Table 2

Descriptive Statistics for Age, Socioeconomic Status and Number of languages spoken.

Variable	Mean	SD	Mode	Range
Age	20.39	1.54	20	18 – 25
Socioeconomic status	6.97	0.17	7	6 – 7
Number of languages spoken	2.48	0.56	2	2 – 4

Note. N = 69; SD = Standard Deviation

In terms of SES, the mean score of 6.97 reveals that the participants were towards the high-end of the SES range. The LEAP-Q captured a range of self-report data about the participants' language profiles. The mean, standard deviation, mode, and range highlight each variable's variability and central tendencies, providing a foundation for further exploration and interpretation in subsequent research sections.

Descriptive Statistics of Working Memory Variables

The main aim of this study was to assess the ecological validity of the three working memory tests in predicting everyday life problems in working memory (as assessed by the WMQ). Table 3 provides a detailed account of the descriptive statistics for working memory measures within the sample of 69 participants. This table encompasses a range of subtests, including Digit Span, Symbol Span, and the *n*-back task. The statistics reveal nuanced aspects of performance, highlighting central tendencies and score variability. Table 4 provides descriptive statistics for working memory questionnaire domains and their total score. The

medians are reflected for non-normally distributed variables and means for the customarily distributed ones.

Table 3

Descriptive Statistics of the Sample (N=69) on the Working Memory Measures

Working Memory Tests	Mean	Median	SD	Range
Digit Span Subtest				
Forwards	10.62	10.00	2.43	5 – 16
Backwards	7.14	7.00	2.06	4 – 13
Sequencing	7.17	7.00	2.16	4 – 14
Total	24.59	24.00	5.24	16 – 39
Symbol Span Subtest	29.88	30.00	9.14	8 – 49
***n*-back Task**				
1-Back accuracy	119.22	120.00	3.73	109 – 125
1-Back response time (ms)	663.82	**644.74***	160.45	416.67 – 1119.74
2-Back accuracy	104.94	107.00	9.27	78 – 118
2-Back response time (ms)	816.88	**799.53***	203.42	419.68 – 1335.62
3-Back accuracy	93.28	**94.00***	9.98	72 – 120
3-Back response time (ms)	800.49	**810.30***	200.49	424.46 – 1273.51

*Note. SD = Standard Deviation; ms = Milliseconds; *indicates a non-normally distributed variable; $p < .05$*

As expected, there is a discernible increase in response time as the task complexity increases from 1-back to 3-back. This increase aligns with the expected cognitive demands associated with higher task difficulty levels. Table 4 offers a comprehensive overview of the descriptive statistics for the WMQ domains, including storage, attention, executive control, and the average working memory total score. These measures provide valuable insights into the central tendencies and variability within our sample of participants.

Table 4

Descriptive Statistics for Working Memory Questionnaire (WMQ) Domains

Variable	Median	Range
Working Memory Domain		
Storage Domain	20	11 – 39
Attention Domain	22	11 – 38
Executive Control	23	11 – 40
Working Memory Total	65	35 – 116

The observed ranges in each domain, and the total score (e.g., 11 - 39 for Storage Domain) underscore the diversity in participants' responses. These ranges highlight the dispersion of scores and contribute to a more comprehensive interpretation of the data.

Inferential Statistics

The inferential analyses consisted of three parts. Firstly, correlations between working memory tests (Digit Span, Symbol Span, and *n*-back) and the components of the WMQ (short-term storage, attention, and executive control) were examined to assess the initial relationship among crucial variables. As a result of the largely nonsignificant relationships between the working memory tests and the WMQ, further correlations between the individual questions of the WMQ and the working memory tests were run. Finally, ordinal logistic regression analyses (because of the ordinal data yielded from the WMQ) were used to determine the extent to which the working memory tests can predict everyday life problems in working memory. The results of these analyses are discussed below.

Correlations

Table 5 presents the pairwise correlations among the variables under investigation. These correlations offer an initial insight into the associations among crucial variables, serving as a foundation for interpreting more complex relationships revealed through ordinal logistic regression analyses.

Spearman’s rho correlation coefficient was employed to examine the relationship between the working memory tests and the Working Memory Questionnaire (WMQ)

components. Spearman's rho is a non-parametric measure of the direction and strength of association between two variables (Gilbert & Prion, 2017). Notably, this statistical tool is applicable when data are measured on at least an ordinal scale, a condition met by all variables considered in this analysis. These correlations are presented in Table 5.

As expected, the different components of the Digit Span task were significantly intercorrelated and correlated significantly with the Symbol Span task. Similarly, the different parts of the *n*-back task were significantly intercorrelated with each other. This provides evidence of construct validity for these tasks (i.e., Digit Span and *n*-back) and suggests that the Digit Span and Symbol Span are tapping-related abilities. However, the Digit Span and Symbol Span were not significantly correlated with the components of the *n*-back task, suggesting that these tap unrelated skills.

There were no significant correlations between the working memory tasks and the WMQ components, except the 2- and 3-back accuracy scores. As a result of the largely non-significant relationships between the working memory tests and the WMQ, further correlations between the individual test items of the WMQ and the working memory tests were run (Table 6). The 2-Back Accuracy variable showed a significantly weak positive correlation with Working Memory Question 3 ($r(69) = .38$ $p = .001$; Do you have problems remembering sequences of numbers, for example, when you must note down a telephone number?). The variable Digit Span Sequencing showed significant, weak negative correlations with Working Memory Question 11 ($r(69) = -.30$ $p = .012$; Do you need to re-read a sentence several times to understand a simple text?), Working Memory Question 12 ($r(69) = -.25$ $p = .039$; Do you have difficulty in organising your time about appointments and your daily activities?) and Working Memory Question 14 ($r(69) = -.28$ $p = .022$; When you are carrying out an activity, if you realise that you are making a mistake, do you find it difficult to change strategy?).

Furthermore, the variable Symbol Span showed significant, weak negative correlations with Working Memory Question 13 ($r(69) = -.27$ $p = .025$; Do you find it challenging to do two (or several) things at the same time?), Working Memory Question 18 ($r(69) = -.25$ $p = .041$; Do you find it difficult to follow the different steps of a user's guide?) and Working Memory Question 21 ($r(69) = -.24$ $p = .045$; If a character in a text is designated in different ways do you have difficulty in understanding the story?) Variable 1-Back Accuracy showed a significant, weak negative correlation with Working Memory Question 15 ($r (69) = -.27$ $p = .027$; Do you have difficulty understanding what you read? The variable 2-Back Accuracy showed significant, positive weak relationships with Working Memory Question 3 ($r(69) = .38$ $p = .001$, Working Memory Question 24 ($r(69) = .27$ $p = .024$; Do you feel that you are very

slow to carry out your usual activities?) and Working Memory Question 28 ($r(69) = .24$ $p = .047$; Do you find that you tire quickly during an activity which demands a lot of attention (for example, reading)? Finally, the variable Digit Span Forward showed a significant, weak negative relationship with Working Memory Question 18 ($r(69) = -.26$ $p = .03$; Do you find it difficult to follow the different steps of a user's guide?).

Table 5

Spearman's Rho Correlations Between Working Memory Tests and Working Memory Domains

	DSF	DSB	DSS	DST	SS	1BA	1BR	2BA	2BR	3BA	3BR	ST	ATT
DSB	.32**	-											
DSS	.36**	.51**											
DST	.75**	.73**	.79*										
SS	.32**	.48**	.35*	.47**									
1BA	-.01	.14	.03	.08	.27*								
1BR	-.05	-.10	-.12	-.12	-.14	.186							
2BA	.09	.09	.02	.07	.33**	.42**	-.01						
2BR	.01	.08	-.01	.03	.09	.42**	.69**	.04					
3BA	-.15	-.03	-.08	-.12	.26*	.41**	-.06	.52**	.17				
3BR	.11	.163	.05	.13	.14	.36**	.62**	.20	.83**	.20			
ST	.02	.05	-.27*	-.12	-.05	-.04	.09	.12	.06	.01	.05		
ATT	.18	.13	-.02	.10	-.03	-.10	.05	.17	.02	-.11	.04	.57**	

EC	-.02	.06	-.14	-.05	-.03	.05	.09	.14	.02	.07	.07	.62**	.61**

Note. N = 69. DSF = Digit Span Forwards; DSB = Digit Span Backwards; DSS = Digit Span Sequencing; DST = Digit Span Total; SS = Symbol Span; 1BA = 1-Back Accuracy; 1BR = 1-Back Average Reaction Tim; 2BA = 2-Back Accuracy; 2BR = 2-Back Average Reaction Time; 3BA = 3-Back Accuracy; 3BR = 3-Back Average Response Time; ST = Short Term Storage Domain; ATT = Attention Domain; EC = Executive Control Domain.

