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The University of Dublin

Examining the Cognitive Linguistic Differences Between Adults with Mild Cognitive Impairment (MCI) and a Group of Healthy Controls using a Devised Cognitive Linguistic Assessment

MSc (Research) in Clinical Speech and Language Studies, Trinity College Dublin, 2023

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Lisa Sheridan
27th March, 2023

Acknowledgements

Firstly, I would like to thank my supervisors, Dr Ciarán Kenny and Prof. Seán Kennelly, for their guidance and support throughout this research. Their expertise, encouragement and patience has been invaluable.

I also wish to thank all the participants who took part in this study. Their time and commitment is what made this research possible.

I would like to extend sincere thanks to my colleagues in Speech and Language Therapy and Age-Related Healthcare in Tallaght University. Their support, advice and insight throughout this journey has been vital in completing this study.

Finally, I would like to thank my husband Kyle, my mother Bernie, my father Thomas and brothers Aaron and Conor for the endless support, encouragement and patience throughout this time.

Abstract

Title: Examining the Cognitive Linguistic Differences Between Adults with Mild Cognitive Impairment (MCI) and a Group of Healthy Controls using a Devised Cognitive Linguistic Assessment.

Background: Changes in language often precede other notable cognitive changes in people who go on to develop dementia, however, given their subtlety, these early-stage communication signs are frequently missed. Speech and language features have been widely cited as highly sensitive markers for early detection of cognitive impairment (Filiou et al., 2019; Thomas et al., 2020; Martinez-Nicholas et al., 2021; Robin et al., 2021; Sanborn et al., 2022) and for this reason, it is imperative we develop screening tools that incorporate detection of these subtle speech and language changes. While we have come quite a long way in identifying speech and language deficits associated with cognitive impairment, there is still a lot to unravel so that it can be utilised to its full potential. Examining the language profile associated with MCI compared with the language profile of healthy older adults can facilitate development of fast, easily accessible cognitive screening tools using cognitive linguistic tasks.

Aim: This study aims to identify the value of commonly used cognitive linguistic assessment tasks in identifying those with mild cognitive impairment (MCI) compared with a healthy control (HC) group and assess if a quick, informal cognitive linguistic assessment completed in digital form and developed by the researcher, similar to ones that are used regularly by Speech and Language Therapists (SLTs), could be more targeted and sensitive in identifying those at risk for cognitive impairment.

Methods: This study included 40 participants (20 HCs and 20 MCI). The study was a quantitative, prospective, cross sectional, observational design. Participants completed a cognitive linguistic assessment in digital form using a tablet that was designed by the researcher and wider research team. The cognitive linguistic assessment included picture naming, repetition, verbal fluency, reading, picture description, list learning, list recall, list recognition and digit span. Differences were examined across groups and across age/years of education. Cognitive linguistic scores were examined for differences across groups using the Mann Whitney U test.

Results: There was a statistical difference across groups in the subtests of picture naming (p <.001), list learning (p <.001), list recall (p <.001), list recognition (p <.001) and repetition (p=.008).

Conclusion: The results of this study indicate that picture naming, list learning, list recall and list recognition were the subtests which could successfully identify participants in the healthy control group versus those in the MCI group. Clinically, it can be difficult to objectively measure, as a SLT, subtle changes in someone's cognitive linguistic profile, however this study has the potential to facilitate this type of assessment. Linguistic measures alongside acoustic, prosodic and voice measures could increase the predictive value of these types of screening tools in the future and this study is the first step in this type of research.

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List of Abbreviations

ABCD	Arizona Battery for Communication Disorders of Dementia
ACE	Addenbrooke's Cognitive Examination
AD	Alzheimer's Disease
AI	Artificial Intelligence
AMPS	Assessment of Motor and Processing Skills
ANP	Advanced Nurse Practitioner
APA	American Psychiatric Association
ARHC	Age-Related Healthcare
ASHA	American Speech-Language Hearing Association
BDAE	Boston Diagnostic Aphasia Examination
CAT	Comprehensive Aphasia Test
CBI-R	Cambridge Behavioural Inventory-Revised
CDR	Clinical Dementia Rating
CIU	Correct Information Unit
CLQT	Cognitive Linguistic Quick Test
CS	Clinical Specialist
CSF	Cerebrospinal Fluid
DMT	Disease Modifying Treatment
DPIA	Data Protection Impact Assessment
DSM-5	Diagnostic and Statistical Manual of Mental Disorders
FAB	Frontal Assessment Battery
FDG-PET	Fluorodeoxyglucose-positron emission tomography
GDPR	General Data Protection Regulation
HADS	Hospital Anxiety and Depression Scale
HC	Healthy Control
HSCP	Health and Social Care Professions
IASLT	Irish Association of Speech and Language Therapists
MASS	Memory Assessment and Support Service
MCI	Mild Cognitive Impairment

MDT	MultidisciplinaryTeam
NDO	National Dementia Office
MMSE	Mini-Mental State Examination
MoCA	Montreal Cognitive Assessment
MRI	Magnetic Resonance Imaging
NIA	National Institute on Aging
NICE	National Institute for Health and Care Excellence
PIL	Participant Information Leaflet
QAB	Quick Aphasia Battery
RBANS	Repeatable Battery for Assessment of Neuropsychological Status
RCSLT	Royal College of Speech and Language Therapists
RSMC	Regional Specialist Memory Clinic
SLT	Speech and Language Therapist
TUH	Tallaght University Hospital
WHO	World Health Organisation
WTE	Whole Time Equivalent

Chapter 1: Introduction

1.1 Background

Changes in language often precede other notable cognitive changes in people who go on to develop dementia, however, given their subtlety, these early-stage communication signs are frequently missed. This study aims to identify the value of commonly used cognitive linguistic assessment tasks in identifying those with mild cognitive impairment (MCI) compared with a healthy control group and assess if a quick, informal cognitive linguistic assessment completed in digital form, similar to ones that are used regularly by Speech and Language Therapists (SLTs) could be more targeted and sensitive in identifying those at risk for cognitive impairment.

This research is one component of a larger study which examines the acoustic, prosodic and other linguistic features that distinguish between these groups through voice and speech analysis using artificial intelligence (AI). The researcher therefore wished to first examine the cognitive linguistic tasks that are used regularly in clinical practice by SLTs and examine the differences between these tasks in a group of healthy controls (HC) and a group of participants with MCI.

The researcher is a Clinical Specialist (CS) SLT working within a Regional Specialist Memory Clinic (RSMC) with ten years' experience working in an older persons' service, most of those years in the memory clinic. The researcher identified a gap in identifying language deficits that distinguish between HCs and people with MCI. This assessment of language deficits in the population presenting with MCI can be difficult to identify using standard

scores from formal assessments. This type of assessment tends to be more suitable for those who have a known cognitive impairment where the difficulties are more easily identified such as the Arizona Battery for Communication Disorders of Dementia (ABCD) (Bayles and Tomoeda, 1993) and the Cognitive Linguistic Quick Test (CLQT) (Helm-Estabrooks, 2001). The researcher has relied on informal assessments/ tasks and a combination of formal subtests used traditionally with other clinical populations. The assessments chosen are based on the researcher's clinical experience of language and cognition and knowledge of neurodegenerative conditions. While it is common for research in this area to focus on people with dementia, it is much rarer to include those at MCI stage (Filiou et al., 2019).

1.2 Study Rationale

Language impairments are well documented in people with dementia (Bourgeois & Hickey, 2011), however, identifying more subtle language changes in the early stages can be challenging. SLTs have a well-established role in dementia care (RCSLT, 2014; ASHA, 2016; IASLT 2016). It is now widely accepted that specific analysis of a language disorder can help to identify the presence and type of dementia and can often facilitate timely diagnosis (IASLT, 2016). SLTs regularly use informal cognitive linguistic assessments regularly in clinical practice to aid this diagnosis due to the lack of formal standardised assessments in the area (Dooley & Walshe, 2020), particularly with people MCI. Worldwide, clinicians working in memory assessment rely on communication assessments from the stroke field (Volkmer, 2016; Dooley & Walshe 2020) as these are widely available and have increased sensitivity in identifying subtle language impairment compared with lengthy cognitive communication batteries. This type of battery is often

used when a diagnosis of dementia is already in place, however, they are not developed or standardised with this population in mind.

Despite the consolidation of SLTs role working with people with dementia, SLTs worldwide have demonstrated a limited knowledge and lack of training in the area of cognitive communication difficulties (Dooley & Walshe, 2020; Saccasan & Scerri, 2020; Lanzi, Saylor and Cohen, 2022). This results in a lack of SLTs leading research in the area. In an Irish survey of SLTs across different grades and services working with people with dementia by Dooley & Walshe (2020), only 14% of the SLTs surveyed had completed any dementia-related research, this encompassed both the areas of dysphagia and communication. This reflects what is seen worldwide. In an American survey of 157 SLTs working with people dementia (Lanzi, Saylor and Cohen, 2022), one of the key recommendations from the survey was a need for more SLTs to engage in dementia-related research, including on the effectiveness of services and practices provided by SLTs.

Use of technology and advances in voice recognition, speech analysis and AI have resulted in widespread research interest in using these systems to benefit healthcare (Mueller et al., 2021; Martinez-Nicolas et al., 2021; Yamada et al., 2021). These systems assess for minute changes in a person's speech and language output and uses this to facilitate detection of cognitive impairment. This type of research could result in people self-monitoring and screening their own cognitive performance longitudinally using speech samples in the home on their own smartphone or tablet. This will only be achieved by ongoing research in examining the relevant speech/language/voice characteristics or

features that are specific and sensitive enough to use and to formulate quick, sensitive screening tools.

Speech and language features such as verbal fluency scores, analysis of speech rate, rate of dysfluencies in speech have been widely cited as highly sensitive markers for early detection of cognitive impairment (Filiou et al., 2019; Thomas et al., 2020; Martinez-Nicholas et al., 2021; Robin et al., 2021; Sanborn et al., 2022). This research examining which cognitive linguistic features that may identify MCI participants from participants in the HC group from an SLT perspective will contribute to a larger landscape of research in this area; be a stepping-stone for SLTs being at the forefront of this type of research; and will have practical benefits to SLTs internationally.

1.3 Conclusion

This chapter introduces the study topic and clarifies the rationale behind the researcher's choice of research topic. The next chapter will examine the literature in the area.

Chapter 2: Literature Review

2.1 Introduction

This chapter explores the current context of dementia care in Ireland the role of SLT within memory assessment services. It also critically reviews the current literature on utilising speech and language features as predictors for cognitive impairment and the use of digital solutions for assessment in this area.

2.2 Dementia

Dementia is a clinical syndrome characterised by a progressive loss of cognitive ability, ultimately resulting in loss of functional independence. Dementia, depending on the cause, can affect memory, thinking, orientation, comprehension, calculation, learning capacity, language, and judgement (WHO, 2017). It impairs a person's ability to carry out daily activities (National Institute for Health and Care Excellence [NICE], 2018). The DSM-V Dementia Diagnostic Criteria (Major Neurocognitive Disorder) (American Psychiatric Association [APA], 2013) include the following:

- Evidence from the history and a clinical assessment that indicate significant cognitive impairment in at least one of the following cognitive domains: learning and memory, language, complex attention, perceptual-motor function and social cognition. The impairment must be acquired and represent a significant decline from a previous level of functioning.
- In the case of neuro degenerative dementia such as Alzheimer's disease, the disturbances are of insidious onset and are progressive, based on evidence from the history or serial mental status examinations.

- The disturbances do not occur exclusively during the course of delirium.

Dementia is considered a global health priority and is a major financial cost for governments, communities, and individuals worldwide (WHO, 2017). Age is the main risk factor for dementia. As the population ages, the number of those living with dementia also increases and there are approximately 64,000 people currently living with dementia in Ireland, with 7752 new diagnoses yearly (HSE, 2020). With the current trends, there will be approximately 150,000 people living with dementia in Ireland by 2045 (HSE, 2020) making it a significant priority for all healthcare providers.

2.3 Current Context of Dementia Care in Ireland

SLTs have gained recognition for their valued role in dementia care (RCSLT, 2014; IASLT, 2016). It is recommended that SLTs are involved at all stages of the person's journey and that people should have access to pre- and post-diagnostic care (IASLT, 2016) however the majority of roles focus on post diagnostic input. Gibb & Begley (2019) examined memory clinics nationwide and only five out of twenty five clinics had access to SLT. However, with the introduction of the Model of Dementia Care in Ireland (National Dementia Office [NDO], 2023), there will be a shift to improved multidisciplinary team (MDT) input in dementia care.

The Model of Dementia Care in Ireland (NDO, 2023) outlines care pathways within the Irish health and social care system for people living with dementia. It sets out a range of many different targets and practice recommendations for dementia care in Ireland. There are recommendations for care at each stage on a patient's journey and specific advice around identification of signs/symptoms; assessment; diagnosis; disclosure; care planning

and post diagnostic support. The model presents the dementia diagnostic model for use in Ireland which has three levels of assessment. Level 1 involves assessment in primary care, Level 2 involves assessment in a Memory Assessment and Support Service and Level 3 involves assessment in a Regional Specialist Memory Clinic (RSMC).

The model is the first national guidance on the recommended SLT staffing requirements in a memory service and gives specific details for levels 2 and 3. The target is 0.5 Senior or Clinical Specialist (CS) SLT whole time equivalent (WTE) for a Level 2 service and 1.0 CS WTE for a Level 3 service. To combat the geographical inequities seen in memory services over the last decade (Begley & Gibb, 2019), there is a target for these clinics to be developed nationwide. These new posts mean SLTs will be at the forefront of dementia assessment and will therefore need to be equipped with the knowledge and tools to do so. SLTs will need the skills in identifying cognitive decline at an early stage.

Speech and language impairment in Alzheimer's disease (AD) dementia has been well documented and researched but is less widely researched in people with MCI and despite well documented speech and language changes in AD, there is no universally accepted system to describe this language impairment (Yeong et al., 2021). AD is the main cause of dementia, however this study doesn't focus solely on amnestic MCI which is the type of MCI usually associated with progression to AD. The research discussed does centre around AD given the concrete pathophysiology associated with AD. This results in well-defined phenotypes that can be researched widely. The National Institute on Aging (NIA) diagnostic guidelines describe AD in three stages – preclinical, MCI and Alzheimer's dementia (McKhann et al., 2011).

2.4 MCI

MCI (or prodromal dementia) is described as a modest cognitive decline in one or more cognitive domain, not sufficient to affect independence (DSM-V; APA, 2013). It is often a transitional period where impact on daily life can be minimal and this lack of impact on function in daily life is what distinguishes it from dementia (Stephan et al, 2015). Many people with MCI can revert to normal cognition or remain stable when observed over time (NDO, 2023). MCI can be subclassified as amnestic MCI or non-amnestic MCI (NDO, 2023). Amnestic MCI predominantly causes difficulties with memory and learning, whereas non-amnestic MCI encompasses difficulties in domains of complex attention, executive ability, language, perception or social cognition (DSM-V; APA, 2013), or a combination of these. Identification of MCI is of huge importance. It is associated with a higher risk of developing dementia in the future (NDO, 2023). The DSM- V criteria for MCI (APA, 2013) includes the following:

- There is evidence of modest cognitive decline from a previous level of performance in one or more of the domains, the cognitive deficits are insufficient to interfere with independence.
- The disturbances are of insidious onset and are progressive, based on evidence from the history or serial mental status examinations.
- The deficits are not attributable to a delirium or another mental disorder.

It is within the SLT's scope of practice to improve diagnostic accuracy by detecting subtle changes in cognition (Lanzi et al., 2021). However, as Lanzi et al. (2021) described in their survey on improving SLT practices for MCI and early stage AD dementia in America, there was reduced overall knowledge of MCI. MCI subtype knowledge and consideration was

examined in the survey and on a scale of 1-5 where 1 was “not much at all” and 5 was “a lot”, 87% of respondents reported their knowledge was 3 or less. This survey also highlighted that SLTs wanted more sensitive and effective measures for assessment in MCI.

Filiou et al. (2019) discuss how relatively few studies included participants with MCI compared with dementia due to AD in their scoping review of connected speech assessment in the early detection of AD and mild cognitive impairment. This review highlights how few studies characterise subtypes of MCI in their studies. This scoping review also supports involving SLT as a crucial team member in the evaluation of persons with cognitive impairment and dementia and highlights how important it is for SLTs to pursue research in this area to enhance protocols such as connected speech analysis. Knowing what is highly sensitive and specific for identifying cognitive linguistic deficits in MCI versus healthy older adults will facilitate and contribute to the growing evidence on what is needed to identify those at the preclinical AD stage.

2.5 Preclinical AD

It is now widely known that the preclinical phase of AD lasts many years where there is no visible evidence of cognitive impairment or impact on daily functioning (McKhann et al., 2011; Whelan et al., 2022). Currently, detecting this preclinical phase is done by measuring levels of amyloid beta protein in cerebrospinal fluid (CSF) taken via lumber puncture and assessing for abnormal levels of amyloid beta protein in clinically healthy individuals, this abnormal level is indicative of an AD pathological process (Ohman et al., 2021). This preclinical phase offers a window of opportunity for preventing decline and so

there is a need to design sensitive screening tools that can monitor for cognitive changes in this time (Ohman et al., 2021). In a time where disease modifying treatments (DMTs) and interventions which target the pathogenic pathway of AD may become widely available and can delay the onset and progression (NDO, 2023), healthcare facilities will need screening tools to identify those early on in the disease process (Whelan et al., 2022). It is imperative that clinicians across disciplines can facilitate timely diagnosis and can identify those at the preclinical and MCI stages to ensure the person can begin this journey as early as possible.

2.6 Linguistic and Speech Markers as Biomarkers of Cognition

Current practices for identifying changes in a person's cognition are usually a result of self-reports/family reports, where symptoms have already manifested (Whelan et al., 2022). There is now a need to detect people with AD in earlier clinical stages and the current practices of self-report/family report this will not be sufficient as there will be no subjective changes in cognition (Whelan et al., 2022). Assessment of cognition includes lengthy neuropsychological testing and expensive, often inaccessible diagnostic tests such as CSF biomarkers/MRI-Brain/FDG-PET (Thomas et al., 2020). There is a significant need to develop fast, affordable, easily accessed and available diagnostic screening tools (Thomas et al., 2020). Early detection of cognitive deficits facilitates a person to access post diagnostic support, psychosocial support and decision making for future health/financial/personal plans (Filiou et al., 2019).

One of the most researched scalable methods for detecting cognitive changes is using speech and language analysis as a passive assessment of cognition (Whelan et al., 2022)

or using speech and language as a “digital biomarker” for identifying cognitive impairment. A biomarker measures normal biological processes, pathogenic processes or responses to an exposure or intervention; when this biomarker is collected using a digital sensing product it is then called a digital biomarker (Troger et al., 2022). Speech and language patterns have been researched more recently as novel biomarkers for identifying cognitive change (Robin et al., 2020; Thomas et al., 2020; Bastardo et al., 2022; Troger et al., 2022; Whelan et al.,2022). Linguistic, acoustic and prosodic features have all been identified as proxy measures for cognitive performance (Thomas et al., 2020).

Automatic speech and voice analysis is one of the most widely researched tools in to detect cognitive impairment in the last decade (Martinez-Nicolas et al., 2021), usually extracting speech features and examining features such as speech rate and rhythm from spontaneous speech samples or picture description tasks. Martinez-Nicolas et al. (2021) conducted a recent systematic review that examined literature on automatic speech analysis for diagnosis of MCI or AD. The study describes the advances that have taken place and the overall trends in practice since Hoffmann et al. (2010) first analysed the voice parameters of spontaneous speech samples in persons with AD dementia and a healthy control group (Martinez-Nicolas et al., 2021). These advances include the development of biomarkers for AD diagnosis resulting in improved diagnostic accuracy and aiding in more defined speech and voice parameters in these cohorts; use of these speech analysis methods in clinical practice and not solely in research centres; and use of an increased number of different speech and voice parameters together to predict cognitive impairment.

Following on from this, Konig et al. (2015) was the first published research examining voice characteristics of an MCI group versus healthy controls. They used machine learning methods to successfully distinguish between MCIs and healthy controls; and AD dementia and MCI/healthy controls. This type of automated speech analysis has significant potential for use as a screening tool in identifying cognitive impairment and studies similar to Konig et al. (2015) have been published widely to the present day. Ostrand & Gunstad, (2021) examined spontaneous speech samples using automated analysis of speech production to predict current and future cognitive performance in a group of older adults and older adults with MCI. Robin et al. (2021) used a tablet administered picture description task and analysed this using automated speech analysis of the linguistic features which were able to distinguish between healthy controls and an MCI group. Sanborn et al. (2022) researched the potential for assessment of spontaneous speech samples in detecting MCI using automated speech production. In a study by Calza et al. (2021) spontaneous speech tasks were used to detect MCI and dementia using automatic extraction of different linguistic features (acoustic, rhythmic, lexical, syntactic, readability). Furthermore Eyigoz et al. (2020) examined the extent to which linguistic markers derived from written responses to the Cookie Theft Picture (Goodglass, Kaplan & Barresi, 2001) could predict AD in healthy older adults using automated linguistic analysis. This study showed that exposing subtle language changes in a written task could predict future cognitive decline.

In a review by Mueller et al. (2018) picture description samples were successful in identifying differences in speech, voice and linguistic measures in people with AD versus healthy older adults. Members of the same research group (Mueller et al., 2021) further contributed to this conversation by examining the associations between amyloid beta

levels and connected speech in adults without cognitive impairment. This study indicated a decrease in content words versus function words in those with abnormal amyloid beta in a connected speech sample, indicating that language differences from a picture description task can be detected in this prodromal group and may potentially be a screening tool for this population.

However, Wisler et al. (2020) found that acoustic and lexical characteristics of spontaneous speech were not sensitive enough to predict Montreal Cognitive Assessment (MoCA) scores. The MoCA is a brief, validated cognitive screening tool (Nassredine et al., 2005). In the Wisler et al. (2020) study, there were 521 older persons, a mix of healthy older adults and those with MCI. The study determined that reduced speech rate and word variation can predict a level of cognitive performance on a more broad level, so it can distinguish HCs (usually above 26 on a MoCA) from an MCI group (usually below 26 on a MoCA), but it is more challenging to specify specific MoCA scores outside of those general ranges.

It is now believed that single picture description/ spontaneous speech tasks are not sensitive enough to predict cognitive impairment alone and that validation against strong cognitive markers are missing from recent research in the area (Troger et al., 2022). Significant work has been completed over the last decade in developing AI algorithms to identify cognitive impairment. However, lack of standardisation has prevented the use of these algorithms for clinical practice/trials (Troger et al., 2022). The Digital Medicine (DiME) Society developed the V3 framework for evaluating digital assessments as fit for purpose in clinical trials to combat this problem. Troger et al. (2022) used this framework

in their validation study of their automated ki:e speech biomarker for cognition. This biomarker analyses speech recordings from two neuropsychological assessments and extracts more than 50 speech features that compose a composite cognitive score. This algorithm significantly differentiated between the clinical groups of MCI and dementia and was strongly correlated with the Clinical Dementia Rating (CDR) (Berg, 1984)and Mini Mental State Examination (MMSE; Folstein et al., 1975) (Troger et al., 2022).

McCullough, Bayles and Bouldin (2018) believe only standardised formal testing instead of quick screening tools should be used to identify those at risk of MCI. The Arizona Battery for Communication Disorders of Dementia (ABCD) (Bayles and Tomoeda, 1993), a standard cognitive communication assessment used by SLTs could identify MCI in 74.6% in their study sample. However, the population in the study were only included if they had concerns over their own cognition and so the assessment was successful in identifying MCI in people who were describing changes in their cognition and hadn't yet attended memory assessment. A limitation of using assessments such as the ABCD is the time taken to complete them. The ABCD can take up to ninety minutes to administer.

Yamada et al. (2021) predicted that more than one behavioural marker would be more sensitive in identifying MCI and AD rather than using speech alone. In this study gait, speech and drawing tasks were used to increase accuracy in identifying MCI and AD versus HCs. There was 93% accuracy for identifying HCs, MCI and AD versus 81.9% when using the highest individual modality alone in a sample of 118 people. This research argues that using combined modalities in identifying cognitive impairment is far superior than using one alone (Yamada et al., 2021).

A recent scoping review by Filiou et al. (2019) revealed that speech production, fluency and semantic outcome measures from connected speech are the most significant measures for differentiating between MCI and healthy control groups. This review examines studies which intended to automate data from connected speech samples to provide a linguistic and speech biomarker for cognition. Some of the same limitations discussed by Filiou et al. (2019) in this scoping review were also highlighted in a study by Thomas et al. (2020). They discuss how they attempted to overcome some of these issues in their most recent study. Thomas et al. (2020) used feature extraction and statistical analysis of voice recordings from the Framingham Heart Study Cognitive Aging Cohort, to identify how linguistic and acoustic features correlate with cognition and neuropsychological measures. They overcome some of the shortcomings highlighted by Filiou et al. (2019) including small sample sizes; non-specific labelling of MCI; limited assessment measures; and only including subjects already diagnosed with dementia (Thomas et al., 2020). In Thomas' study they included a large sample size of 135 participants with 170 audio recordings. They included groups of healthy controls, people with MCI and people with mild/moderate/severe dementia. They used many different assessment measures other than picture description tasks such as audio recordings from verbal fluency tasks and digit span tasks. These features were correlated with different assessments including the Boston Naming Test (Kaplan, Goodglass & Weintrab, 1983), verbal fluency measures and digit span measures. The results revealed several linguistic and acoustic biomarkers that show correlations with different levels of cognitive impairment.

While the majority of these types of studies focus on speech and expressive language, Sung et al. (2020) also examined sentence comprehension as a predictor of MCI from normal aging. The study found that people with MCI experienced increased difficulties in processing syntactically complex sentences, particularly with a passive sentence structure. The research proposed the use of sentence comprehension tasks in early diagnostic processes.

Yeung et al. (2021) also presented how there have been no studies which had examined correlations between clinician rated speech characteristics and linguistic and acoustic variables that are extracted through automated speech analysis and natural language processing. Their study provided evidence that automatic speech analysis and natural language processing can detect objective changes in speech and language in people with MCI and AD. This was directly correlated with clinician's assessment. Agreement was high in rating word finding difficulty and incoherence and perseveration. Word finding difficulty and incoherence were able to distinguish MCI and AD groups from HCs using a picture description task.

2.7 Benefits and Challenges to Digital Assessment

Digital assessment solutions have been widely proposed to facilitate early detection of cognitive impairment. Innovative solutions have been suggested both for reimagining current assessments in digital form and also newly developed solutions that can be used as cognitive screening tools (Bastardo et al., 2022). Ohman et al. (2021) discuss many of the benefits and challenges in utilising digital assessments to detect cognitive changes or to longitudinally monitor cognitive impairment in their review article examining the

advances in this area for preclinical AD. Usually, these assessments can be accessed on a smartphone or tablet, completed from home and repeated at different intervals, which would significantly improve the accessibility of cognitive screening. The current process involves clinic visits, extensive neuropsychological testing or invasive procedures (Robin et al., 2021). Using speech as a modality for digital assessment of cognition requires very little instruction and is quite straightforward given most smartphones and tablets have high quality microphones (Robin et al., 2021). More frequent assessments would lead to reliable longitudinal personalised data, be more accessible and cost-effective, while self-administration would have a huge impact on waiting lists for memory services. AI models can usually change targets and tasks easily and on a regular basis which would minimise version effects. Pen and paper testing often lacks the sensitivity of subtle cognitive change and digital assessment would allow more sensitive analysis of cognitive data (Ohman et al., 2021) Increased ecological validity has also been cited as a huge benefit as the pressure/confinements of clinic rooms and examiners may affect the participant's overall performance (Ohman et al., 2021). An unexpected benefit acknowledged after the Covid-19 pandemic is that a wider ranging population are now very familiar with virtual and remote testing via technology (Konig et al., 2021).

Ohman et al. (2021) describe many of the challenges involved in digital assessment. If the assessment is facilitated remotely it can be quite difficult to maintain participant engagement. There are also some concerns regarding data privacy issues. Data breaches put the participant at risk of personal data being leaked. The examiner also cannot ensure it is the person themselves doing assessment. There is a concern that family members/carers may try encourage/help the person in their assessment resulting in

reduced validity of the assessment. Another challenge to these developments are that certain cohorts may be excluded from this digital assessment trend if they are not tech savvy. Versions can be updated frequently making it difficult to validate digital tests and these digital assessments are not currently widely validated with biomarkers of AD pathology or established cognitive composites (Ohman et al., 2021). Existing literature emphasises the potential for these types of novel instruments but warns that further research is needed to establish significant associations between biomarkers and assessment results to ensure they are sensitive enough to detect early AD pathology. Feasibility studies are recommended worldwide to establish any further potential barriers in this area and to further consolidate the current research (Ohman et al., 2021).

2.8 Research Benefits

In Ireland, individuals with dementia represent the fastest growing clinical population served by SLTs, influenced particularly by greater lifespan (IASLT, 2016). There is an increasing awareness of our role as SLTs working with individuals with cognitive impairment. Use of speech, linguistic and voice characteristics as “digital biomarkers” for identifying cognitive change in this prodromal phase have begun to be widely researched (Thomas et al., 2020; Yamada et al., 2021; Whelan et al., 2022), however it is rare SLT that are involved in this research and it is rare that tasks other than picture description alone are used.

It is rare that SLTs use digital forms of assessment in clinical practice currently, however to utilise the innovative solutions that are to become widely available in the near future,

it is something that will need to be considered strongly as a regular form of practice. This study will utilise this means of assessment.

The Irish Association of Speech and Language Therapists (IASLT) have been advocating for specialist roles in dementia care for many years and identified creation of these roles as a key recommendation for change in their position statement on "Speech and Language Therapy for People with Dementia" (2016). With the creation of a small number of these posts in memory clinics around the country in 2022, there is a responsibility to be an integral team member in identifying gaps in the knowledge base and carrying out research in the area (IASLT, 2016). The researcher aims to contribute to the evidence base of developing sensitive screening tools for identifying cognitive impairment using speech and language features but from a clinical perspective that will also facilitate SLTs working in memory clinics nationwide. This study will ensure that SLTs are at the forefront of leading this type of research in Ireland. The current study will contribute towards the growing research in the area by identifying and developing a quick, sensitive screening tool that can detect cognitive impairment and can facilitate remote longitudinal monitoring of cognition using AI.

2.9 Research Aim, Questions and Objectives

Aim:

This research aims to identify if certain cognitive linguistic tasks can differentiate between people with MCI versus healthy older adults.

Research questions:

- Can selected cognitive linguistic subtests discriminate between HC and MCI groups?
- What are the differences in language scores between healthy controls and MCI using a devised informal cognitive linguistic assessment?

Objectives:

- To examine whether MCI and healthy control groups have statistically significantly different scores on the following subtests: picture description, picture naming, repetition, verbal fluency, reading, list learning, list recall, list recognition, digit span forward and backward.

2.10 Conclusion

This chapter has explored the relevant background literature on using speech and language samples and analysis in identifying cognitive impairment. The next chapter will focus on the methodology used to achieve the research aim, questions and objectives.

Chapter 3: Methodology

3.1 Introduction

This chapter discusses the research methodology utilised in this study to address the research question and aims. This includes a detailed description of study design, procedure, participants, ethical considerations, methods and materials and data analysis.

3.2 Study Design

This study seeks to identify if certain cognitive linguistic tasks are effective at distinguishing between people with mild cognitive impairment (MCI) versus healthy older adults. The study design is a quantitative, prospective, cross sectional, observational design. The researcher chose a quantitative methodology design as this was the most suited to answer the research question. Quantitative research involves research where the data is in the form of numbers, it also tends to seek out the facts in a controlled way while the researcher is removed from the data and takes an "outsider" perspective (Blaxter, Hughes and Tight, 2010). A retrospective approach was rejected because the researcher wanted to control the variables that were used in the study and a retrospective approach would not have allowed for this. More specifically, an observational cross-sectional approach was taken, because it is one where the researcher observes and records events but does not alter the events in any way (Stommell & Wills, 2004). It gives the opportunity to take a snapshot of the population and gather information at a certain point in time (Laake, Benestad and Olsen, 2015). Qualitative research involves collecting data in many forms but mainly non-numeric. (Blaxter, Hughes and Tight, 2010). It tends to examine data in great detail and can often focus on smaller numbers (Blaxter, Hughes and Tight, 2010). A qualitative approach was rejected as the researcher did not want to

examine attitudes or ideas to cognitive linguistic assessment but rather wanted to examine the differences in specific cognitive linguistic across two groups and so a quantitative design was most appropriate in investigating this question.

3.3 Ethical Approval

Ethical approval for this research was obtained from the St James' Hospital / Tallaght University Hospital (TUH) Joint Research Ethics Committee on 13.04.2021 (Appendix A) and an amendment form was completed and approved on the 16.05.22. This was to extend the study duration due to delays owing to the Covid-19 pandemic, and to add a co-investigator (Appendix B). A Data Protection Impact Assessment (DPIA) was advised by the Ethics Committee due to the processing of audio recordings from participants and use of a new app. This was approved on 31.01.22 (Appendix C). Four fundamental ethical principles were considered during this research, as suggested by Beauchamp & Childress (2013): autonomy; nonmaleficence; beneficence and justice. These principles and how they were taken into consideration during the study are detailed below.