**p < .05; **p < .01.*

Table 6

Spearman's rho Correlations between Working Memory Tests and The Individual Working Memory Scores

	WMQ1	WMQ2	WMQ3	WMQ4	WMQ5	WMQ6	WMQ7	WMQ8	WMQ9	WMQ10	WMQ11	WMQ12	WMQ13	WMQ14	WMQ15	WMQ16	WMQ17	WMQ18	WMQ19	WMQ20	WMQ21	WMQ22	WMQ23	WMQ24	WMQ25	WMQ26	WMQ27	WMQ28	WMQ29	WMQ30	DSF	DSB	DSS	DST	1BA	2BA	3BA	NBT
WMQ1	-																																					
WMQ2	.45**																																					
WMQ3	.26*	.30*																																				
WMQ4	.32**	.34**	.31**																																			
WMQ5	-.04	.09	.08	.32**																																		
WMQ6	.31**	.10	.27**	.15	-.04																																	
WMQ7	.24**	.36**	.33**	.27**	.15	.28*																																
WMQ8	.231	.19	.19	.39**	.17	.02	.29*																															
WMQ9	.03	.23	.28*	.26*	.01	.02	.25*	.23																														
WMQ10	.24*	.14	.34**	.37**	.18	.10	.15	.27	.18																													
WMQ11	.21	.27*	.26*	.39**	.29	.14	.39**	.17	.22	.23																												
WMQ12	.28*	.48**	.25*	.07	.09	.15	.45**	.18	.18	.00	.30																											
WMQ13	.13	.07	.04	.28*	.13	-.07	.10	.29**	.19	.17	.08	.22																										
WMQ14	.04	.23	.13	.24*	.20	.13	.41**	.25*	.45**	.12	.42**.	.41**	.26*																									
WMQ15	.13	.28	.33**	.36**	.37**	.27	.61**	.07	.22	.21	.57**	.35**	-.02	.40**																								
WMQ16	.41**	.12	.07	.31*	.06	.21	.16	.22	-.01	.14	-.04	.14	.10	.12	.12																							
WMQ17	.10	.22	.28*	.19	.34**	.14	.29**	.03	.40**	.19	.27*	.33**	.15	.33**	.40**	.21																						
WMQ18	-.06	.15	.18	.20	.15	.10	.16	.12	.29*	.33**	.04	.16	.162	.38**	.14	.07	.41**																					
WMQ19	.17	.14	.11	.39**	.23	.06	.23	.34**	.21	.37**	.10	.17	.30*	.34**	.14	.23	.18	-																				
WMQ20	.45**	.20	.13	.42**	.08	.12	.07	.46**	.16	.41**	.04	.07	.30*	.32**	.03	.37**	.17	.28*	-																			

	WMQ1	WMQ2	WMQ3	WMQ4	WMQ5	WMQ6	WMQ7	WMQ8	WMQ9	WMQ10	WMQ11	WMQ12	WMQ13	WMQ14	WMQ15	WMQ16	WMQ17	WMQ18	WMQ19	WMQ20	WMQ21	WMQ22	WMQ23	WMQ24	WMQ25	WMQ26	WMQ27	WMQ28	WMQ29	WMQ30	DSF	DSB	DSS	DST	1BA	2BA	3BA	NBT
WMQ21	.08	.13	-.18	.25**	-.01	-.10	.14	.37**	.20	.32**	.16	.07	.27*	.16	-.04	.01	.07	.19	.41**	.35**																			
WMQ22	0.4	.28*	.15	.20	.14	.13	.09	.15	.22	.13	.01	.17	.36**	.22	.01	.12	.30*	.35*	.33**	.19	.21																	
WMQ23	.25*	.29*	.41**	.14	.02	.18	.30*	.07	.24	.23	.21	.42**	.14	.41**	.40**	.14	.39**	.23	.16	.29*	.09	.19																
WMQ24	.27*	.36**	.12	-.02	.07	.17	.33**	.21	.23	-.01	.22	.48**	.05	.26**	.22	.13	.34**	.01	-.02	.17	-.0.6	.19	.37**															
WMQ25	.09	.10	.29*	.08	.32**	.38**	.38**	-.01	.15	.15	.23	.29	.08	.31*	.46**	.26*	.25*	.07	.12	.00	-.31**	.07	.19	.09														
WMQ26	.27*	.34**	.33**	.10	.26*	.20	.19	.29	.19	.20	.26*	.36*	-.01	.25*	.24	.16	.36**	.22	.12	.32**	.10	.22	.42**	.29*	.24*													
WMQ27	.35**	.28*	.30*	.24*	.30*	.21	.27*	.27*	.34**	.19	.38**	.37**	.13	.39**	.38**	.09	.36**	.13	.30*	.89**	.20	.24*	.29*	.25*	.33**	.52**												
WMQ28	.34	.23	.14	.14	.09	.18	.45**	.16	.20	.24*	.39**	.26*	-.08	.38**	.28**	.34**	.30**	.02	.12	.26*	.12	-.02	.28*	.43**	.19	.29*	.35**											
WMQ29	.25*	.03	.08	.08	-.09	.43**	.04	.08	-.07	.22	.02	.13	-.02	-.02	.12	.11	.00	.01	.16	.29*	-.04	.03	.07	.07	.18	.10	.13	.12										
WMQ30	.28*	.29*	.05	.33**	.24**	.22	.23	.28*	.32**	.22	.28*	.21	.32**	.47**	.28*	.25*	.41**	.18	.35**	.36**	.45**	.33**	.34**	.27*	.10	.27*	.53**	.35**	.02									
WMQT	.45**	.54**	.45**	.52**	.36**	.38**	.56**	.42**	.41**	.41**	.49**	.55**	.23	.59**	.55**	.40**	.56**	.37**	.51**	.52**	.26*	.36**	.56**	.43**	.42**	.62**	.68**	.54**	.27*	.63**								
DSF	.05	.08	-.03	.19	.07	.02	.20	.12	-.09	-.01	-.08	.07	-.03	-.16	-.02	.17	-.04	-.26*	.09	.05	.15	-.13	.01	.14	-.13	-.10	-.03	.08	-.20	.10	.08							
DSB	.08	.05	.08	.15	.06	-.11	.05	-.07	.05	-.01	-.05	-.06	-.02	0.1	.05	.15	-.00	-.07	.01	.23	-.18	.03	.10	.11	-.04	.02	.10	.09	-.10	.03	.09	.32**						
DSS	.02	-.12	-.22	.03	-.05	-.16	-.12	-.00	-.22	-.14	-.30*	-.25*	-.15	-.28*	-.22	.08	-.20	-.19	-.17	.20	-.09	-.11	-.14	-.03	-.20	-.07	-.15	-.00	.02	-.17	-.16	.36**	.51**					
DST	.06	.01	-.11	.14	.01	-.11	.05	.05	-.13	-.07	-.19	-.11	-.08	-.18	-.11	.15	-.12	-.25	-.06	.18	-.01	-.11	-.04	.09	-.19	-.05	-.08	.04	-.11	-.01	-.02	.75**	.73**	.79**				
SS	.06	.08	.09	.03	.10	-.20	.01	-.03	-.05	.00	-.09	-.08	-.27*	-.13	.01	-.04	-.10	-.25*	-.01	.06	-.24*	-.14	.03	.13	-.11	-.03	-.03	.12	.06	-.11	-.05	.32**	.48**	.35**	.47**			
1BA	-.06	-.04	.05	-.18	-.01	-.17	-.16	.00	.03	-.14	-.09	-.02	-.07	.01	-.27*	-.02	.01	-.04	-.12	.09	-.18	.01	-.01	.05	.04	.18	.16	.18	-.05	-.08	-.01	-.01	.14	.03	.08	.27*		
2BA	.19	.18	.38**	.01	.08	.17	.15	.14	-.17	.16	.01	.02	-.15	-.06	-.12	.00	-.04	-.08	.03	.23	-.18	.07	.03	.27*	.13	.15	.06	.24*	.115	-.06	.15	.09	.09	.02	.07	.33**	.42**	
3BA	.07	.14	.09	-.14	-.00	.03	-.02	.01	.01	-.18	-.01	-.02	-.23	-.08	-.16	-.16	-.10	-.15	-.03	-.02	-.03	.00	-.14	.06	.02	.17	.18	.15	.12	-.07	.00	-.15	-.03	-.08	-.12	.52**		
NBT	.10	.15	.25*	-.08	.03	.05	.04	.08	-.07	-.04	-.01	-.02	-.20	-.08	-.16	-.10	-.03	-.12	-.04	.11	-.13	-.01	-.06	.16	.05	.14	.11	.24*	.08	-.08	.05	-.02	.06	-.02	-.00	.84**	.85**	-

Regression Analyses Investigating Working Memory Variables

To investigate whether the Digit Span test, Symbol Span test, and the *n*-back test predict everyday life problems in working memory, post-regression outputs were examined to assess whether assumptions of ordinal logistic regression were met. The first assumption was that the dependent variable should be measured at the ordinal level. Since the components of the working memory questionnaire were measured on a Likert scale, the first assumption was met. The second assumption is that one or more independent variables should be continuous, ordinal, or categorical. The *n*-back task was measured continuously; therefore, the second assumption was met. The third assumption stipulates that the data must not show multicollinearity. It was assessed by examining correlation coefficients and Tolerance/VIF values. The intercorrelation between various Digit Span subcomponents was considered to address multicollinearity concerns, and only the Digit Span total score was included in the regression analysis. Similarly, to mitigate multicollinearity, only the *n*-back total score was included. Additionally, as the Symbol Span and Digit Span scores were found to be intercorrelated, the Symbol Span score was not included in the same regression as the Digit Span. Thus, to ensure the integrity of the regression analyses, only the Digit Span total score and working memory total accuracy scores were utilised in the subsequent regression analyses. Therefore, this assumption was met. The fourth assumption stipulates that there should be proportional odds. The goodness-of-fit test indicated that the assumption was met ($p > 0.05$) (Laerd, 2018).

An ordinal regression analysis between the WMQ total score and the predictor variables, Digit Span, and *n*-back did not yield a statistically significant result (χ^2 (2) = .09, $p > 0.05$), indicating that the model did not predict a significant portion of the variance in the WMQ total scores. Moreover, Digit Span and the *n*-back task did not significantly predict the WMQ total score, as evidenced by their non-significant p-values ($p = 0.9$ and 0.7 respectively).

Additional ordinal logistic regression analyses were conducted to further investigate the nuanced relationship between the *n*-back task, Digit Span and specific components of the WMQ. These analyses focused on the individual WMQ items that exhibited significant correlations with the *n*-back total score (Table 7). Table 8 presents the parameter estimates for predicting correlated WMQ questions with the *n*-back task.

Table 7

Ordinal Regression Analysis for predicting WMQ Questions from n-back task.

Model	-2 Log Likelihood	Chi-Square	Df	Sig.
Intercept Only	447.27			
Final	417.84	29.43	15	0.01*

The ordinal regression analyses revealed a significant relationship between the *n*-back task and Questions 28 as evidenced by the significant p-value ($p < 0.05$). These findings suggest a connection between the construct of working memory assessed by the *n*-back task and specific components of the WMQ. To further investigate this relationship, Table 8 presents the parameter estimates from the ordinal regression analysis aimed at predicting specific components of the WMQ using the *n*-back task as a predictor variable to identify which questions were significant predictors.

Table 8

Parameter Estimates for predicting WMQ Questions from n-back task.