3.3.1 Autonomy

Autonomy refers to the rights of all people to make their own decisions (Varkey, 2021). This principle was maintained during the study by ensuring the researcher fully disclosed all elements of the study including purpose, procedures and duration of the assessment to the participant, this detailed information was included in the Participant Information Leaflet (PIL) (Appendix D). The PIL also included information on the participant's rights and how to withdraw. The participants were advised that they could withdraw at any time from the study without impacting their care in TUH in any way. Any further queries or

concerns were discussed with the researcher on the day of the assessment. Participants were also provided with contact details for: the researcher, the research manager and Data Protection Officer (DPO) should they have any further concerns. Informed consent was acquired from all participants prior to commencing the study using a written consent form (Appendix E). This provided the legal basis for processing participants' personal data as per General Data Protection Regulation (GDPR).

3.3.2 Beneficence

This principle refers to actions aimed at benefiting others and preventing harm (Timko, 2001; Beauchamp, 2019). It is believed that this research will add to the existing and growing research in the area of early identification of cognitive impairment by non-invasive means.

3.3.3 Non-Maleficence

Non-maleficence is the obligation not to cause harm (Varkey, 2021). This principle was respected throughout this study by ensuring confidentiality and anonymity. All participants were given an identifier from the beginning of the study and no identifying information was collected throughout. All participants were facilitated for the appointment time and date that suited them best, to reduce any burden associated with attending.

3.3.4 Justice

Justice encourages equality in treatment and the equal distribution of access and benefits associated with the research to all individuals (Lavrakas, 2008). This principle was

maintained throughout the research process by ensuring that the participants' rights were always prioritised and considered, including the right to withdraw from the study without any consequences to their standard medical care which is stated clearly in the PIL. Participation in the study was voluntary and participants were treated equally throughout. All prospective participants were given equal access to the study.

3.4 Recruitment

This study used convenience sampling to recruit participants attending the Age-Related Health Care (ARHC) department in TUH. The gatekeeper for this study was the research manager within the ARHC department. Participants for the healthy control group were volunteers recruited through local advertising within TUH or family members of persons attending the ARHC department in TUH. Potential participants for the MCI group were identified by the gatekeeper through chart reviews at the weekly clinic or during the weekly consensus meeting. The consensus meeting is a weekly multidisciplinary discussion and diagnostic evaluation process of all persons attending the memory service. The gatekeeper then used the inclusion/exclusion criteria (Table 3.1 and 3.2) to check for eligibility to participate in the study. The gatekeeper contacted the potential participants either by phone or in-person if it was at a clinic visit and they were informed about the purpose of the study and given the PIL and invited to take part in the study. The PIL was posted to the participant if the initial contact was by phone from the gatekeeper. The researcher then contacted the person after a minimum of three days from receiving the PIL and if the person was interested in taking part in the study the researcher then arranged the initial appointment over the phone. The consent form was completed with

the participant on the day of their appointment. A letter was sent to participants' GP following participation (Appendix F).

Table 3.1 Inclusion criteria

Inclusion criteria	Rationale
Male/Female aged 50 years and above	This age was chosen as it was the accepted referral age to the RSMC
Be a member of either group: Healthy controls Has a diagnosis of MCI from TUH	All participants in the MCI group were given a diagnosis through TUH as per ethical approval
MMSE >19	Below a score of 19 a person is considered to have significant cognitive impairment and would likely find it quite challenging to engage in the study
Adequate literacy abilities	To ensure the participant was able to engage in all elements of the testing which includes a reading subtest and reading instructions throughout
Able to give informed consent	To ensure the participant is fully aware of all elements of the study and what to expect if they agree to take part
Own or have access to a smartphone	This point was part of the wider study where a longitudinal speech task needed to be accessed via their own phone

Table 3.2 Exclusion criteria

Exclusion criteria	Rationale
Evidence of clinically relevant or unstable psychiatric disorder based on DSM- V (APA, 2013) criteria (*major depression in remission was not considered exclusionary)*	A person presenting with a psychiatric disorder would present with a different cognitive linguistic profile which is not the target of this study
Presence of delirium	The results would not be a true reflection of a person's cognitive performance while they present with delirium

3.5. Participants

Participants included patients attending the Regional Specialist Memory Clinic (RSMC) in TUH with a diagnosis of MCI who met the inclusion criteria, and healthy controls with no documented cognitive difficulties. All participants had received a diagnosis of MCI through the TUH standard procedure of cognitive assessment. The diagnostic process includes Advanced Nurse Practitioner (ANP) assessment, Health and Social Care Professional's (HSCP) assessment, multidisciplinary consensus meeting, neuroimaging and medical review. The memory assessment procedure in TUH currently meets the "gold standard" for assessment of MCI internationally using DSM-5 (APA, 2013) criteria and National Institute on Ageing (NIA) criteria for AD (McKhann et al., 2011) for confirmed MCI due to AD diagnosis. Participants with MCI due to AD had positive Cerebrospinal Fluid (CSF) biomarkers, recommended by NIA criteria (McKhann et al., 2011) and NICE criteria for

diagnostics in AD (NICE, 2018). The recommended standard assessments of Clinical Dementia Rating (CDR) (Berg, 1984), Dementia Screening Interview (AD8) (Galvin, 2005), Cambridge Behavioural Inventory-Revised (CBI-R) (Wear et al., 2008), Mini Mental State Examination (MMSE) (Folstein et al., 1975), Addenbrooke's Cognitive Examination (ACE) III (Hsieh et al., 2013)/Repeatable Battery for Assessment of Neuropsychological Status (RBANS)(Randolph, 1998), Frontal Assessment Battery (FAB) (Dubois et al., 2000), 4AT delirium screen (Bellelli et al., 2014), Hospital Anxiety and Depression Scale (HADS) (Zigmond & Snaith, 1983) and / or Assessment of Motor and Processing Skills (AMPS) (Fisher, 1997) are all included in the work up for diagnosis. All participants had normal or corrected vision and hearing. This ensured participants could accurately engage with the assessments. There were audio elements requiring adequate hearing on the app and visual elements including picture naming and reading which required adequate vision and hearing. Sample size calculation using G* Power (Faul et al., 2007) indicated that a sample size of 26 participants in each group would be needed to detect a large effect size (d=0.8).

3.6 Procedures

The study tasks were administered by the researcher over a sixty to ninety minute session in a research room within the ARHC department in TUH. Information regarding the procedure was discussed with the participant at the beginning of the session. In-person written consent was obtained from all participants. Screening assessments were completed by traditional pen and paper assessment and the devised cognitive linguistic assessment was completed in digital form through an app on a tablet device.

3.7 Materials and Methods

This section discusses participant demographic information and assessment tasks used in this study.

3.7.1 Demographic information

Age, gender, years of education and duration of diagnosis in months were all collected at the beginning of the assessment (Table 3.3).

Table 3.3 Demographic details and rationale

Demographic	Rationale
Age	To include age-range results
Gender	To report number of participants per gender group
Education	Educational level is known to influence cognitive decline and has been suggested to be a protective factor in preventing cognitive decline and dementia (Kremen et al., 2022).
Duration of diagnosis	To examine any association between duration of diagnosis with cognitive linguistic scores

3.7.2 Cognitive Screen

Montreal Cognitive Assessment (MoCA) (Nasreddine et al., 2005) was used as a general cognitive screen. MoCA and MMSE (Folstein et al., 1975) were both considered, however the MoCA has been shown to be superior to the MMSE in both sensitivity and specificity (Damian et al., 2011). Discussions with expert ANP and medical colleagues contributed to

its inclusion, as this would be their preferred clinical tool. MMSE is often used as an initial screen by GPs or during initial cognitive testing, so use of the MoCA helped to eliminate any recall effects that might have occurred due to previous MMSE administration. Standard MoCA instructions and a paper-based format were used. Participants had to achieve a score of 19 or above on the MoCA to proceed with the rest of the assessment.

3.7.3 Receptive Language Screen

Sentence and paragraph level comprehension subtests of the Comprehensive Aphasia Test (CAT) (Swinburn, Porter and Howard, 2004) were used as a screen of receptive language skills. This assessment was used as it is the one most frequently used by the researcher clinically. This involves comprehension of a spoken sentence and choosing the matching picture from a choice of four. There are three distractor pictures in this sentence level subtest. The paragraph subtests involves retrieving meaning from extended speech by responding to yes and no questions. Though the spoken paragraph is lengthy compared to the sentences, it is much less linguistically complex and so many participants with dementia may find this subtest less complex than the sentence subtest as they can derive the overall context of the paragraph. Receptive language was screened to ensure ability to continue with the main cognitive linguistic assessment. The standard test instructions and scoring were used by the researcher. Spoken language comprehension only was used rather than spoken and written due to assessment burden for the participants and overall time taken for the assessments.

3.7.4 Cognitive Linguistic Assessment

This assessment was specifically designed for use in this research study, the app was developed with an industry partner Canary Speech Inc., Provo, Utah, USA. This app was developed with other members of the wider RSMC team and the researcher is involved in data collection with the wider team separate to this research study. The researcher identified subtests to be included and developed each subtest in conjunction with the app developers. The researcher chose the targets to be used within each subtest and all instructions were developed by the researcher based on the knowledge of regular instructions used in these type of assessments.

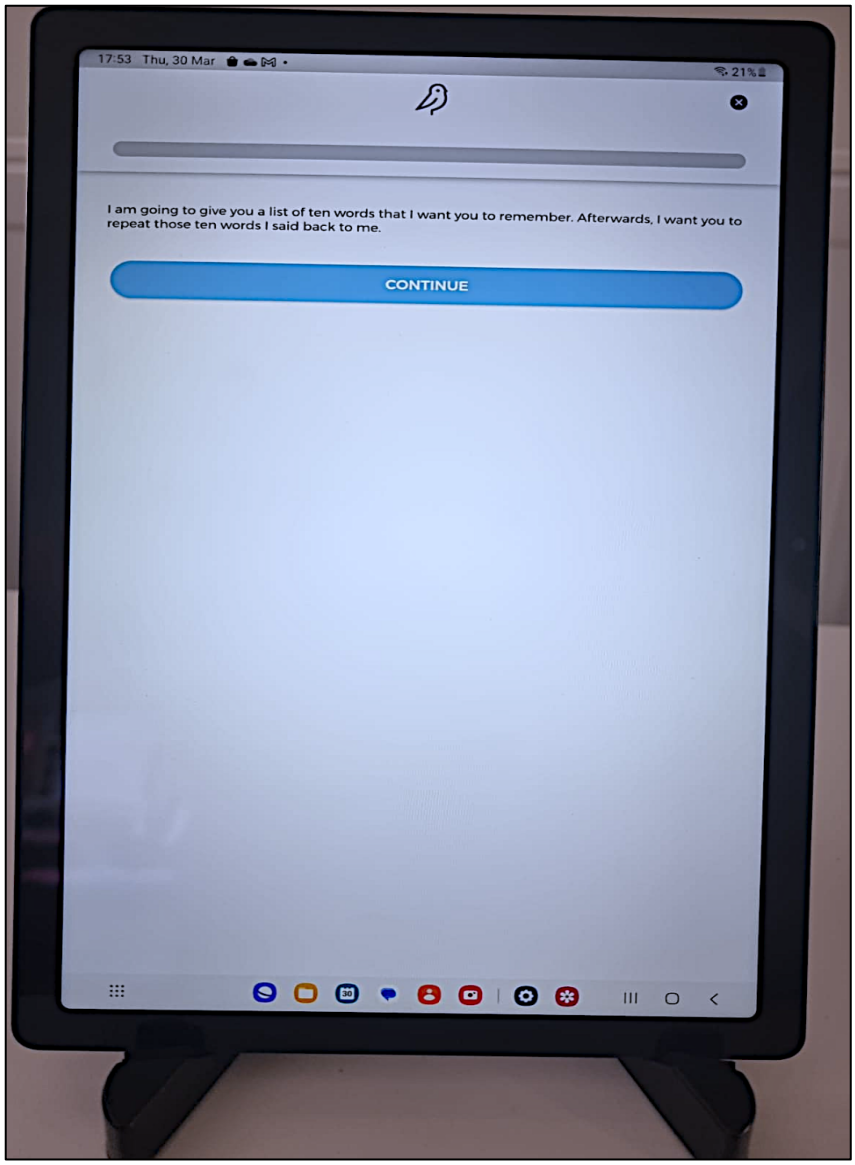
Participants performed the tasks with a tablet device, a Samsung Galaxy A8 tablet with a 10.5 inch screen. The following subtests were used in chronological order: list learning, digit span forward and backward, phonemic and semantic verbal fluency, picture naming, repetition, reading, list recall, list recognition and picture description using the Cookie Theft picture adapted from the Boston Diagnostic Aphasia Examination (BDAE) (Goodglass, Kaplan & Barresi, 2001). The chosen subtests represent the majority of cognitive domains usually assessed as part of a neuropsychological assessment . This includes attention, memory and language (Randolph, 1998; Hsieh et al., 2013), but visuospatial tasks were not included as they are not as easily completed by app. The specific targets and subtests chosen were based on the researcher's experience in using such assessments in regular clinic settings and based on commonly-used linguistic, neuropsychological and cognitive assessments such as the RBANS (Randolph, 1998), the Cognitive Linguistic Quick Test (CLQT) (Helm-Estabrooks, 2001) and the ACE III (Hsieh et al., 2013). Standard SLT assessment as part of the memory clinic diagnostic process involves assessment of naming, semantics, verbal fluency, auditory comprehension,

repetition, reading and a speech sample derived from a picture description. The subtests chosen for the app from an SLT perspective reflected this. Speech data was recorded using a Zoom recorder (core audio format, 44,100 Hz, 16-bit) and the tablet's internal microphone. Throughout the tasks, the researcher recorded participant's responses using a response sheet (Appendix G).

List learning, recall and recognition:

List recall is a widely used assessment in neuropsychological testing. It entails the person learning a list of words, then recalling those words after a time delay and then forced choice recognition of the words (Gavett, 2009). Participants were given the written instruction "I am going to give you a list of ten words that I want you to remember. Afterwards, I want you to repeat those ten words I said back to me"(Figure 3.1). The participants were then presented with ten words, one at a time. When all words are presented, they were asked to press the record button and recite from memory as many words as they could recall. This task was repeated four times. The researcher chose a mix of high and low frequency words and the task took the shape of the subtest that is presented widely in many neuropsychological and cognitive tests. One point was given for each correct word and the sum total of the four trials was the achieved score.

Figure 3.1 List learning instructions on app



After a delay (after the reading subtest) participants were presented with the written instruction “Can you remember the words that were shown to you at the beginning? Record as many of these words as you can remember now”. Participants then press the record button and relayed as many of the words remembered. One point for each correctly recalled word was given.

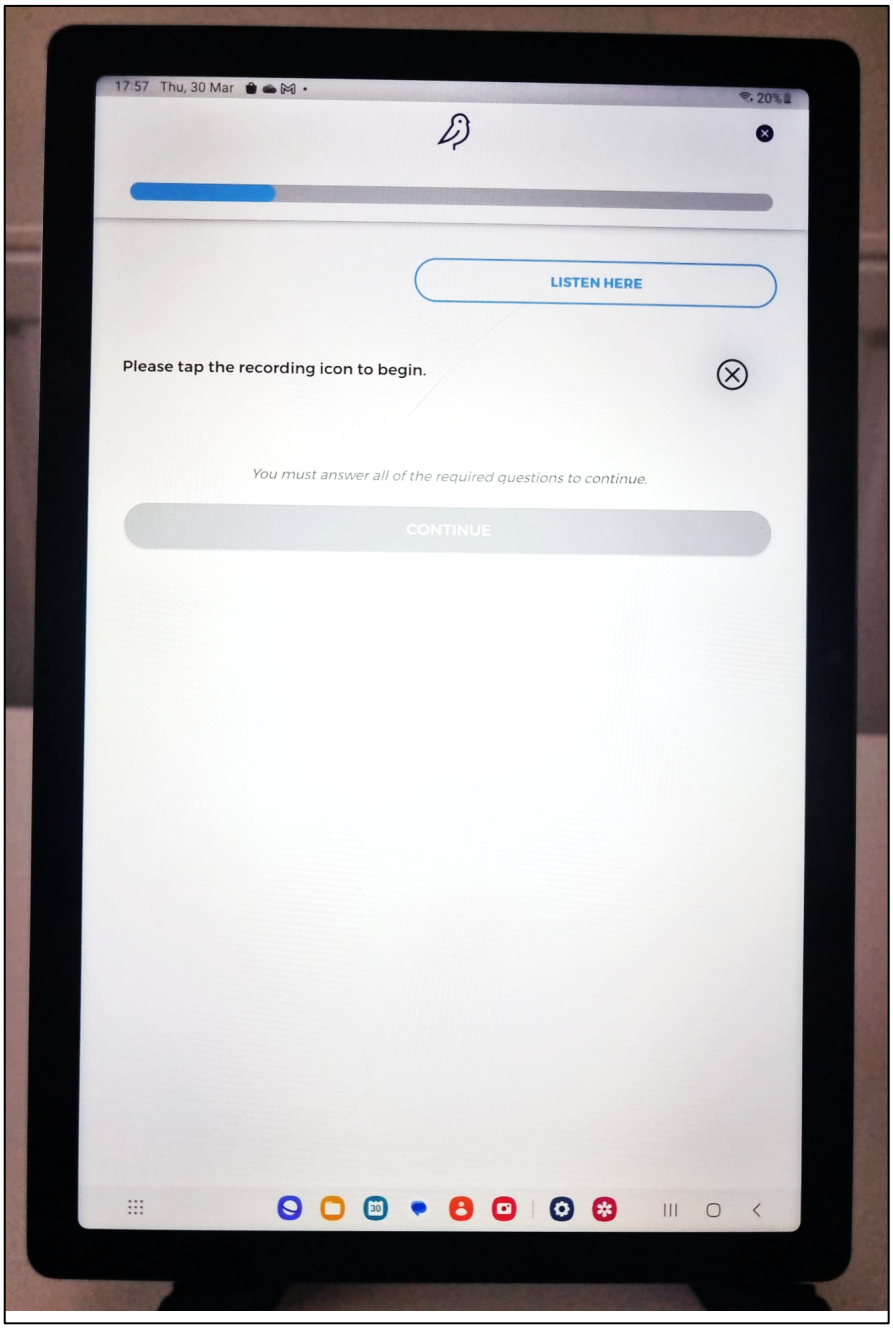
Participants were then presented with the written instruction “Below you will hear some words, some of which were on the list earlier and some that weren’t. Which of the words

were on the earlier list?" Participants press the "Listen Here" button to hear the word and then clicks either "Yes" or "No" to indicate if they recognise the word from the earlier list. One point for every Yes/No response was given.