							95% Confidence Interval	
		Estimate	S E	Wald	df	Sig.	LB	UB
Location	[wm_q3=1]	-1.13	1.35	0.70	1	0.40	-3.76	1.51
	[wm_q3=2]	0.31	1.33	0.05	1	0.82	-2.30	2.91
	[wm_q3=3]	0.04	1.34	0	1	0.98	-2.70	2.79
	[wm_q3=4]	1.05	1.72	0.37	1	0.54	-2.33	4.42
	[wm_q3=5]	0	-	-	0	-	-	-
	[wm_15=1]	1.14	1.23	0.87	1	0.35	-1.26	3.55
	[wm_q15=2]	0.75	1.23	0.37	1	0.54	-1.66	3.16
	[wm_q15=3]	-2.07	1.36	2.32	1	0.13	-4.74	0.59
	[wm_q15=4]	0	-	-	0	-	-	-
	[wm_q24=1]	0.39	1.98	0.04	1	0.85	-3.48	4.26

[wm_q24=2]	0.21	1.91	0.12	1	0.91	-3.54	3.96
[wm_q24=3]	1.07	2.05	0.27	1	0.60	-2.95	5.08
[wm_q24=4]	-0.18	2.09	0.01	1	0.93	-4.27	3.92
[wm_q24=5]	0	-	-	0	-	-	-
[wm_q28=1]	-2.11	1.02	4.25	1	0.04	-4.12	-0.11
[wm_q28=2]	-1.37	0.88	2.41	1	0.12	-3.09	0.36
[wm_q28=3]	-0.32	0.89	0	1	0.97	-1.78	1.71
[wm_q28=4]	-1.13	1.01	1.24	1	0.27	-3.12	0.86
[wm_q28=5]	0	-	-	0	-		-

Notes. N = 69; S *E = Standard Errors; LB = Lower Bound; UB = Upper Bound; df = Degrees of Freedom*

Notably, among the parameter estimates, only question 28 of the WMQ exhibited significant associations with the *n*-back task. The significant negative coefficient for wm_q28=1, indicates that higher performance on the *n*-back task is associated with lower scores on question 28 (Do you find that you tire quickly during an activity which demands a lot of attention (for example, reading) of the WMQ.

Table 9 presents the results of an ordinal regression analysis aimed at predicting specific questions of the WMQ using the Digit Span total score as a predictor variable.

Table 9

Ordinal Regression Analysis for Predicting Correlated WMQ Questions with Digit Span total.

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	344.60			
Final	326	18.60	17	.35

The relationship between the Digit Span total score and the predictor variables, Working Memory Questions 11, 12, 14 and 18 did not yield a statistically significant result (χ^2 (17) =

.18.60, $p > 0.05$), indicating that the model did not predict a significant portion of the variance in the Digit Span total score.

In this chapter, the results of the statistical analyses were provided to address the research questions presented in Chapter one. Descriptive data analyses provided an overview of the data, while inferential statistics explored the statistical relationships between the variables answering both research questions. There were significant but weak relationships between some of the variables, but fewer than anticipated. The results of the regression analysis demonstrated that these relationships were not significantly predictive. Further regressions were run, and it was found that only one of the WMQ questions that correlated significantly with the *n*-back task was significantly predictive. These results are interpreted and discussed in the following chapter.

Chapter 4: Discussion

This research aimed to assess the ecological validity of the *n*-back test, the Symbol Span subtest, and the Digit Span subtest in predicting everyday life problems in working memory. This aim was addressed by investigating the convergent relationship between the tests above and self-reported working memory errors as tapped by the Working Memory Questionnaire (WMQ). As outlined in Chapter one, the study thus investigated (1) whether there was a significant relationship between the *n*-back test, the Digit Span test, the Symbol Span test, and working memory errors as tapped by the WMQ and (2) whether the three working memory tests (Digit Span, Symbol Span, and *n*-back test) predicted everyday working memory errors as tapped by the WMQ. The previous chapter provided the study's results in line with the abovementioned research questions.

In this chapter, these results are discussed regarding the relationship between the working above memory tests and the extent to which these tests predict working memory errors as tapped by the WMQ. These interpretations are drawn from the preliminary statistical analyses and are informed by the theoretical and empirical literature included in Chapter 1. This study's theoretical and practical contributions will then be discussed, alongside theoretical and methodological limitations that may have biased the results, followed by suggestions for future research in this study area.

Understanding the demographic characteristics contextualises the study's findings within the sample population. Participants who were university students, predominantly female (89.90%), exhibited a relatively high socioeconomic status and reported speaking two or more languages. The gender disparity limits the representativeness of our sample and warrants careful consideration when interpreting our findings. In contrast, the predominance of female participants may reflect underlying student demographics (i.e. more females enrol for Psychology courses than males). Although gender differences in working memory performance are not consistently observed in adults across studies (Alatorre-Cruz et al., 2018), the skewed gender distribution could potentially impact the generalisability of our results, particularly if the phenomena under investigation exhibit gender-related variations. However, a study conducted among 40 proficient Marathi-speaking young adults aged 18 to 25, with both genders represented, aimed to explore potential differences in phonological processing between words and non-words found no significant gender effect on phonological processing performance, including working memory tasks (Surana et al., 2023). This suggests that gender does not impact working memory abilities.

Furthermore, this study found that gender differences in working memory may be task-specific and related to the nature of the stimuli. However, there is no consistent evidence of general gender differences in working memory (Surana et al., 2023). Therefore, it would not be anticipated that gender influences performance on working memory tasks based solely on existing literature. However, gender differences in self-report questionnaire responses may exist due to social desirability and social approval biases, which can differ between men and women (Hebert et al., 1997).

Regarding age distribution, our sample had a mean age of 20.39 years, with a relatively narrow range spanning from 18 to 25 years, which is to be expected from a student population. This concentration around the early twenties is a demographic often characterised by unique developmental trajectories, life experiences, and perspectives. Research suggests that working memory performance improves with age across the early elementary school period (6-7 years), early adolescence (11-13 years), and peaks in early adulthood (18-25 years; Forseberg, 2023). This developmental trajectory suggests that individuals in the early adulthood phase, such as those in our sample, may exhibit enhanced working memory capabilities compared to younger or older age groups. Additionally, this age range typically coincides with critical educational and vocational development periods, where individuals are actively engaged in acquiring new skills and knowledge. Consequently, the unique cognitive and socio-environmental factors associated with this developmental stage may have influenced the working memory performance observed in our study (Forseberg, 2023).

The descriptive statistics provided in Tables 3 and 4 of the Results chapter offer valuable insights into participants' performance on the various working memory measures and their implications for cognitive functioning. From the analysis of working memory test performance, it is evident that participants exhibited varying levels of proficiency across the different subtests, including Digit Span (Forwards, Backwards, Sequencing), Symbol Span and *n*-back. The mean scores indicate an average performance level, while the scores' variability highlights individual differences in working memory capacity. Furthermore, the response time analysis from the *n*-back task demonstrates an expected increase in response time as task complexity rises from 1-back to 3-back tasks. This finding aligns with existing literature that the performance of individuals in *n*-back tasks can be influenced by task complexity and practice. Research has shown that response time and error rate in *n*-back tasks increase with increasing working memory load, indicating the effect of task complexity on performance (Murray et al., 2005). Comparing these results with existing literature on working memory performance, it is noteworthy that our findings are consistent with previous studies, emphasising the reliability

of the employed working memory measures (He et al., 2022; Manchón et al., 2023). Overall, these descriptive findings contribute to our understanding of individual differences in working memory capacity and have implications for clinical and educational settings, where assessing and addressing cognitive difficulties is paramount.

The current study aimed to explore the relationship between the working memory tests. Intercorrelations were observed between the various working memory tests. Digit and Symbol Span tasks are commonly used to measure working memory capacity. The significant correlations between these tasks confirm that they tap into a typical working memory element. This aligns with the concept that working memory involves temporarily storing and manipulating information, regardless of the input's modality (verbal or visuospatial). A study explored the effectiveness of Digit Span tasks as a measure of visuospatial bootstrapping in working memory and found that when to-be-remembered numbers are paired with additional visuospatial information, those numbers are generally better remembered than single numbers, potentially due to binding between verbal and visuospatial short-term memory with long-term memory representations, creating a visuospatial bootstrapping effect (Findlay, 2014). The observed improvement in memory performance, when to-be-remembered numbers are paired with additional visuospatial information, implies that there may be interactions between verbal and visuospatial components of working memory. This implies that the relationship between Digit Span and Symbol Span tasks may not be solely based on their respective modalities but may also involve processes related to integrating or binding different types of information within working memory. Therefore, the significant correlations between these tasks reflect their shared involvement in temporary storage, manipulation, and information integration rather than purely modality-specific processes. The theory supported by the findings regarding the visuospatial bootstrapping effect in working memory aligns more closely with the framework proposed by Baddeley (1998). Baddeley's (1998) model includes multiple components, one of which is the visuospatial sketchpad, responsible for temporarily storing and manipulating visual and spatial information, while the episodic buffer plays a crucial role in integrating and binding information across different modalities. The concept of visuospatial bootstrapping, where the pairing of visuospatial information enhances memory performance for verbal information, is consistent with Baddeley's idea of interactive processes within working memory, where different types of information can interact and support each other (Bruyer & Scailquin, 1998).

Furthermore, a study aimed at comparing laboratory and clinical working memory tests and their prediction of fluid intelligence conducted on undergraduate university students found

that, in general, the working memory subtests of the WAIS-III (Digit Span) and WMS-III (Symbol Span) were highly related to the laboratory working memory measures, suggesting that performance on these tests was essentially tapping resources from the same psychological construct (Shelton et al., 2008).

Studies have shown varying correlations between the *n*-back task and different working memory tasks. Some studies report medium to strong correlations between *n*-back and complex span tasks (Shamosh et al., 2008), while others find stronger correlations with simple span tasks (Jaeggi et al., 2010). It was anticipated that the *n*-back task, which measures working memory capacity as processing load increases, would show significant correlations with both the Digit Span subtest and the Symbol Span subtest, as they represent measures of complex working memory. For the *n*-back task to demonstrate its construct validity as a working memory measure, it would be expected to correlate with tasks involving manipulating and processing information in addition to simple storage or rehearsal (Kane et al., 2007). Symbol Span correlated significantly with 1- and 2-back accuracy, suggesting they may share visuospatial working memory elements. The Digit Span subtest, however, did not correlate significantly with any aspects of the *n*-back. This may be because the Digit Span task is primarily considered a measure of verbal working memory, while the format of the *n*-back task was visuospatial. These findings are supported by a study that revealed no significant correlation between *n*-back performance and Digit Span backward; instead, the *n*-back accuracy score significantly correlated with a measure of processing speed (Miller et al., 2009). These findings contribute to the construct validity of the working memory tests, demonstrating that the test components within each task are significantly intercorrelated and primarily correlated with measures that tap into similar cognitive skills.

Relationships between the working memory tests and components of the WMQ and their predictive nature

The correlations between the working memory tests and components of the WMQ provide insights into the relationship between laboratory-based assessments of working memory and individuals' subjective experiences of cognitive challenges in daily life, the focus of this study. These correlations offer a detailed exploration of how performance on specific cognitive tasks may be associated with self-reported difficulties across various domains of working memory functioning. Following this, the relationships between individual questions from the WMQ and working memory tests were investigated, as summarised in Table 10.

Furthermore, Table 11 highlights the specific aspects of working memory tapped by individual WMQ questions.

Table 10

Summary of Correlations between Working Memory Tests and WMQ Components

Working Memory Test	WMQ Question(s)
Digit Span Forward	18 (executive domain)
Digit Span Sequencing	11(storage domain), 12 (executive domain), 14 (executive domain)
Symbol Span	13 (attention domain), 18 (executive domain), 21 (storage domain)
1-Back	15 (storage domain)
2-Back	3 (storage domain), 24 (attention domain), 28 (attention domain)

Table 11

Summary of the significantly correlated questions from the WMQ

WMQ	Question
3	Do you have problems with remembering sequences of numbers, for example, when you must note down a telephone number?
11	Do you need to re-read a sentence several times to understand a simple text?
12	Do you have difficulty in organising your time about appointments and your daily activities?
13	Do you find it difficult to do two (or several) things at the same time such as: - DIY and listening to the radio at the same time?

	- Cooking and listening to the radio at the same time?
14	When you are carrying out an activity, if you realise that you are making a mistake, do you find it difficult to change strategy?
15	Do you have difficulty understanding what you read?
18	Do you find it difficult to follow the different steps of a user's guide (putting kit furniture together, installing a new electrical device)?
21	If a character in a text is designated in different ways (he, him), do you have difficulty in understanding the story?
24	Do you feel that you are very slow to carry out your usual activities?
28	Do you find that you tire quickly during an activity which demands a lot of attention (for example, reading)?

The observed significant, yet weak, correlations between working memory tests (Digit Span, Symbol Span, and *n*-back test) and components of the WMQ prompt a deeper exploration into the relationship between laboratory-based assessments and real-world working memory errors. These correlations fall within the identified domains of storage, attention, and executive functions, shedding light on specific facets of the complex interplay between theoretical models and practical outcomes.

Storage Domain

The observed weak negative correlation between Digit Span Sequencing and the Short-Term Storage component of the WMQ suggests an exciting aspect of working memory function. In line with Baddeley's model (1992), which emphasises the role of sequencing in dynamic information maintenance, this negative relationship may imply a trade-off between the ability to maintain information in a dynamic sequence and the capacity to store information temporarily. Specifically, individuals who excel at sequencing tasks, as assessed by the Digit Span Sequencing task, may allocate more cognitive resources to manipulating and organising information within working memory. Consequently, they may have relatively lower capacity for simple storage processes, as reflected in the Short-Term Storage component of the WMQ. Conversely, individuals who perform well on tasks measuring short-term storage may prioritise

the efficient retention of information over dynamic manipulation or sequencing. Thus, they may perform weaker tasks requiring sequencing abilities, such as Digit Span Sequencing. This is an unexpected finding, as it would be expected that sequencing deficits may manifest as short-term storage challenges (Miyake & Friedman, 2012). This unexpected finding highlights the need for an understanding of working memory processes and raises questions about the extent to which traditional working memory tests can accurately reflect the multifaceted nature of working memory functioning in everyday life; however, it also adds to the ongoing debate over the sensitivity of traditional working memory tests, such as the Digit Span, in capturing real-world cognitive functions (Nussbaum et al., 1995) as none of the other aspects of the Digit Span were significantly correlated with the WMQ components.

Since none of the other WMQ domains were significantly correlated with the working memory tests, this study further explored the individual WMQ questions to find any possible relationships. Some significant correlations were discovered (See Table 12) and are discussed below.

The significant weak negative correlation between 1-Back Accuracy and Working Memory Question 15 suggests a potential association between lower accuracy in the 1-Back task and challenges related to comprehension difficulties during reading, which are indicative of issues within the storage domain of working memory.

Individuals who need help understanding what they read may encounter obstacles in effectively storing and retrieving information in their working memory. In the context of the 1-Back task, which involves comparing current stimuli with those held in memory, individuals experiencing comprehension difficulties may struggle to retain and recall the sequence of stimuli accurately. This could lead to lower accuracy rates on the task.

This aligns with the attentional control demands associated with working memory tasks (Engle & Kane, 2004). They suggested that individuals with higher working memory capacity exhibit more efficient attentional control, enabling them to effectively manage cognitive demands across various tasks (Engle & Kane, 2004). The negative correlation between 1-Back Accuracy and Working Memory Question 15 supports this idea, indicating that individuals with lower accuracy in the 1-Back task may experience challenges in attentional control, leading to difficulties in tasks such as reading comprehension.

Attention Domain

Within the attention domain, the significant weak negative correlation between Symbol Span and WMQ questions 13, 18, and 28 emphasises potential connections between

visuospatial working memory and challenges in attention. The negative correlation indicates that individuals with higher scores on the Symbol Span task, which assesses visuospatial working memory, tend to report fewer difficulties in tasks related to multitasking, following instructions, and sustaining attention.

For instance, Question 13 enquires about the ability to perform multiple tasks simultaneously, such as DIY activities while listening to the radio or cooking while listening to the radio. The negative correlation with Symbol Span suggests that individuals with more vital visuospatial working memory skills may find multitasking less challenging in such scenarios. This aligns with theoretical perspectives proposing the relevance of visuospatial working memory in managing complex, multitasking situations (Mayers et al., 2009). Similarly, Question 18 assesses the ability to follow the different steps of a user's guide or perform tasks that require sequential instructions, such as assembling furniture or installing electrical devices. The negative correlation between Symbol Span and this question implies that individuals with better visuospatial working memory may find it easier to follow sequential instructions due to their enhanced ability to mentally visualise and manipulate spatial information.

Furthermore, Question 28 addresses the endurance of attention during demanding activities, such as reading. The negative correlation with Symbol Span suggests that individuals with stronger visuospatial working memory may experience less fatigue or quicker recovery during tasks that demand sustained attention. This could be attributed to their enhanced ability to efficiently manage visuospatial information within working memory, thereby reducing cognitive load during attention-demanding tasks.

However, the non-predictive nature of these relationships calls into question the specific contributions of Symbol Span to real-world cognitive challenges. While the negative correlations suggest an association between visuospatial working memory and attention functions, they do not indicate a causal relationship.

In contrast, the significant positive weak correlations between 2-back Accuracy and Working Memory in Questions 3, 24, and 28 suggest that higher accuracy in the 2-back task is associated with fewer reported challenges in specific cognitive domains. When considering Question 3, which asks participants about their difficulties in remembering sequences of numbers, such as when noting down a telephone number, the positive weak correlation with 2-back accuracy indicates an anticipated connection. Individuals who perform better on the 2-Back task, involving the continuous recall and updating sequences, tend to report fewer difficulties remembering numerical sequences in daily life. This association underscores the

relevance of working memory processes in tasks requiring the retention and manipulation of numerical information.

Moreover, Question 24 explores whether individuals perceive themselves as slow to carry out their usual activities. The positive weak correlation between 2-back accuracy and this question implies that participants with higher accuracy in the 2-back task perceive themselves as more efficient in task completion. This suggests that better working memory performance may be linked to perceived cognitive efficiency in decision-making and task execution, reflecting a connection between working memory and attentional functions in daily functioning.

Lastly, Question 28 delves into whether participants experience quick fatigue during activities demanding a lot of attention, such as reading. The positive weak correlation with 2-Back accuracy suggests that individuals who perform better on the 2-Back task, requiring sustained attention and monitoring of stimuli, report less fatigue during attention-demanding activities. This association implies that higher working memory capacity may be linked to enhanced attentional control and resilience during cognitively demanding tasks, supporting the growing evidence highlighting the connection between working memory and executive functions in daily life.

These findings resonate with the growing body of evidence emphasising the connection between working memory and executive functions in daily life (Quilez-Robres et al., 2021).

Executive Domain

Within the executive domain, the significant weak negative correlations between Digit Span Sequencing and Working Memory Questions 11, 12, and 14 underscore potential deficits in executive control aspects for individuals with weaker sequencing abilities. This relationship between sequencing and executive functions resonates with existing literature highlighting the multifaceted nature of working memory (Logie et al., 2010). However, the non-predictive nature of these relationships, as indicated by the regression analysis, suggests that the Digit Span Sequencing test may capture only a portion of the variance in real-world executive functioning.

Participants who need to re-read sentences several times to understand a simple text (Question 11), who have trouble in organising their time regarding appointments and daily activities (Question 12), or who struggle to change strategies when realising mistakes during activities (Question 14) may exhibit weaker performance on tasks requiring sequencing abilities. This suggests a potential inverse relationship between sequencing abilities and

executive functioning skills, wherein weaker sequencing abilities are associated with more significant difficulties in executive control tasks.