Digit span forward and backward:

Digit span tests are some of the oldest and widely used screening tools for verbal short term memory deficits (Richardson, 2007). Participants were presented with the written instruction "You will hear some numbers. Afterward, repeat the numbers back in order/ in reverse order" for each of these tasks. Participants then press "Listen Here" (Figure 3.2) to hear an audio recording of each of the digit strings. They are presented one by one with increasing length at a rate of one digit per second and after each digit string the app automatically records the participant's response. The task begins with two numbers and increases to nine numbers. This task was discontinued after two consecutive incorrect responses. One point was scored for each string recalled correctly. No incomplete strings were accepted.

Figure 3.2 "Listen Here" button on app



Phonemic and semantic verbal fluency:

Verbal fluency assessments are commonly used in neuropsychological testing and have been considered an excellent adjunct to screen for MCI and dementia (McDonnell, 2020). Participants were presented with the written instruction "Name as many animals as you can in one minute" and "Name as many words beginning with the letter "s" as you can in

one minute, but not the names of people or places". Participants must then press the record button to begin and all responses are recorded. Once the time of one minute is reached the recording automatically stops. One point for each correctly produced target was given.

Picture naming:

Picture naming has long been used in cognitive testing due to the common lexical retrieval and semantic deficits that present in AD (Paplikar et al., 2022). Participants were presented with the written instruction "Name the following pictures". Specific low frequency targets were chosen from common language assessments including the Boston Naming Test (Kaplan, Goodglass & Weintrab, 1983) and the Quick Aphasia Battery (QAB) (Wilson et al., 2018). One point for every correctly produced name was given. Low frequency targets were chosen given the nature of the groups being assessed; participants in the HC and MCI group may find high frequency targets much less challenging.

Repetition:

This subtest requires the participant to repeat words and sentences that vary in frequency, length and imageability, the researcher devised the targets based on examples from the CAT (Swinburn, Porter and Howard, 2004), QAB (Wilson et al., 2018), Sydney Language Battery (Savage et al., 2013), the majority of the targets are low frequency and imageability. Participants were presented with the written instruction "Repeat the following words/sentences", the participant presses the button "Listen Here" for the target and then the response is automatically recorded once the target has been played.

One point for every correctly produced word/sentence was given, any partially repeated word or sentence was scored as incorrect.

Reading:

Participants were presented with the written instruction “Read each of the following words aloud”. Participant then press the record button to read each of the words out loud. The target words are specifically designed to identify surface dyslexia e.g. choir, yacht. One point for every correct word was given.

Picture description:

The Cookie Theft picture description task was used from the BDAE (Goodglass, Kaplan & Barresi, 2001). Picture description tasks have been widely used to capture language skills and deficits in a variety of populations (Berube et al., 2019) and most notably the Cookie Theft task. The picture was presented in landscape mode on the tablet. Participants were asked to “Tell me everything you see in the picture” and were given two minutes to describe the scene. Participants’ description was recorded using the app and the digital sound recorder and analysed by the researcher following the assessment.

Scoring:

All tasks except the picture description task were scored by the researcher at the time of the assessment. The picture description task was recorded and analysed by the researcher at a later time following the assessment to ensure accuracy of the analysis.

3.8 Validity and Reliability

Validity is described as “whether a test measures what it is intended to measure” (Howitt & Cramer, 2017). Reliability is referred to as the absence of any unsystematic, random measurement error and includes consistency of measurement across persons, locations, occasions, instruments (Stommel et al., 2004). Validity and reliability considerations throughout the study are discussed below.

3.8.1 Validity

Consideration for the validity of the assessment was ensured by planning the content and piloting the assessment which is discussed below. The researcher’s clinical knowledge and experience working in a memory clinic along with a review of the literature led to the inclusion of test content. The subtests chosen are very commonly used in cognitive linguistic assessment and have significant correlation with traditional neuropsychological/ cognitive/ linguistic measures and have been validated. The RSMC uses the DSM-5 criteria (APA, 2013) and NIA criteria (McKhann et al., 2011) for diagnosing MCI which ensures the accuracy of testing the subtests against this group.

3.8.2 Reliability

The same room was used for every participant. This room was separate to the busy clinical environment, ensuring no noise distractions. Participants were offered assessment times across the day. Some participants felt they had more energy/were more attentive in morning/afternoon and were facilitated for the times that suited. The researcher accounted for brightness/volume of the app before every participant by ensuring the volume and brightness were at the same consistent level across participants. The same

instructions were presented to each participant and this ensured consistency across participants.

3.9 Piloting of the Study

The original procedure was tested with three other SLTs, a nurse specialist in the area of memory assessment and a post-doctoral researcher with experience in the area. A log was held of all changes that were made throughout (Appendix H). Key changes that were made following piloting include introducing automatic recording of the participants' responses following the target on the repetition and digit string tasks. This ensured no spontaneous response was lost.

3.10 Data Analysis

All data was entered into an excel spreadsheet and checked for missing data/outliers by the researcher in preparation for statistical analysis. For the picture description task, the researcher analysed voice recordings and the number of Content Information Units (CIU) (Nicholas & Brookshire, 1993) were recorded and this number was used for statistical analysis. Descriptive and statistical analysis was completed on the data. Descriptive analysis included examining differences in age/gender/education/MoCA score across both groups. The data was displayed using tables and bar charts. For statistical analysis the data was entered into the IBM SPSS Statistics Version 27 software package. Non-parametric tests, specifically the Mann-Whitney U test, was completed to examine differences in cognitive linguistic scores across both groups as the data sets were not normally distributed.

3.11 Conclusion

This chapter discussed the research methodology used in this study, which included study design, procedure, participants, ethical considerations, methods and materials and data analysis. The procedure of data collection was discussed in detail. The results of the study will be discussed in the next chapter.

Chapter 4: Results

4.1 Introduction

This chapter reports the results of this research study which investigates the ability of cognitive linguistic tasks to detect cognitive impairment in a group with mild cognitive impairment (MCI) versus a healthy control (HC) group. It also investigated the distinct differences in speech and language characteristics between HCs and those with MCI using the same devised informal cognitive linguistic assessment. This chapter presents the results of the study, using both descriptive and inferential statistics. The data collected was analysed using IBM SPSS Statistics Package Version 27. The data presented was non-normal data and therefore the median was used as a measure of central tendency throughout and non-parametric statistical tests were used. Standard level of significance at the p <0.5 level was used throughout.

4.2 Participation rate

A total of n = 40 participants were recruited from the Regional Specialist Memory Clinic (RSMC) in Tallaght University Hospital (TUH). The recruitment period began in August 2022, and as this study is part of a larger research study, recruitment will continue until June 2023. The estimated sample size of 52 (26 in each group) was not achieved within the timeline of the author's MSc programme, but data collection will continue in order to produce more robust results for publication purposes. All the intended data was included, there were no missing values. There were no withdrawals of participants throughout the data collection period.

4.3 Demographics

There were 20 participants in both groups (HC and MCI). Descriptive statistics were used to summarise this demographic data (Table 4.1 and 4.2).

Table 4.1 Demographic data for the HC group

Participant	Age	Gender	Education (years)	MoCA score
1	63	F	10	28
2	65	M	18	26
3	52	F	18	27
4	68	F	18	28
5	55	F	14	29
6	80	M	18	22
7	56	F	19	26
8	80	M	9	25
9	51	F	18	30
10	59	F	14	26
11	58	M	17	26
12	60	F	17	29
13	65	M	26	28
14	53	F	18	28
15	59	F	14	28
16	52	F	20	28
17	53	F	16	28
18	67	F	10	27
19	59	F	13	27
20	51	M	23	24

Table 4.2 Demographic data for the MCI group

Participant	Age	Gender	Education (years)	MoCA
21	71	M	10	25
22	68	M	11	24
23	69	M	7	24
24	70	F	18	27
25	79	F	11	22
26	54	F	15	23
27	85	F	20	20
28	82	M	21	25
29	77	M	10	26
30	71	F	12	26
31	68	F	12	23
32	75	F	14	24
33	68	M	10	28
34	72	M	12	22
35	76	M	14	25
36	79	M	13	22
37	78	F	12	19
38	77	M	12	23
39	70	F	9	19
40	89	F	12	24

The median age of the HC group was 59 years with a range of 51 – 80 and an interquartile range (IQR) of 11; the median age of the MCI group was 73.5 with a range of 54 – 89 and an IQR of 9. Of the HC group 14/20 (70%) were female and 6/20 (30%) were male, 9/20 (45%) of the MCI group were female with 55% (11/20) male participants. Figure 4.1 and

4.2 represent the age and gender distribution across groups. Education level in years was compared across groups; the median years of education in the HC group was 17.5 years with a range of 9 - 26 years and the median years of education in the MCI group was 12 years with a range of 7 – 21 years. Figure 4.3 represents the distribution of years of education across groups.

All participants met the inclusion criteria of a Montreal Cognitive Assessment (MoCA) score above 19. Of those in the HC group, 85% (17/20) scored 26 or above in the (MoCA) which is considered to be within the normal range; 20% (4/20) of the MCI group scored 26 or above in the MoCA with 80% (16/20) scoring below 26. The median MoCA score for the HC group was 27.5 with a range of 22 – 30 and the median MoCA score for the MCI group was 24 with a range of 19 – 28.

Figure 4.1 Age distribution

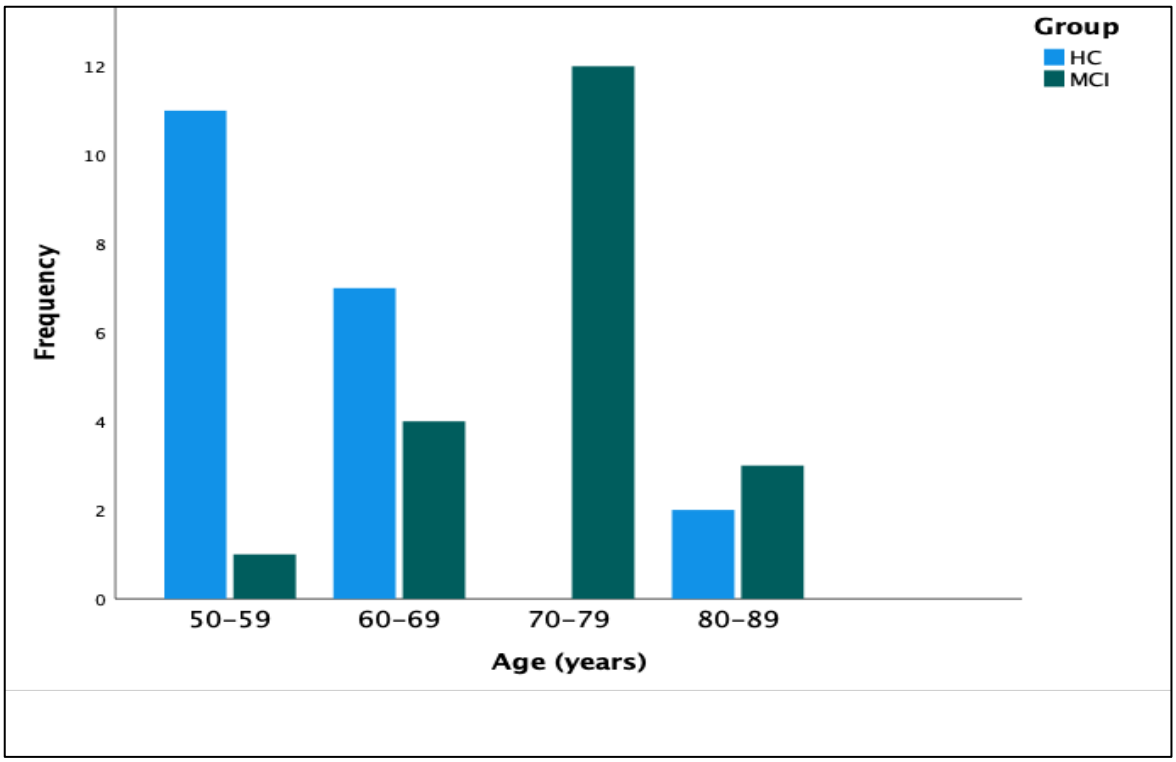


Figure 4.2 Gender distribution

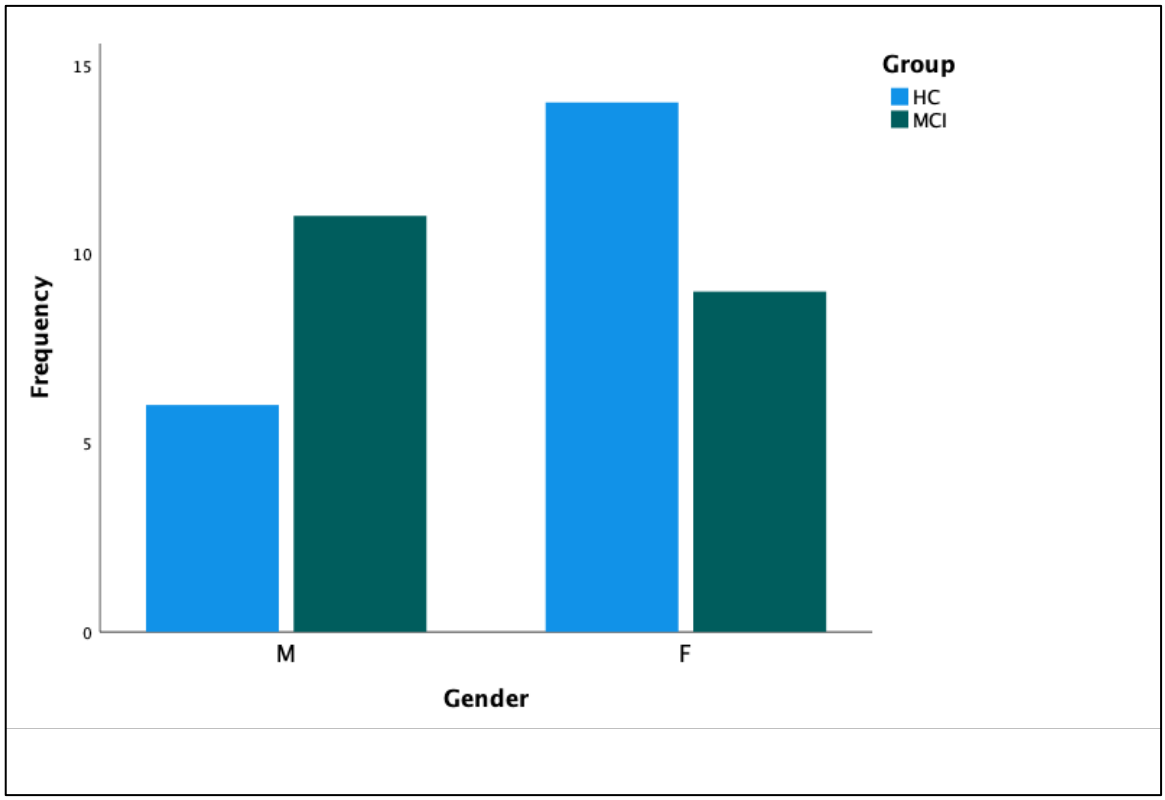
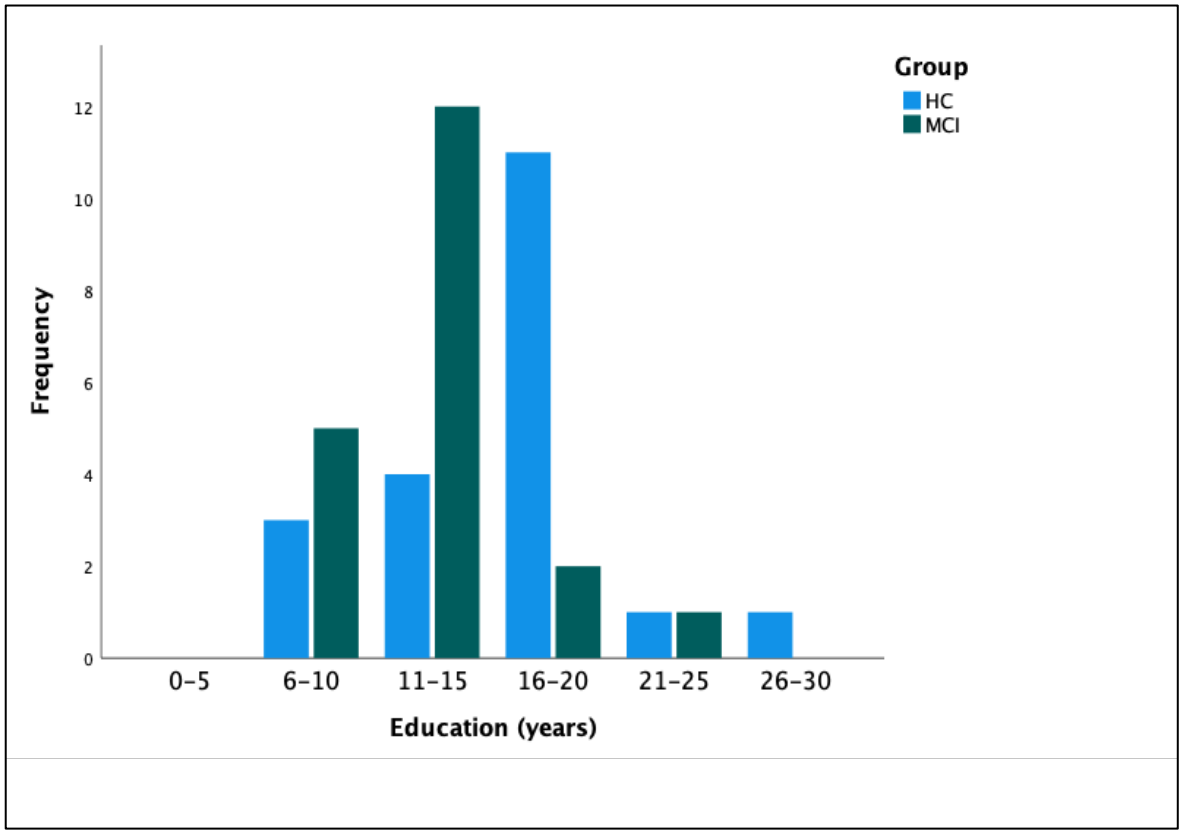