Further analyses were performed to investigate the components of working memory assessed by the *n*-back task and their associations with subjective experiences reported in the WMQ. Interestingly, the results revealed a significant relationship between the *n*-back task and Question 28 (Do you find that you tire quickly during an activity that demands much attention (for example, reading?) from the WMQ, as indicated by the significant p-value ($p < 0.05$). This finding underscores a specific link between the construct of working memory assessed by the *n*-back task and subjective experiences related to fatigue during attention-demanding activities, such as reading.

The cultural and linguistic factors explored in the Digit Span subtest become pertinent within the South African context. Individuals from different linguistic backgrounds and proficiency levels may approach verbal working memory tasks (administered in their second or third language) differently than English first-language speakers, potentially affecting their performance on the Digit Span subtest (Razani et al., 2007). This lens suggests that the cross-cultural applicability of traditional working memory tests, such as Digit Span, may be influenced by linguistic factors, thus impacting their ecological validity in linguistically diverse populations.

While considering cognitive resources and socio-economic factors is crucial for interpreting working memory test scores (Ziemnik & Suchy, 2019), it is essential to recognise the potential impact of our sample's composition. The sample represented more individuals from higher SES, as reflected in their LSM scores (mean = 6,97), which may limit the generalisability of our findings to the broader population.

Nonetheless, the context of limited resources in developing countries like South Africa highlights the importance of identifying assessment tools that are culturally and socioeconomically appropriate. The present study underscores the significance of considering socio-economic factors in interpreting working memory tests, particularly regarding their predictive power for real-world errors. While the study reveals a few significant correlations between the working memory tests and components of the WMQ, the non-predictive nature of these relationships prompts a re-evaluation of traditional working memory assessments. The discrepancies may be attributed to real-world working memory errors' multifaceted and context-specific nature, emphasising the importance of considering cultural, linguistic, and socio-economic factors in interpreting test scores. Future research should continue to explore

these factors and their implications for the ecological validity of working memory assessments, paving the way for more holistic and culturally sensitive evaluation tools.

Contributions of the study

This study exhibits several notable strengths that enhance its significance and contribute to the broader understanding of working memory assessment. It addresses a gap in the existing literature, systematically examining the ecological validity of three working memory tests—the *n*-back test, Symbol Span subtest, and Digit Span subtest—in predicting real-life challenges associated with working memory. By emphasising ecological validity, the study directly probes the applicability of traditional working memory tests beyond controlled laboratory environments, filling a significant void in the current research landscape. Drawing on insights from the literature review, this approach aligns with the ongoing discourse emphasising the necessity of context-specific evaluations of working memory assessments (Nussbaum et al., 1995).

One of the strengths of this study lies in its inclusion of a culturally diverse sample of sixty-nine bilingual and multilingual young adults aged 18 to 25. This demographic specificity adds a unique contextual dimension to the research, particularly relevant in South Africa. As highlighted, cultural and linguistic factors can influence working memory test performance (Razani et al., 2007). Therefore, this inclusion ensures a more comprehensive understanding of the relationships between working memory tests and everyday challenges in a population characterised by linguistic diversity.

Furthermore, the research aligns with previous studies that underscore the importance of considering cultural and linguistic factors in working memory assessments (Conway et al., 2007). By extending this exploration to the South African context, the study broadens our understanding of working memory. It contributes to the ongoing conversation about the cross-cultural applicability of cognitive assessments.

Limitations and Recommendations for Future Research

While this study significantly contributes to understanding working memory assessment in the South African context, it is imperative to acknowledge certain limitations that influence the generalisability of findings and provide recommendations for future research. Firstly, the small sample size of 69 participants may have limited the statistical power to detect significant predictive relationships between the working memory tests and the WMQ. With a larger sample size, the variability in working memory performance and everyday working

memory errors could be more adequately captured, potentially leading to stronger predictive relationships.

Furthermore, the self-report nature of the WMQ introduces inherent limitations in assessing everyday working memory errors. Participants' responses on the WMQ may be influenced by subjective perceptions, recall biases, or other individual factors that could affect the accuracy and reliability of the reported errors. As a result, the discrepancy between the significant correlations and the lack of predictive power in the regression analyses may partially stem from the methodological constraints of self-reported measures. This aligns with the literature, emphasising the need for a multifaceted approach combining self-report instruments with objective performance measures (Vallat-Azouvi, 2012). Future research in working memory assessment should consider incorporating a more diverse range of assessment tools to provide a comprehensive understanding of the relationship between working memory tests and daily challenges.

Additionally, the complexity of everyday working memory errors may be partially captured by the working memory tests employed in this study. While laboratory-based tasks provide valuable insights into specific aspects of working memory function, they may only partially represent the multifaceted nature of working memory errors encountered in real-world settings. Everyday working memory errors may involve diverse cognitive processes, situational factors, and contextual influences that are not fully addressed by traditional working memory tests (Frost et al., 2019).

Moreover, other cognitive and non-cognitive factors beyond working memory capacity alone may contribute to everyday working memory errors. Factors such as attentional control, cognitive flexibility, task demands, stress, fatigue, and individual differences in coping strategies could all influence the frequency and severity of working memory errors in daily life (Lücke et al., 2021). Therefore, the predictive utility of working memory tests in explaining everyday working memory errors may be limited when considered in isolation from these broader cognitive and environmental factors.

While the significant correlations between the working memory tests and the WMQ suggest a theoretical relationship between laboratory-based working memory performance and everyday functioning, the lack of significant predictive power highlights the need for caution in extrapolating from laboratory findings to real-world contexts. This finding aligns with the broader discourse on the ecological validity of working memory tests, emphasising the need for context-specific considerations (Nussbaum et al., 1995).

Furthermore, this study's correlational and non-experimental design limits the establishment of causal relationships between working memory tests and real-life challenges. The inability to manipulate independent variables hinders definitive conclusions about the predictive nature of the assessed working memory tests.

Moreover, the reliance on convenience sampling, while practical, introduces a potential limitation regarding the generalisability of the findings. The sample, predominantly comprising bilingual and multilingual young adults, primarily female, from a single university, may need to fully capture the diversity inherent in the broader South African population. Drawing on literature discussing the importance of diverse participant pools (Conway et al., 2007), future research could benefit from recruiting a more extensive and varied sample encompassing different age groups, educational backgrounds, and linguistic profiles.

Cultural and linguistic factors, acknowledged as potential influences, were not systematically controlled or explored in-depth, leaving room for confounding variables that could impact the ecological validity of working memory tests. Building on insights from the literature review (Razani et al., 2007), future research should systematically investigate and control for cultural and linguistic influences, ensuring a more nuanced understanding of how these factors interact with working memory assessments, particularly in diverse populations.

To strengthen causal inferences and deepen our understanding of long-term predictive capabilities, future research could benefit from longitudinal studies. Tracking changes in working memory performance over time would provide valuable insights into the stability and trajectory of working memory abilities. This recommendation aligns with existing literature suggesting the need for longitudinal approaches in studying cognitive functions (Best & Miller, 2010).

While this study significantly contributes to the discourse on working memory assessment in the South African context, addressing these limitations and implementing the recommended strategies in future research would further enhance the validity, generalisability, and depth of our understanding in this field.

Conclusion

In summary, this thesis aimed to explore the ecological validity of commonly used working memory tests, namely the *n*-back test, Symbol Span subtest, and Digit Span subtest, within a culturally diverse South African population. The study's results revealed significant but weak correlations between the working memory tests and components of the Working Memory Questionnaire. The nuanced relationships observed between laboratory-based

assessments and real-world working memory errors underscore the multifaceted nature of working memory. The findings highlight the complexities in translating laboratory-based working memory performance to everyday cognitive challenges.

Despite the observed correlations, the non-predictive nature of these relationships, as indicated by the regression analysis, emphasises the need for caution in relying solely on traditional working memory tests for predicting real-life cognitive functioning. This study contributes to the broader discourse on ecological validity by contributing data from a more socioeconomically and linguistically diverse sample than is traditionally studied. Insights from the literature further underscore the importance of considering diverse participant profiles in working memory research.

The study's limitations, including the non-experimental design, reliance on self-report measures, and potential confounding variables related to cultural and linguistic factors, provide avenues for future research. Recommendations for future studies, informed by the literature and the study's limitations, include adopting experimental designs, diversifying participant pools, incorporating objective performance measures, and systematically exploring cultural and linguistic influences.

In conclusion, this study contributes valuable insights into the ecological validity of working memory tests, particularly in the unique context of South Africa. This research enhances our understanding of the complexities of assessing real-world working memory challenges by integrating theoretical foundations, empirical evidence, and diverse participant perspectives. The nuanced relationships uncovered underscore the importance of refining and contextualising working assessments better to capture the intricacies of cognitive functioning across diverse populations.

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Appendices

Appendix A: Participant Information Sheet

Psychology

School of Human & Community

Development

University of the Witwatersrand

Private Bag 3, Wits, 2050

Tel: 011 717 4503

Fax: 011 717 4559

Study Title: Every day working memory: the ecological validity of three working memory tests.

Dear student,

I am a student in the Department of Psychology at Wits University, and I would like to invite you to participate in my research, which examines three working memory tests and their ability to predict everyday life problems in working memory. If you agree to take part in this study, the procedure can be completed individually at a time suitable for you.

Details of the Study

This first part of the study can be conducted online at your convenience. The activities will include: (1) reading though this information sheet (Appendix A: 5-10 minutes); (2) completing the informed consent form (Appendix B: 3 minutes), and (3) completing the demographic questionnaire and the Working Memory Questionnaire which will be completed online, on an online platform called REDCap. (4) completing the Digit Span test, the Symbol Span test and the *n*-back test. The *n*-back test will be the only computerised test, the other two are paper-and-pencil tests. Each participant will be assessed individually in the neuroscience laboratory in one session that will be approximately 45 minutes.

Risks

There are minimal risks associated with participating in this study.

Benefits

Participation in this study requires an investment of your time, which we greatly appreciate. There are no direct benefits associated with participation. Given that participants must complete this study in person, each participant will receive R150 towards travel expenses.