Figure 4.3 Years of education across groups



In the MCI group the median disease duration was 18.50 months with a range of 3 – 84 months. Subtypes of MCI were not examined but there were 12/20 (60%) that had positive cerebrospinal fluid (CSF) biomarkers for Alzheimer's disease (AD).

All participants achieved above the level of cut-off for comprehension scores (sentence and paragraph) on the Comprehensive Aphasia Test (CAT) indicating adequate receptive language skills to engage in the assessment. The median sentence comprehension score in the HC group was 16.00 with a range of 14 - 16 and the median paragraph comprehension score in the MCI group was 14.50 with a range of 12 – 16.

4.4 Cognitive Linguistic Variables

All participants completed all cognitive linguistic tasks. Descriptive statistics for language and cognitive tasks completed are outlined in Table 4.3.

Table 4.3 Descriptive statistics for cognitive linguistic measures

Variables	Median (IQR)	Min – Max (Range)
Picture Naming (max:10)		
HC	10.00 (2)	4 – 10 (6)
MCI	8.00 (3)	3 – 10 (7)
Verbal fluency (semantic)		
HC	20.50 (17)	8 – 39 (31)
MCI	18.00 (13)	4 – 25 (21)
Verbal fluency (phonemic)		
HC	19.00 (25)	7 – 33 (26)
MCI	14.00 (19)	4 – 25 (21)
Repetition (max: 14)		

HC	14.00 (2)	11 – 14 (3)
MCI	12.50 (4)	10 – 14 (4)
Reading (single word) (max: 5)		
HC	5.00 (0)	5 – 5 (0)
MCI	5.00 (0)	4 – 5 (1)
List learning (max: 40)		
HC	30.00 (12)	17 – 38 (21)
MCI	19.50 (22)	7 – 33 (26)
List recall (max: 10)		
HC	7.00 (8)	1 – 10 (9)
MCI	2.00 (10)	0 – 10 (10)
List recognition (max: 20)		
HC	20.00 (3)	17 – 20 (3)
MCI	17.50 (10)	8 – 20 (12)
Digit span forward (max: 8)		
HC	5.50 (2)	3 – 8 (5)
MCI	5.00 (4)	1 – 7 (6)
Digit span backward (max: 8)		
HC	3.50 (2)	2 – 7 (5)
MCI	3.00 (4)	1 – 5 (4)
Picture description (CIUs)		
HC	122.00 (131)	33 – 280 (247)
MCI	91.50 (71)	32 – 286 (254)

Grouped boxplots and frequency distribution charts were performed for each cognitive linguistic variable to demonstrate a visual representation of the distribution of cognitive linguistic scores across the two groups. All outliers present in the boxplots below were true outliers in the data, representative of participants' performance and so were

included. Scores in the HC group were higher on all subtests apart from reading single words versus the MCI group. Participants in the MCI group had reduced verbal fluency (semantic and phonemic), impaired picture naming, reduced repetition at sentence level, used fewer correct information units (CIUs) when describing the picture description task and reduced list learning, list recall and list recognition scores. Reading at single word level, digit span forward and backward showed little to no difference across both groups.

Figure 4.4 Boxplot representation of picture naming scores across groups

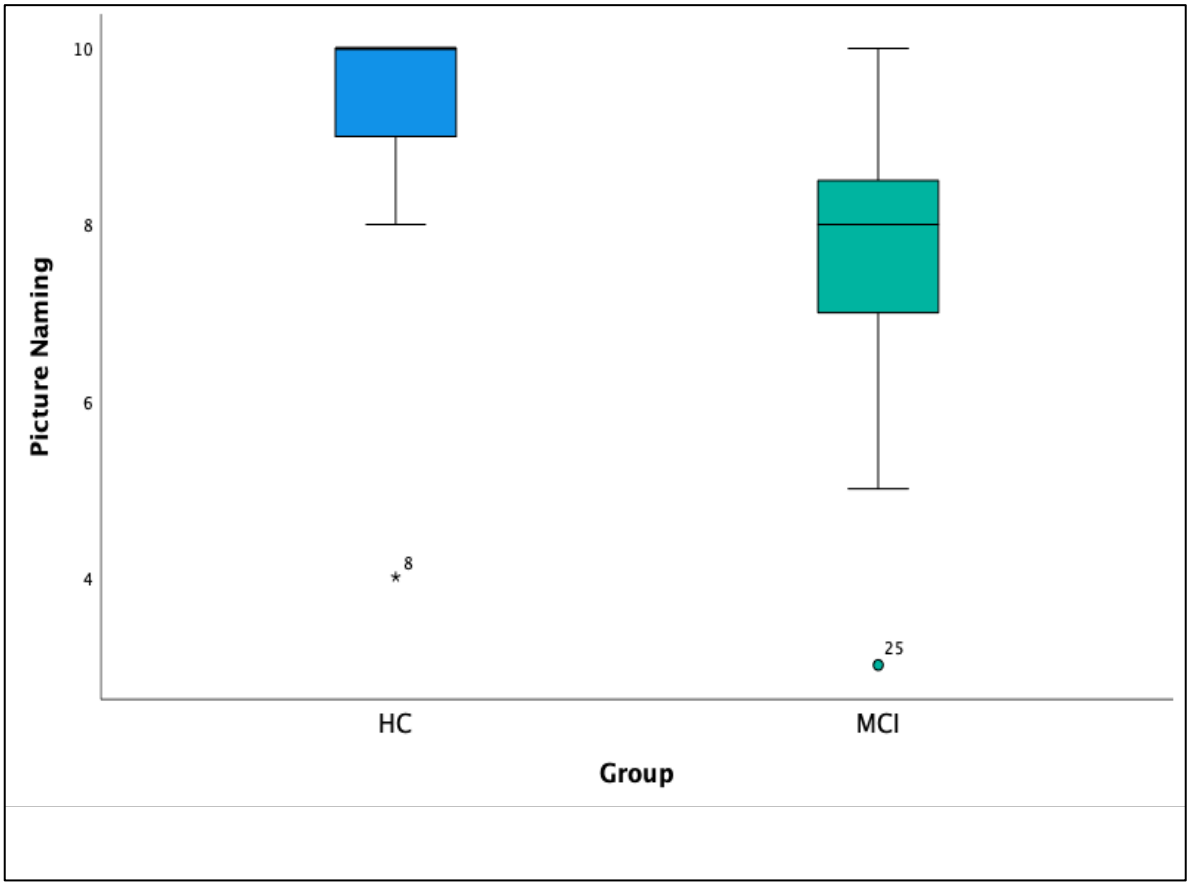


Figure 4.5 Frequency distribution of picture naming scores across groups

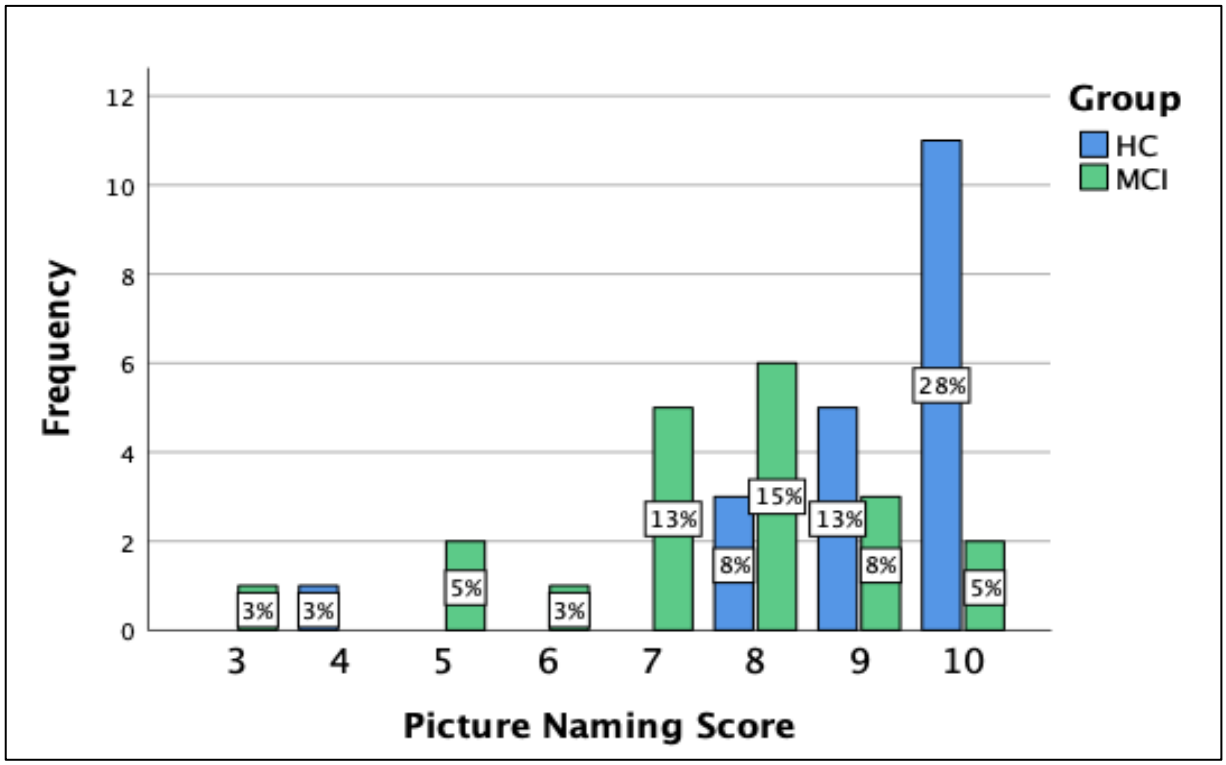


Figure 4.6 Boxplot representation of verbal fluency (semantic) scores across groups

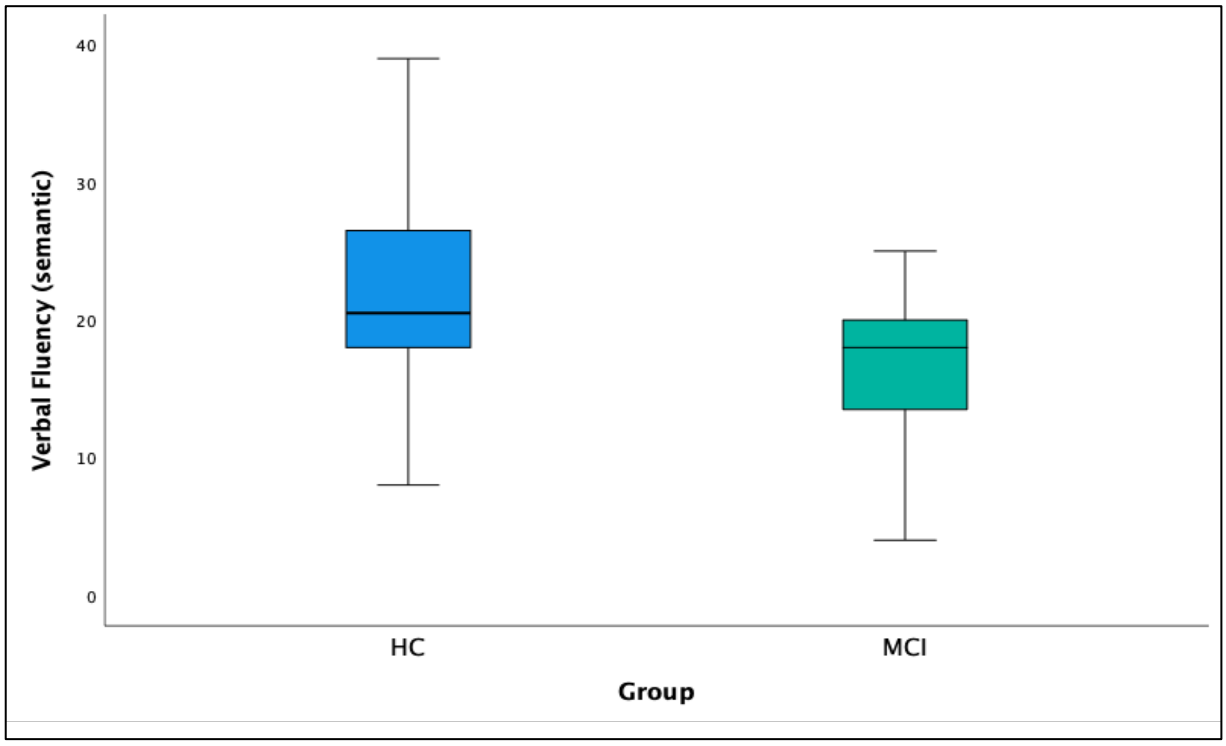


Figure 4.7 Frequency distribution of verbal fluency (semantic) scores across groups

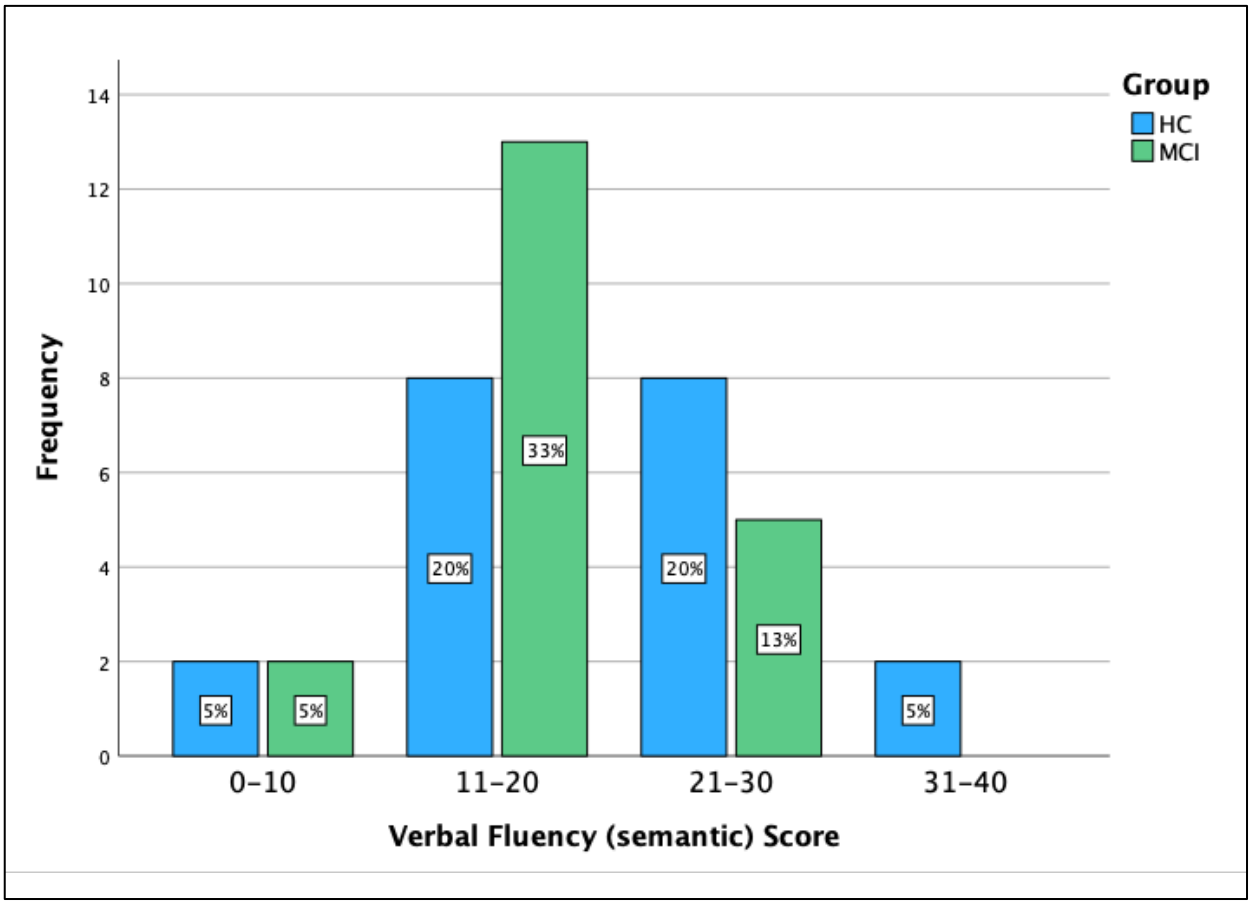


Figure 4.8 Boxplot representation of verbal fluency (phonemic) scores across groups

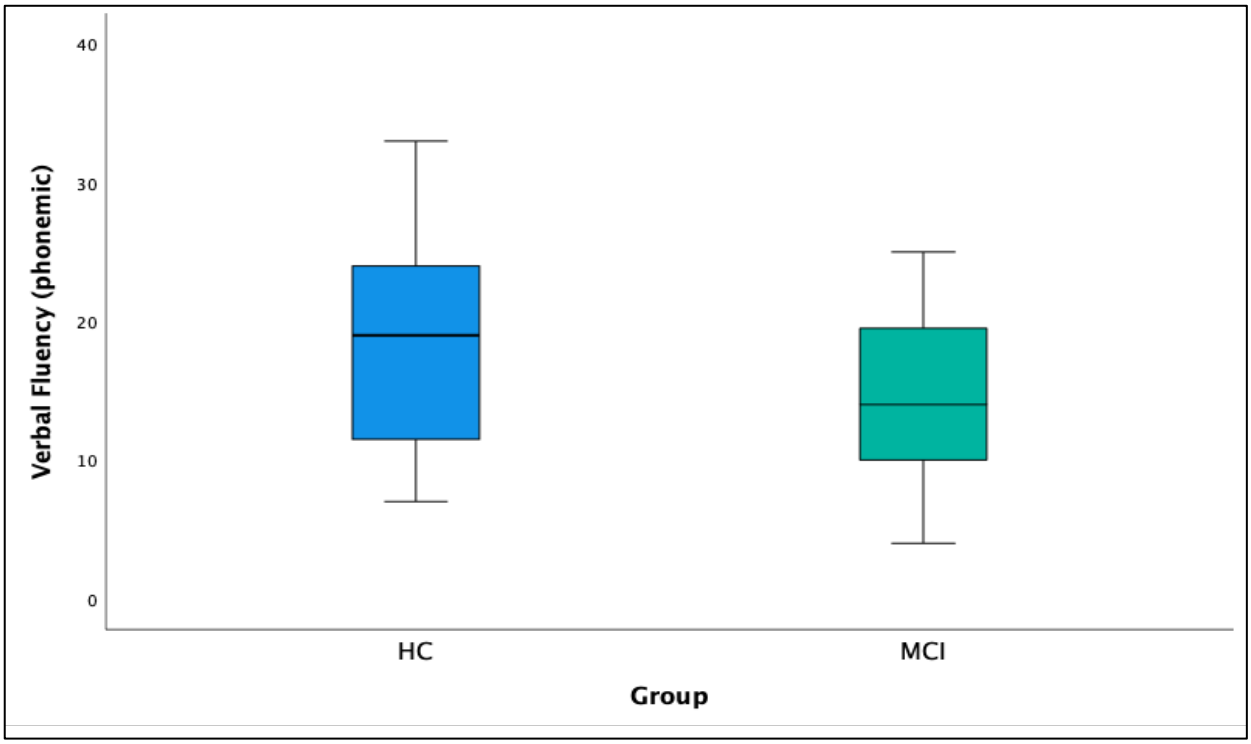


Figure 4.9 Frequency distribution of verbal fluency (phonemic) scores across groups

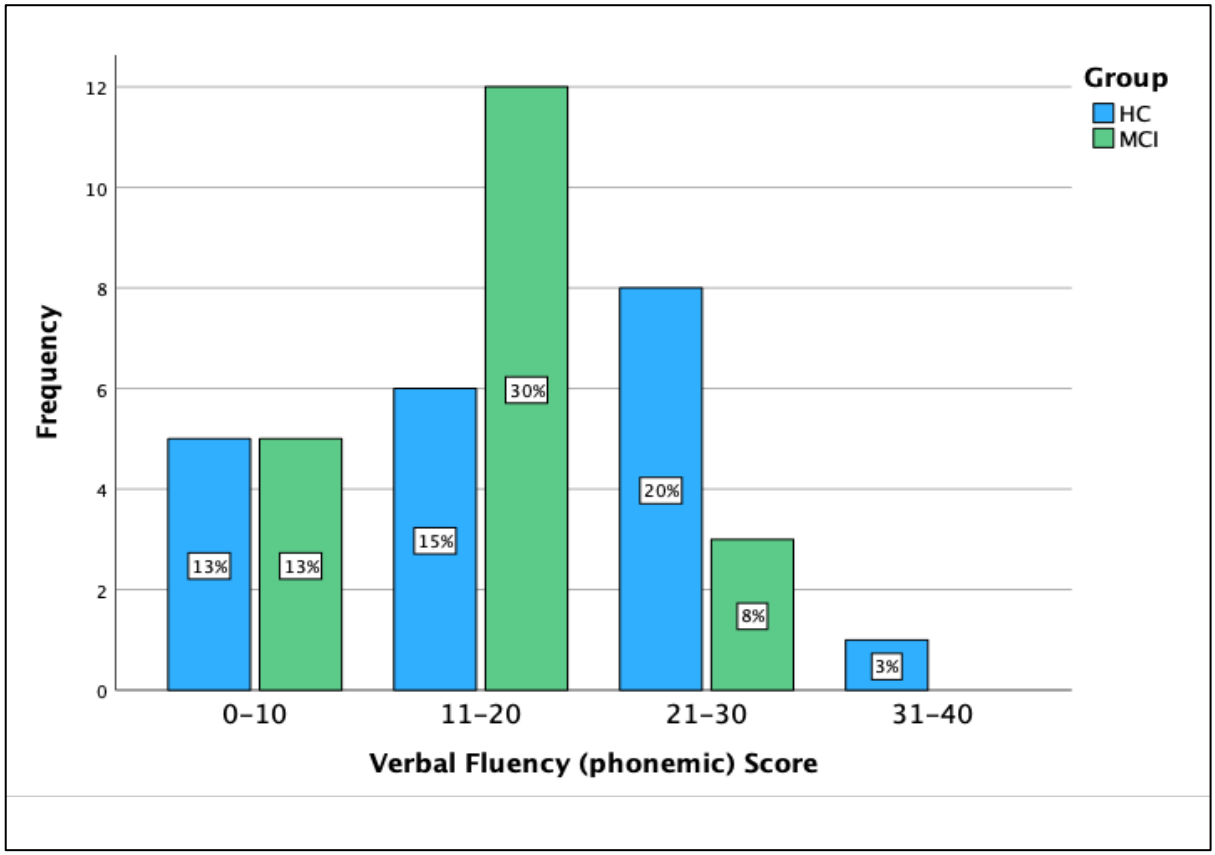


Figure 4.10 Boxplot representation of repetition scores across groups

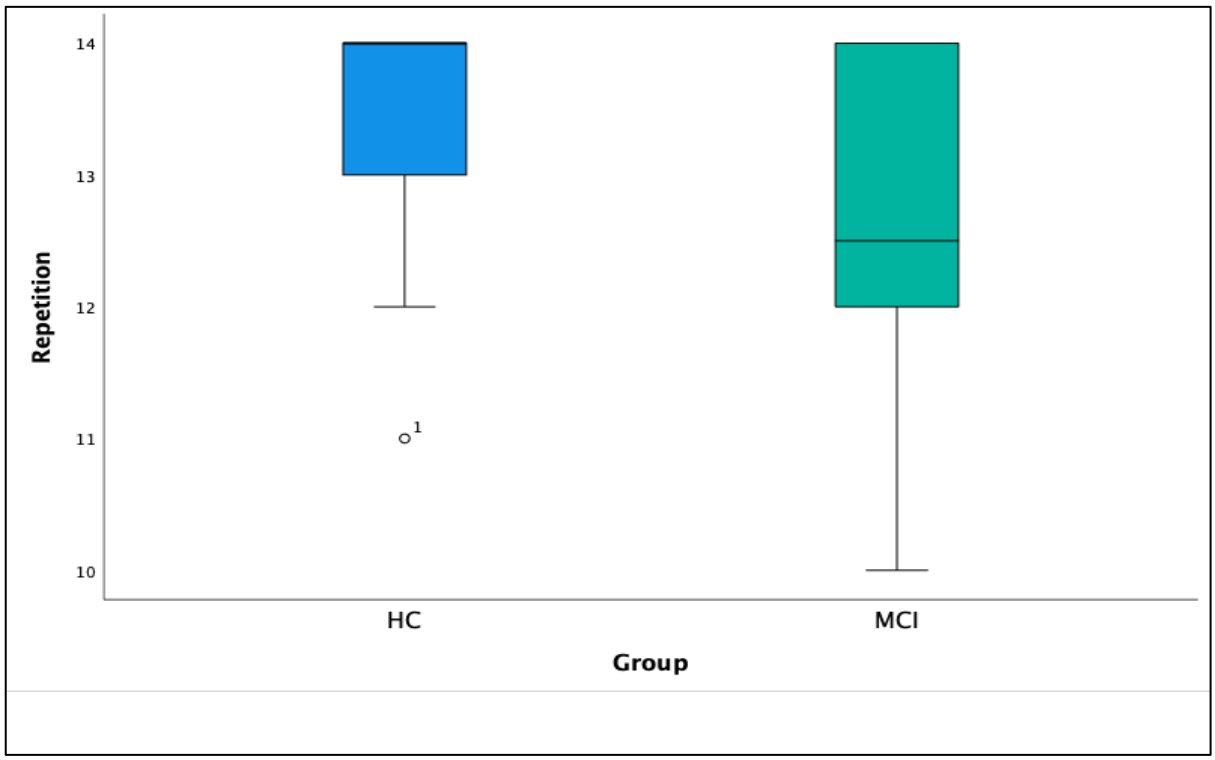


Figure 4.11 Frequency distribution of repetition scores across groups

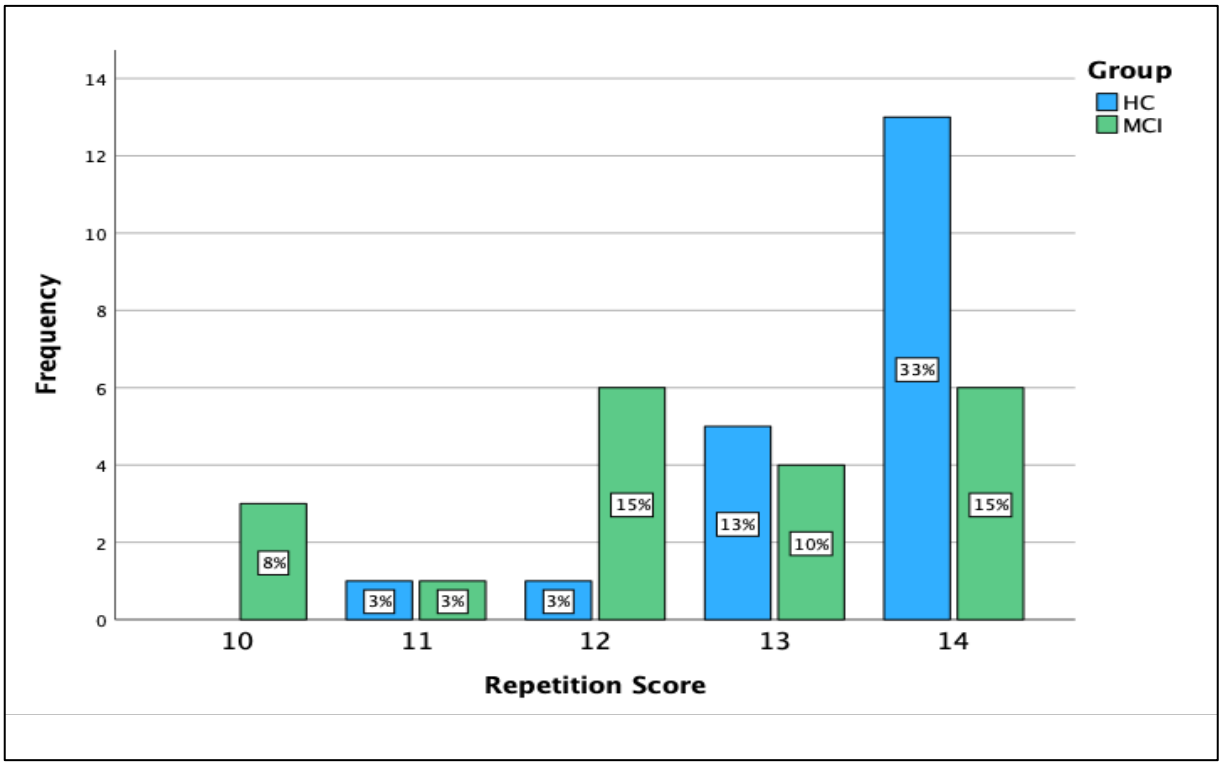


Figure 4.12 Boxplot representation of reading (single words) scores across groups