Confidentiality and Anonymity

The data obtained from this study will not be linked to any academic results or be traceable to participants, as it will be collected with an anonymous participant number only. Anonymity is guaranteed in any resulting publications and presentations. All data will be kept confidential in anonymized, password-protected files, stored on an external hard drive, and only the researchers will have access to the questionnaires and corresponding data. The results of this

research will not be used to examine individual performance, instead only group performance will be analysed.

Withdrawal from this Study

Participation is entirely voluntary, and you are not obliged to be involved in this study. If you do decide to participate, you have the right to withdraw from the study at any time, and this will not be held against you in any way. If you choose to withdraw, any collected data will be destroyed and will not be used in subsequent analyses.

Research Outputs

The results of this study will be disseminated through publications and conference papers. Participants may request further information about the study, although individual feedback on performance will not be available as the collected data will be anonymous. Data may be used for possible secondary analyses.

Contact Details of the Principal Investigator

Please contact Nqobile Mnisi if you require further information about this study, or feedback on the progress of this research.

Contact Details of the HREC Administrator and Chair

Please contact Professor Clement Penny (Clement.Penny@wits.ac.za / 011 7172301), if there are any formal complaints or reservations about the ethical conduct of this research, stating the nature of your query. The Committee secretarial can also be contacted telephonically: 011 7172700/1234, or on email addresses: Zanele.Ndlovu@wits.ac.za and Rhulani/Mukansi@wits.ac.za. Any issues will be treated in confidence and investigated fully, and you will be informed of the outcome.

Thank you for taking the time to read this information sheet. If you are satisfied with the information provided, and are interested in participating in the study, please contact Nqobile Mnisi (2128451@students.wits.ac.za). You will be contributing to research that will provide insight into the cognitive benefits of linguistic diversity in our country.

Date: 30/04/2022

Appendix B: Informed Consent

Appendix B: Informed Consent

Psychology
School of Human & Community Development
University of the Witwatersrand
Private Bag 3, Wits, 2050
Tel: 011 717 4503 Fax: 011 717 4559

Project: Every day working memory: the ecological validity of three working memory tests.

Researcher: Nqobile Mnisi

I …… agree to participate in this research project. The research has been explained to me and I understand what my participation will involve. I agree to the following:

(Please cross the relevant options below).

I have read the participant information letter and my questions have been answered to my satisfaction.	YES	NO
I acknowledge that participation is entirely voluntary.	YES	NO
I am aware that I can withdraw from the study at any time. I do not need to provide a reason, and this will not be held against me.	YES	NO
My data will remain anonymous (participants will be represented as a 'code number').	YES	NO
I give my consent to use my data for the purposes mentioned in the participant information letter.	YES	NO

…… (Signature)
…… (Name of Participant)
…… (Date)

Appendix C: Ethics Clearance Certificate

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

SCHOOL OF HUMAN AND COMMUNITY DEVELOPMENT ETHICS COMMITTEE

CONSTITUTED UNDER THE UNIVERSITY HUMAN RESEARCH ETHICS COMMITTEE (NON-MEDICAL)

CLEARANCE CERTIFICATE NUMBER: MASPR/23/05	**PROTOCOL**
PROJECT TITLE:	Every day working memory: the ecological validity of three working memory tests.
INVESTIGATOR	Mnisi Nqobile (2128451)
SCHOOL/DEPARTMENT OF INVESTIGATOR	SHCD/Psychology
DATE CONSIDERED	01 June 2023
DECISION OF THE COMMITTEE	Approved unconditionally

RISK LEVEL Minimal Risk

EXPIRY DATE 31 December 2025

ISSUE DATE OF CERTIFICATE: 23 May 2023

CHAIRPERSON: _____

(Dr Aline Ferreira Correia)

cc: Prof. Kate Cockcroft

Supervisor

DECLARATION OF INVESTIGATOR

To be completed in duplicate and **ONE COPY** returned to the Chairperson of the School/Department ethicscommittee.

I/we fully understand the conditions under which I am/we are authorized to carry out the abovementioned researchand I/we guarantee to ensure compliance with these conditions. Should any departure be contemplated from the research procedure as approved, I/we

undertake to submit an amendment of the protocol to the Committee.



Signature **Date:** 06/07/2023

Appendix D: Normality Outputs

Table 1

Normality Statistics for Working Memory Variables

Variable	Skewness	Kurtosis	Kolmogorov – Smirnov
Digit Span Forwards	0.27	-0.31	0.14
Digit Span Backwards	0.93	0.57	0.20
Digit Span Sequencing	0.68	0.45	0.14
Digit Span Subtest (Total)	0.72	0.29	0.12
Symbol Span Subtest	-0.08	-0.62	0.12
1-Back Accuracy	-0.77	0.44	0.15
1-Back Average Reaction Time	0.88	0.85	0.10*
2-Back Accuracy	-1.17	1.05	0.15
2-Back Average Reaction Time	0.18	-0.43	0.64*

3-Back Accuracy	0.27	0.12	0.05
3-Back Average Reaction Time	0.14	-0.52	0.05*
N-back Accuracy Test (Total)	-0.29	-0.36	0.10
N-back Test Total Reaction Time	0.32	-0.32	0.07*

Notes. *p < .05

Figure 1

Distribution Pattern of Digit Span Forwards (n = 69)

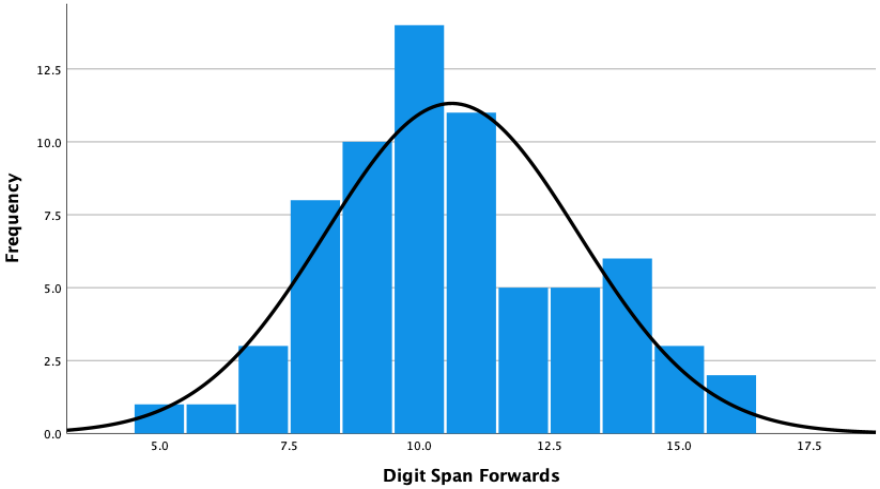


Figure 2

Distribution Pattern of Digit Span Backwards (n = 69)

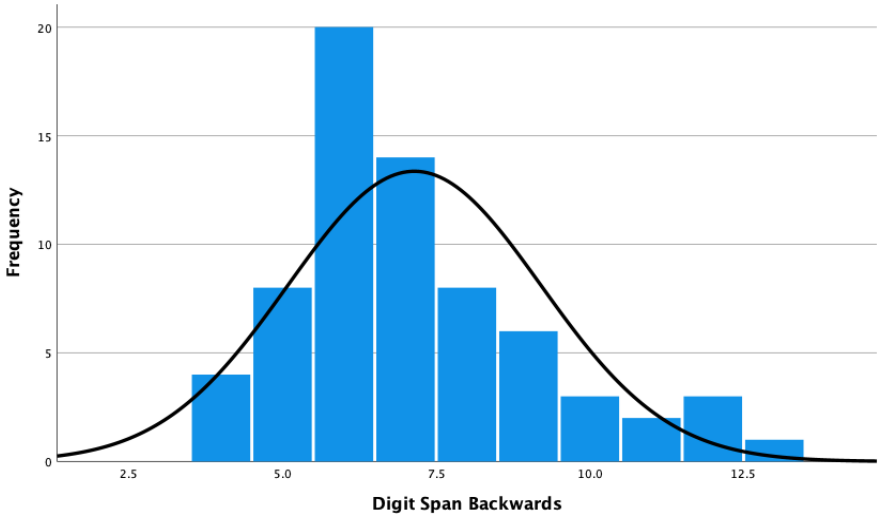


Figure 3

Distribution Pattern of Digit Span Sequencing (n = 69)

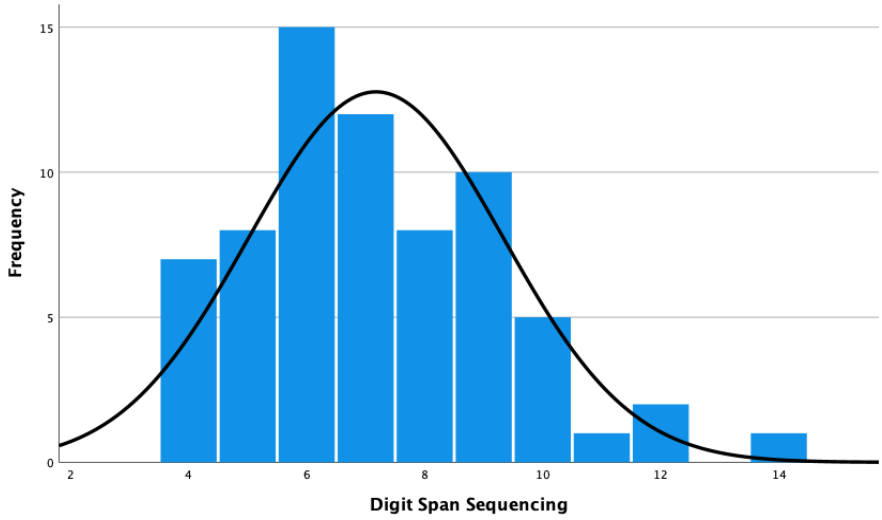


Figure 4

Distribution Pattern of Digit Span Total (n = 69)