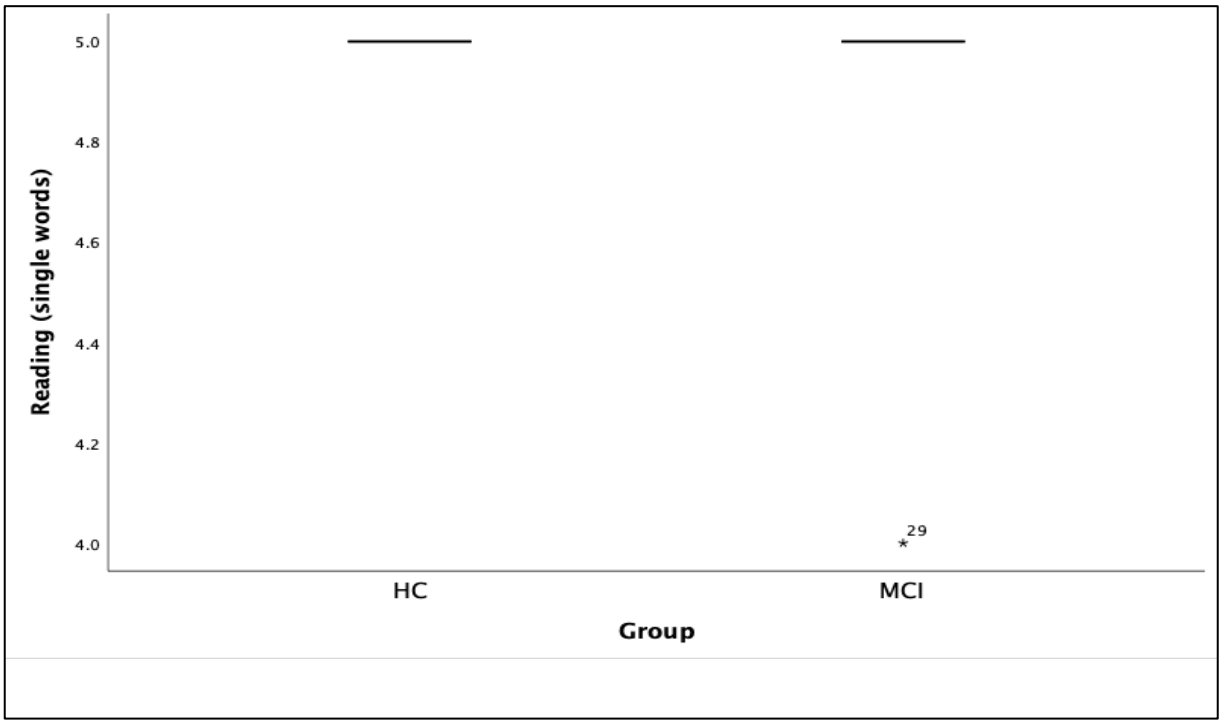


Figure 4.13 Frequency distribution of reading scores across groups

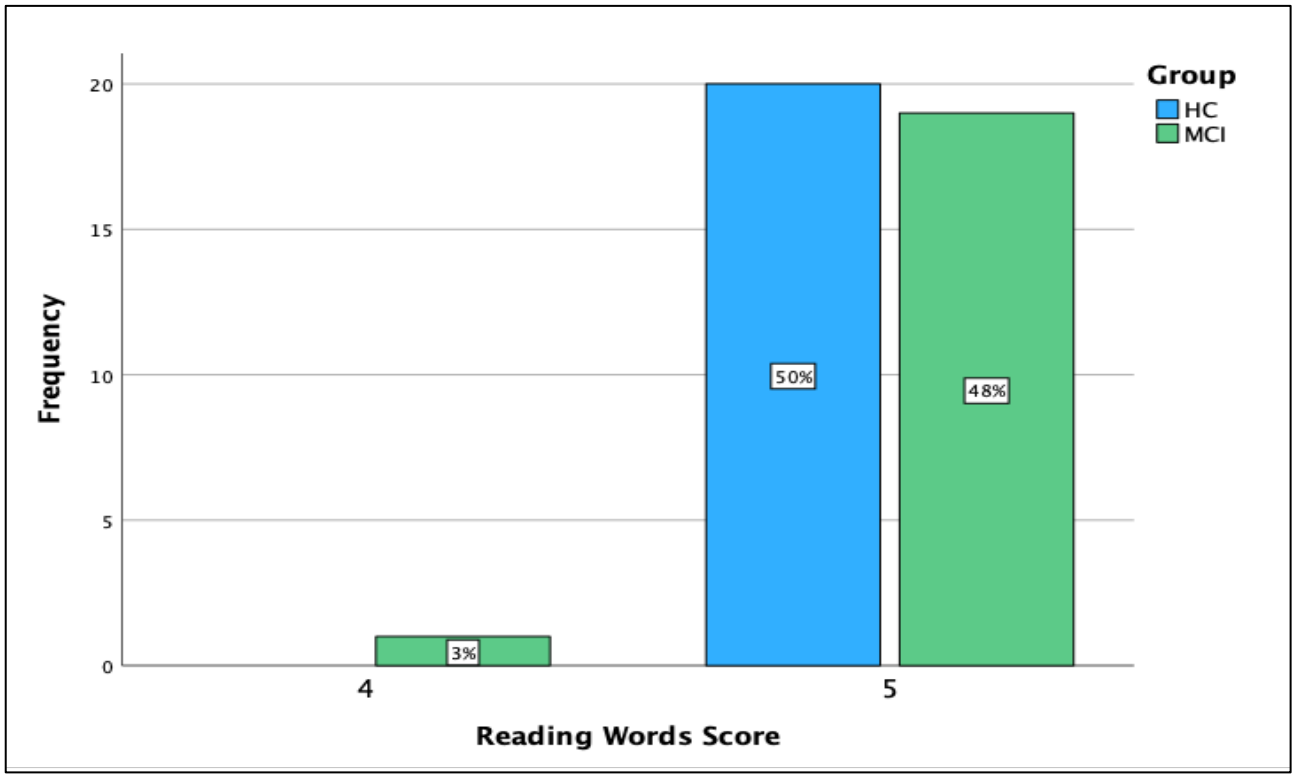


Figure 4.14 Boxplot representation of digit span (forward) scores across groups

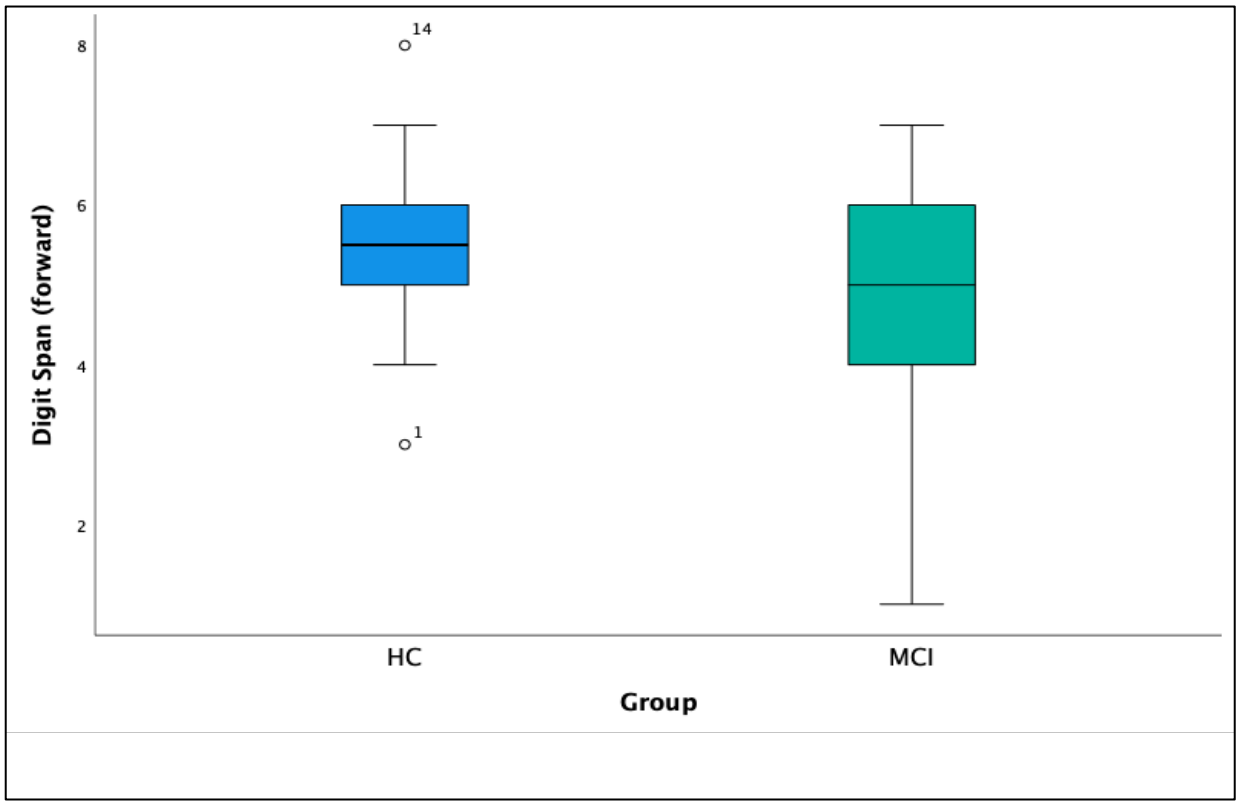


Figure 4.15 Frequency distribution of digit span (forward) scores across groups

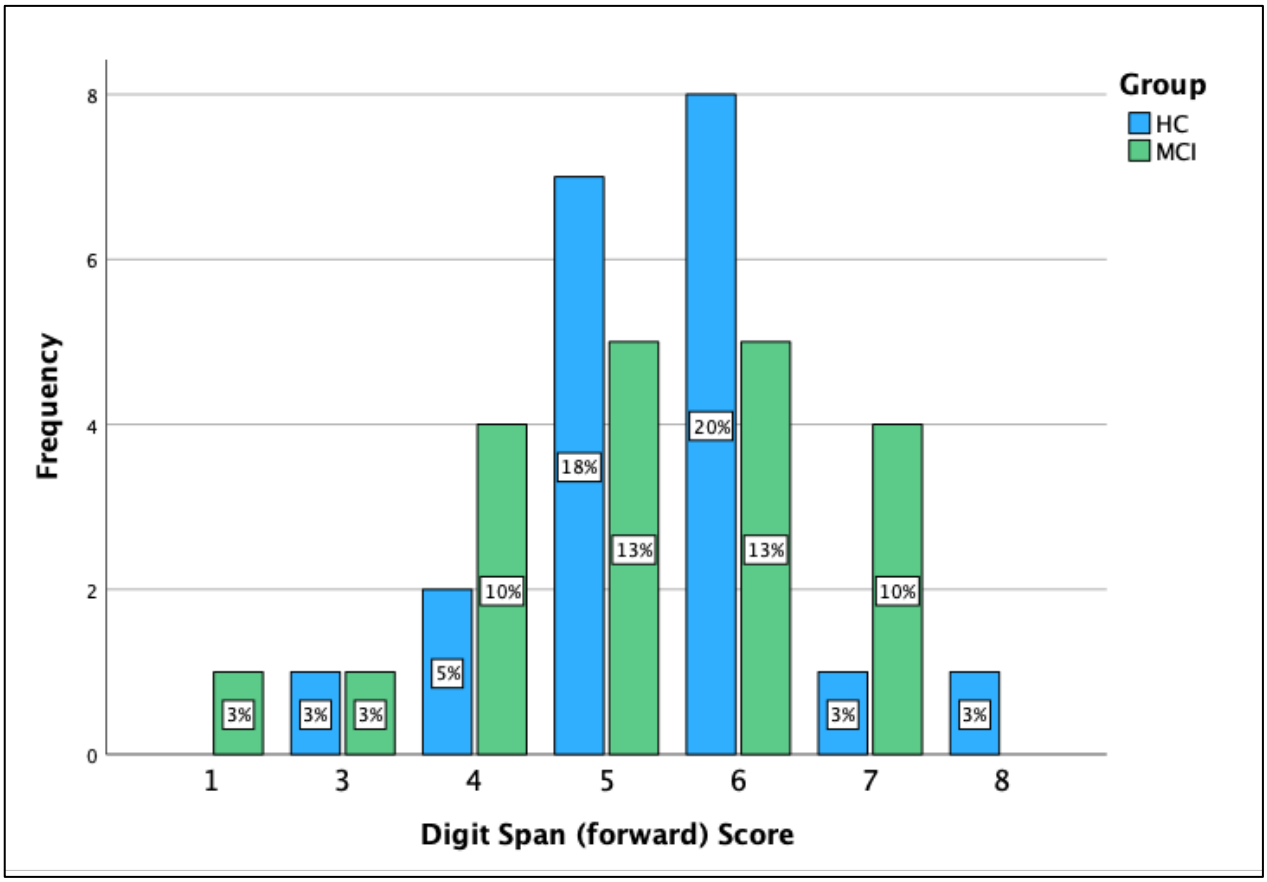


Figure 4.16 Boxplot representation of digit span (backward) scores across groups

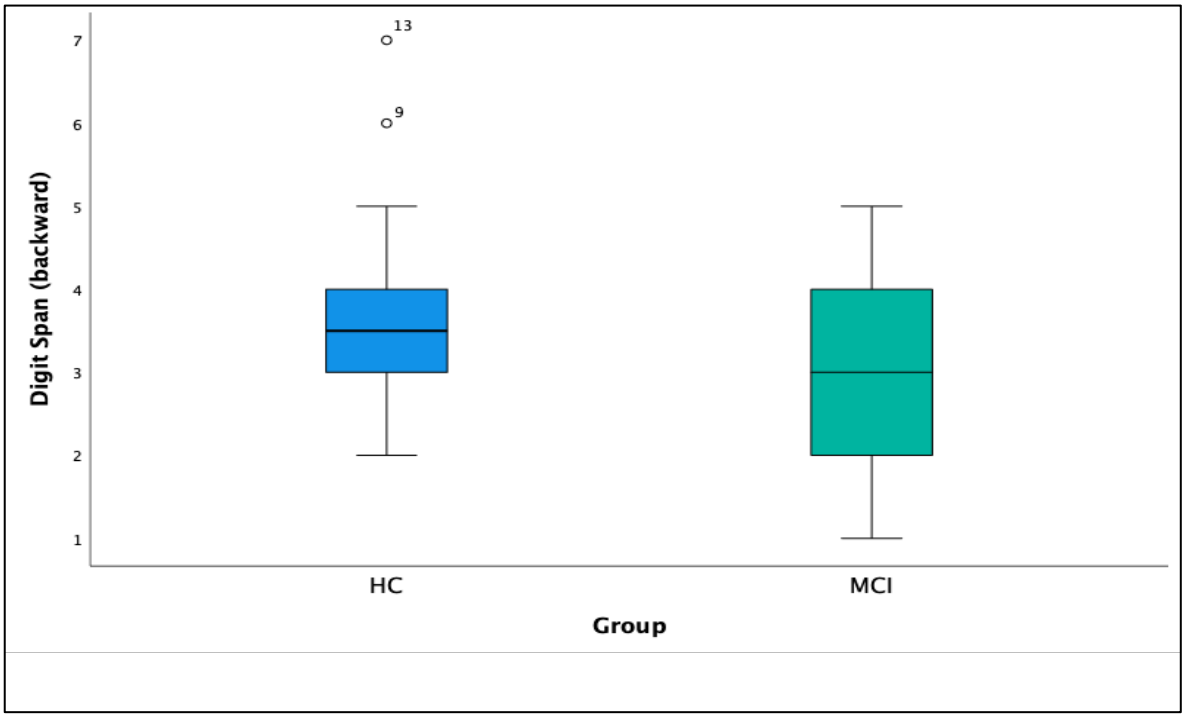


Figure 4.17 Frequency distribution of digit span (backward) scores across groups

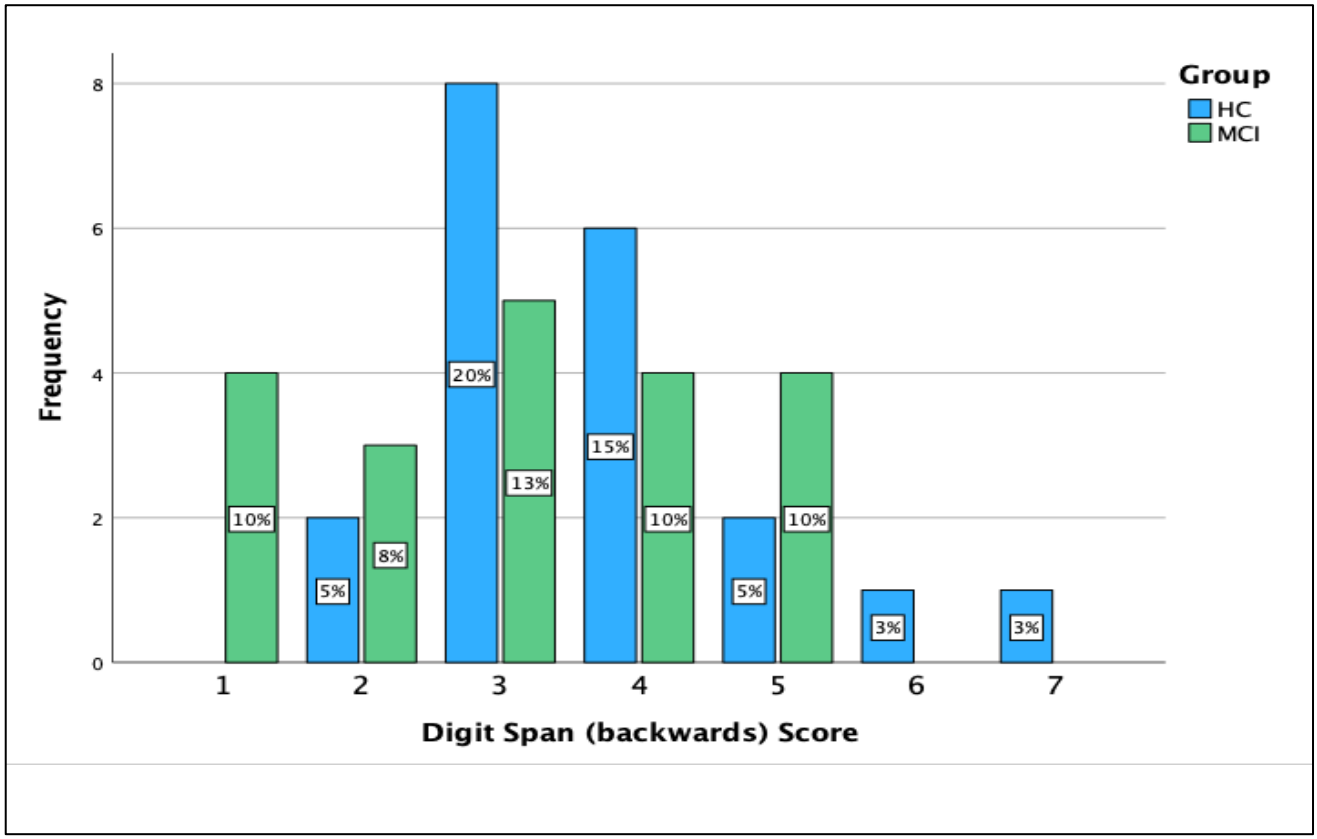


Figure 4.18 Boxplot representation of list learning scores across groups