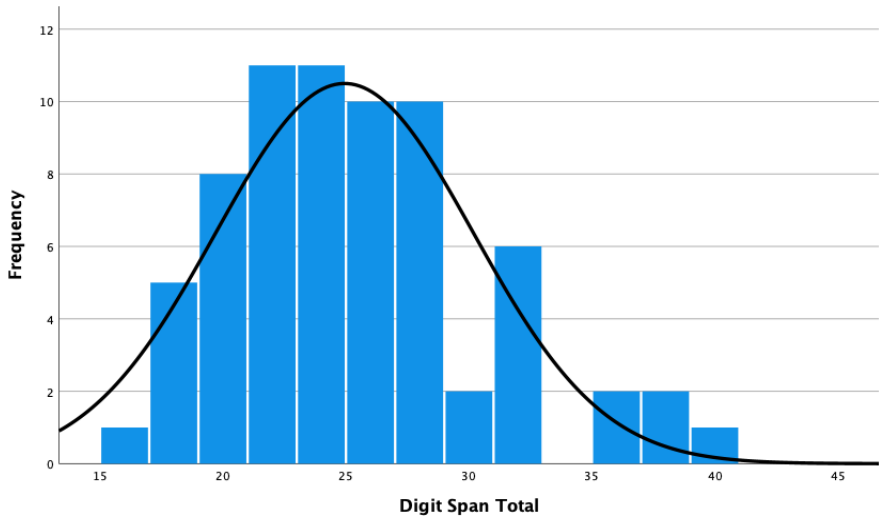


Figure 5

Distribution Pattern of Symbol Span (n = 69)

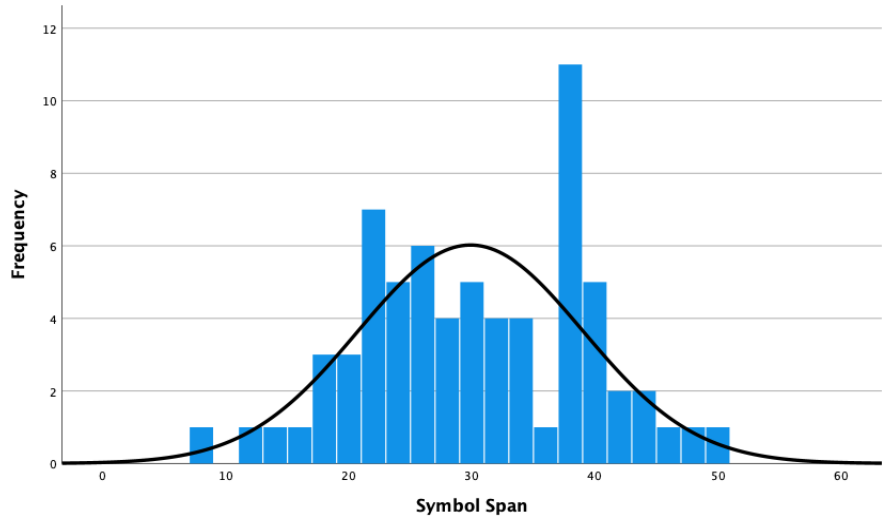


Figure 6

Distribution Pattern of 1-Back accuracy (n = 69)

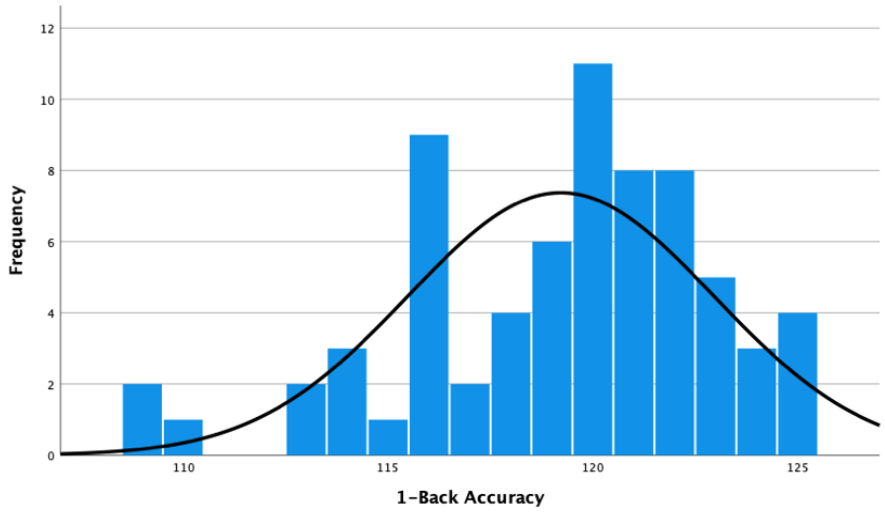


Figure 7

Distribution Pattern of 1-Back Response time (n = 69)

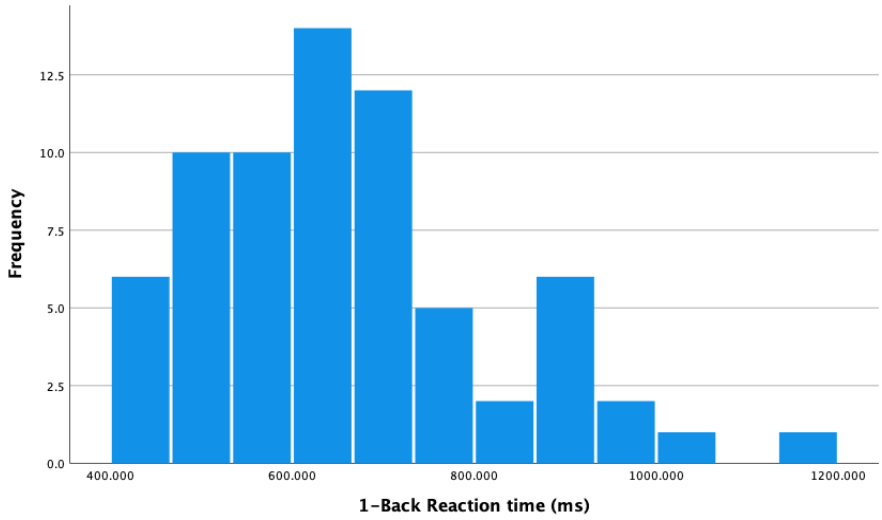


Figure 8

Distribution Pattern of 2-Back Accuracy (n = 69)

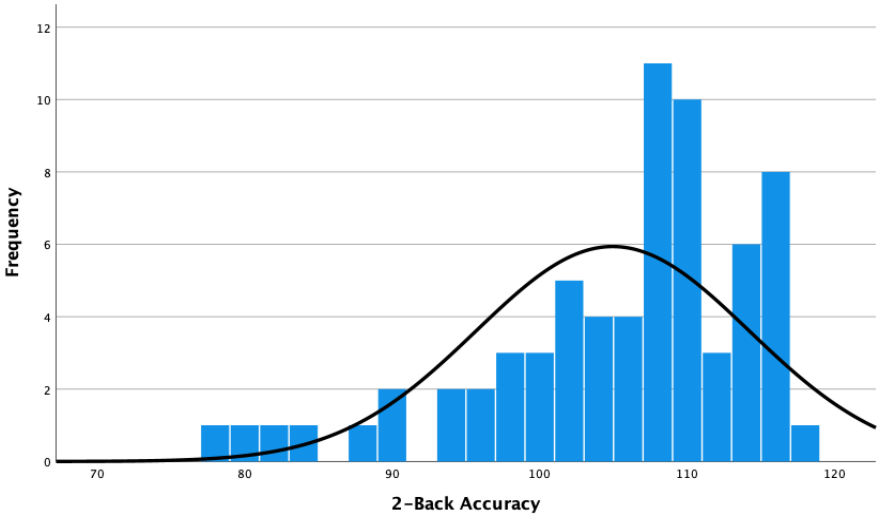


Figure 9

Distribution Pattern of 2-Back Response time (n = 69)

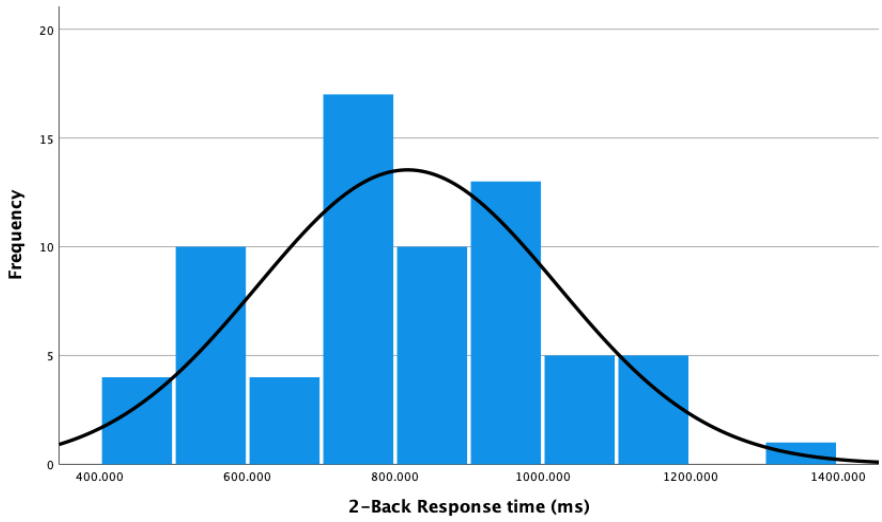


Figure 10

Distribution Pattern of 3-Back Accuracy (n = 69)

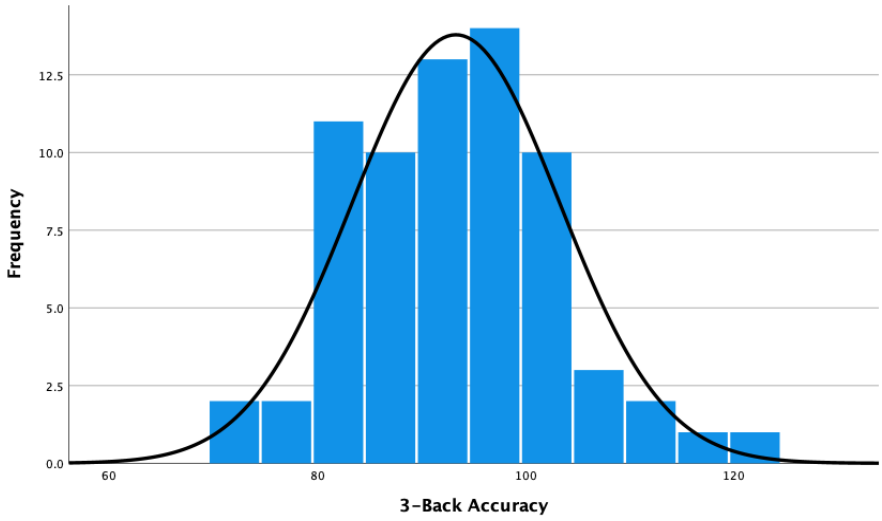


Figure 11

Distribution Pattern of 3-Back Response time (n = 69)

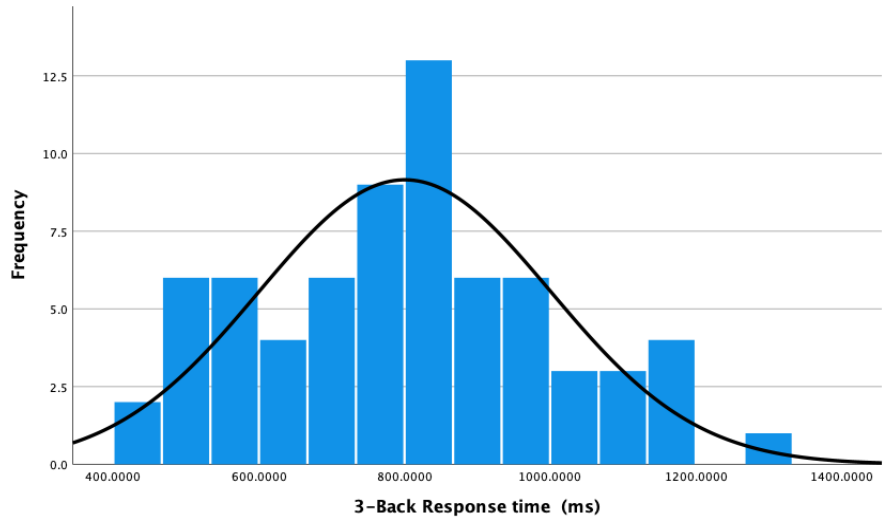


Figure 12

Distribution Pattern of N-back Accuracy (n = 69)

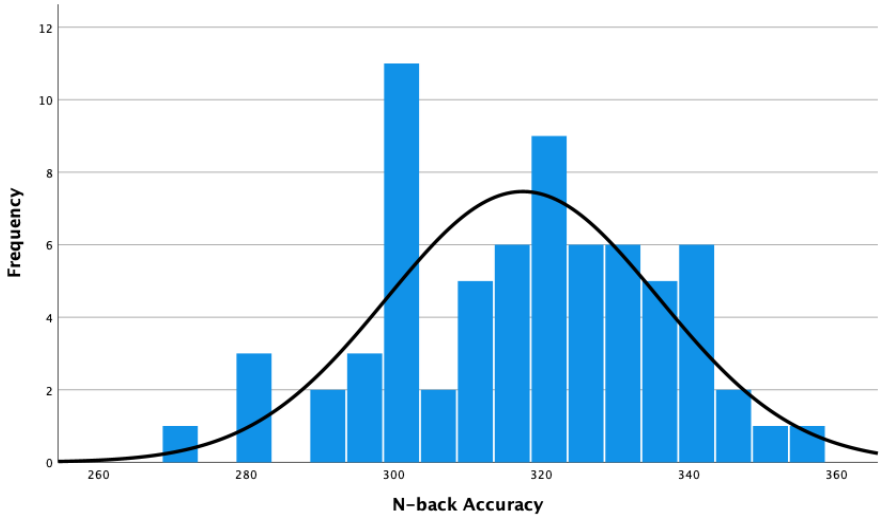
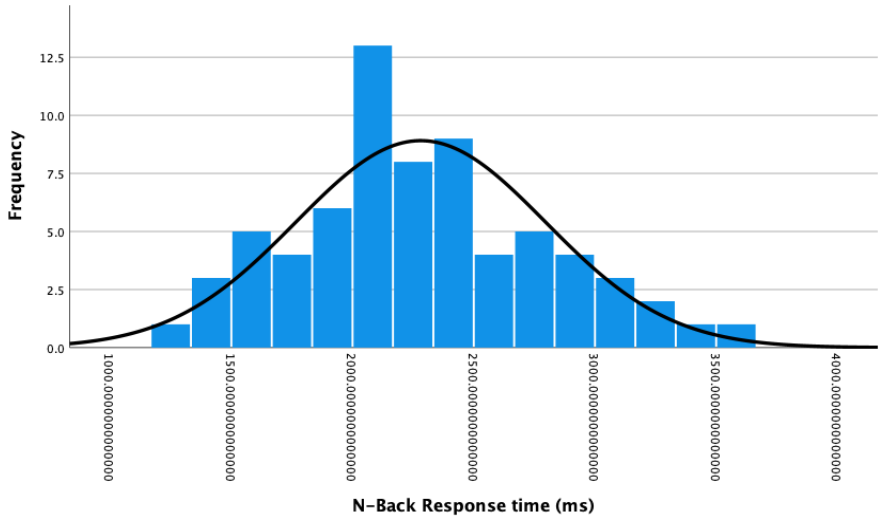


Figure 13

Distribution Pattern of total N-back Response time (n = 69)



Appendix E: Regression Assumptions

Figure 1

Homoscedasticity Scatter plot for Symbol predicting WMQ total.

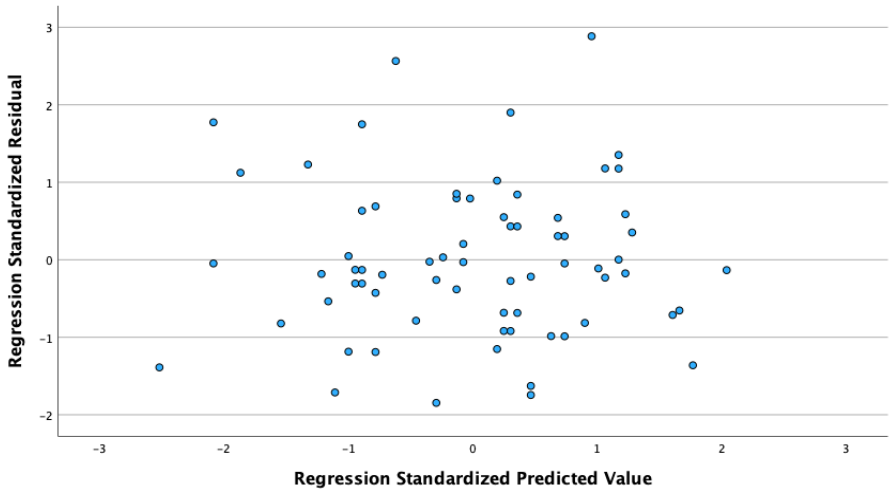


Figure 2

Residual Distribution for Symbol Span predicting WMQ total

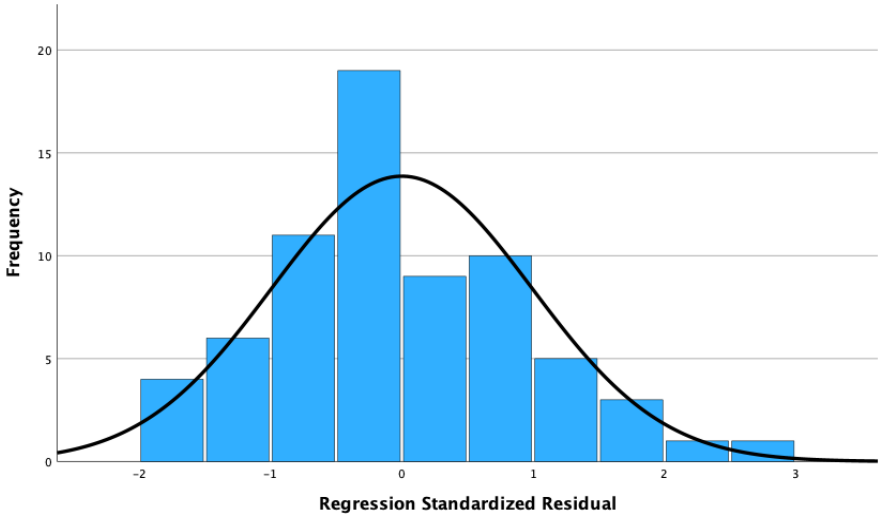


Figure 3

Homoscedasticity Scatter plot for n-back predicting WMQ total.

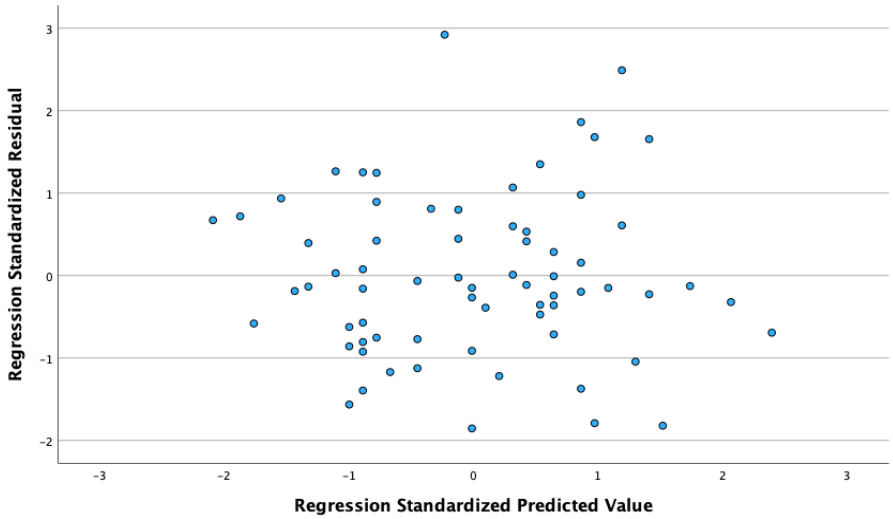


Figure 4

Residual Distribution for n-back predicting WMQ total.