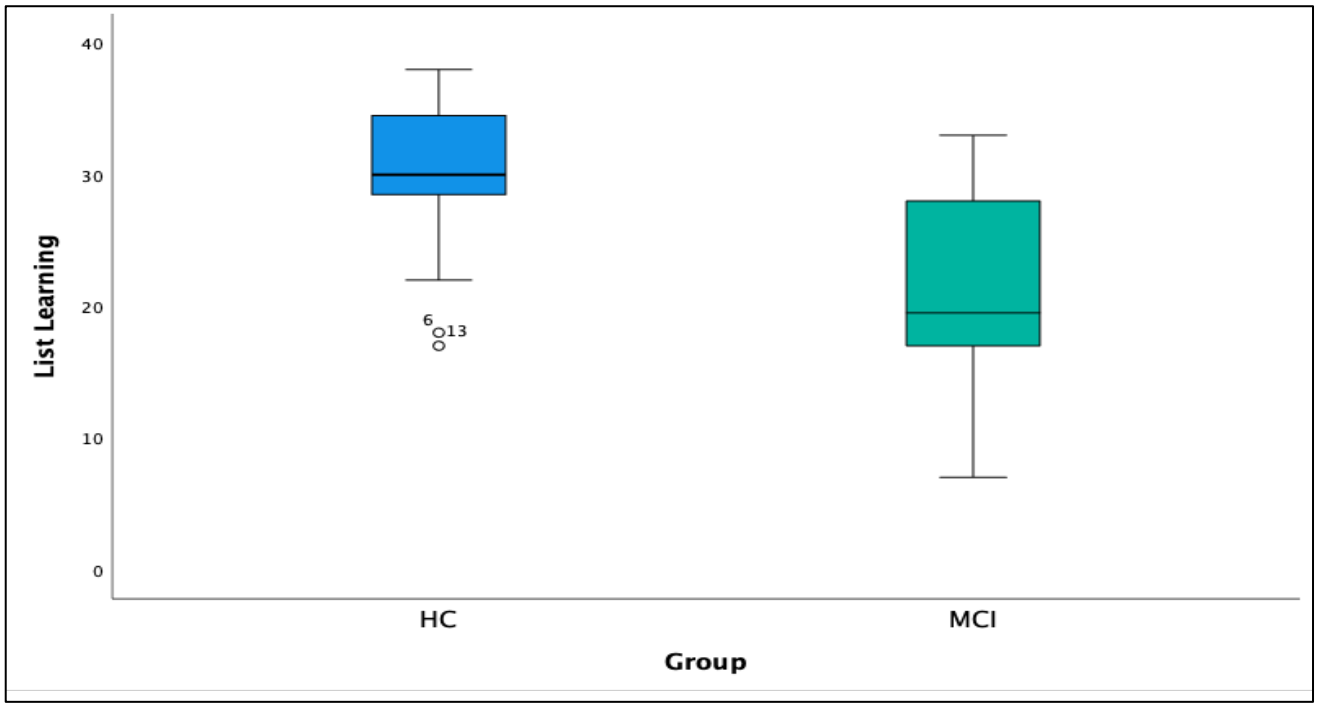


Figure 4.19 Frequency distribution of list learning scores across groups

Figure 4.20 Boxplot representation of list recall scores across groups

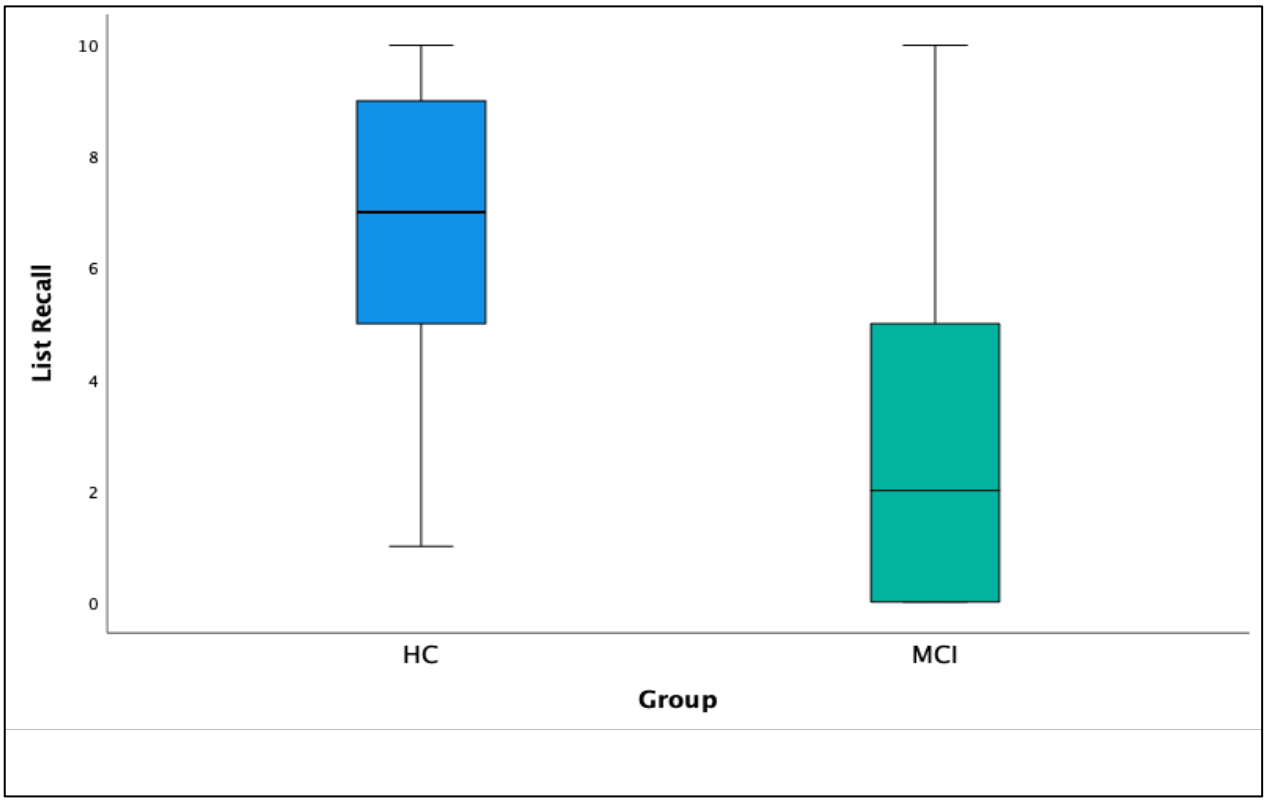


Figure 4.21 Frequency distribution of list recall scores across groups

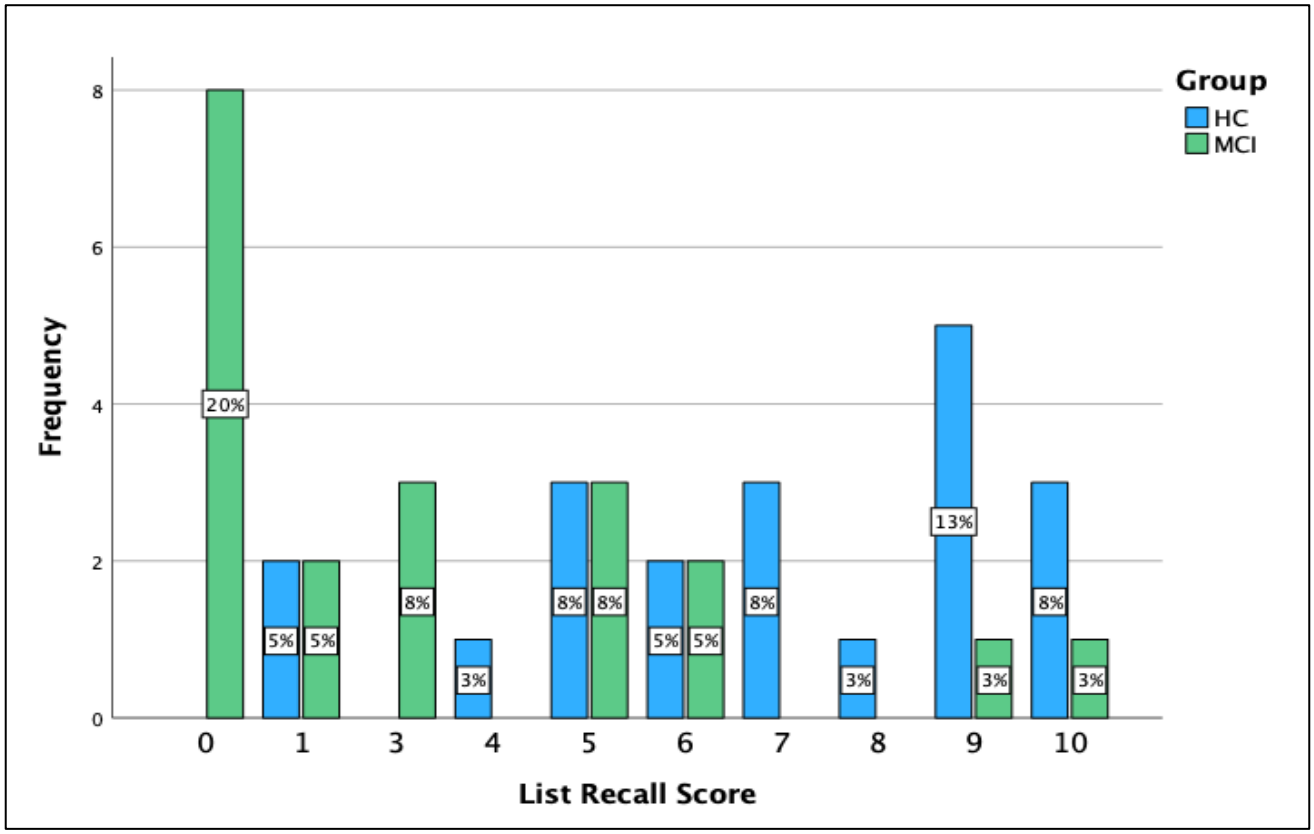


Figure 4.22 Boxplot representation of list recognition scores across groups

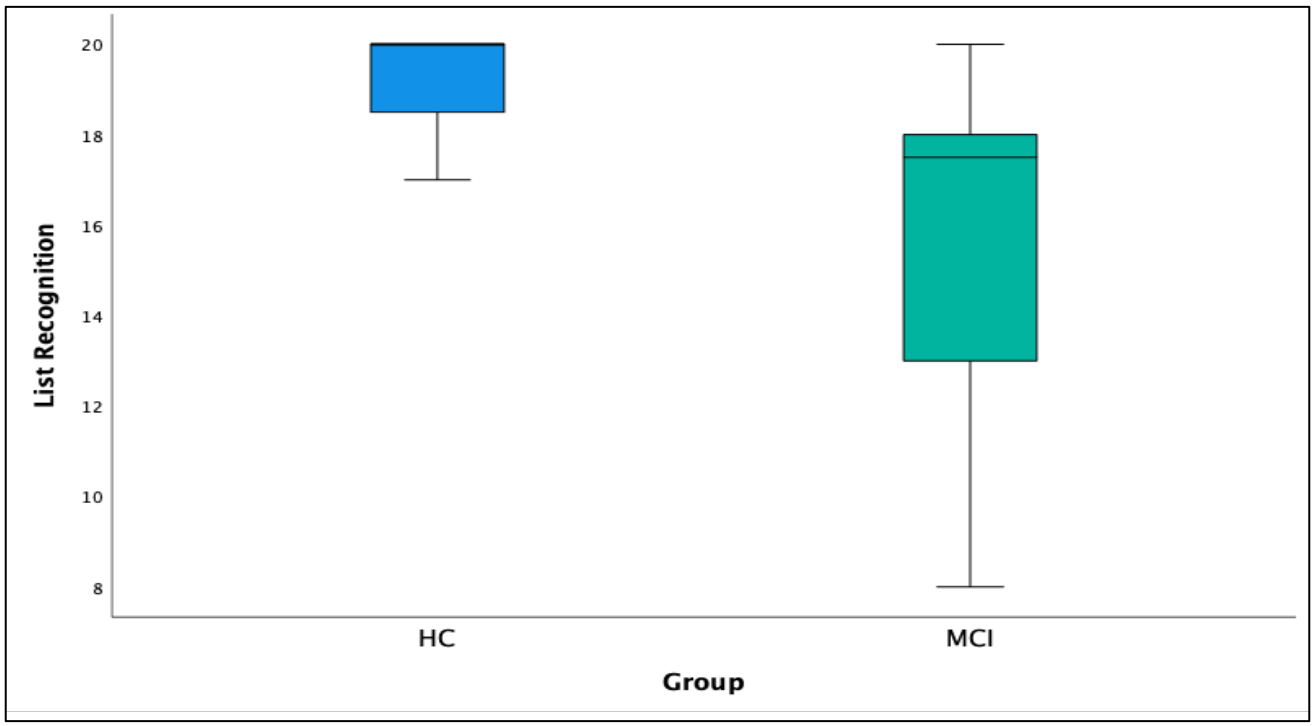


Figure 4.23 Frequency distribution of list recognition scores across groups

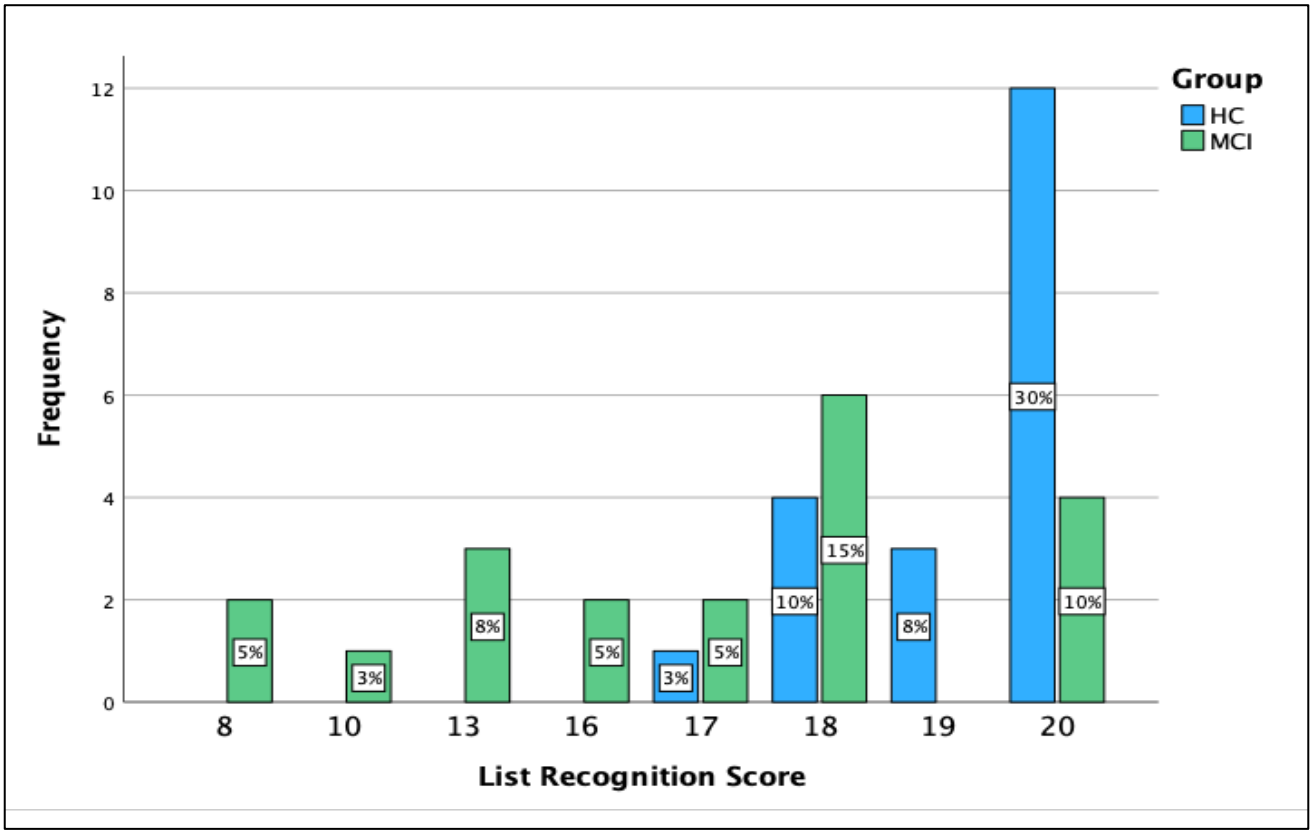


Figure 4.24 Boxplot representation of picture description scores measured in CIUs

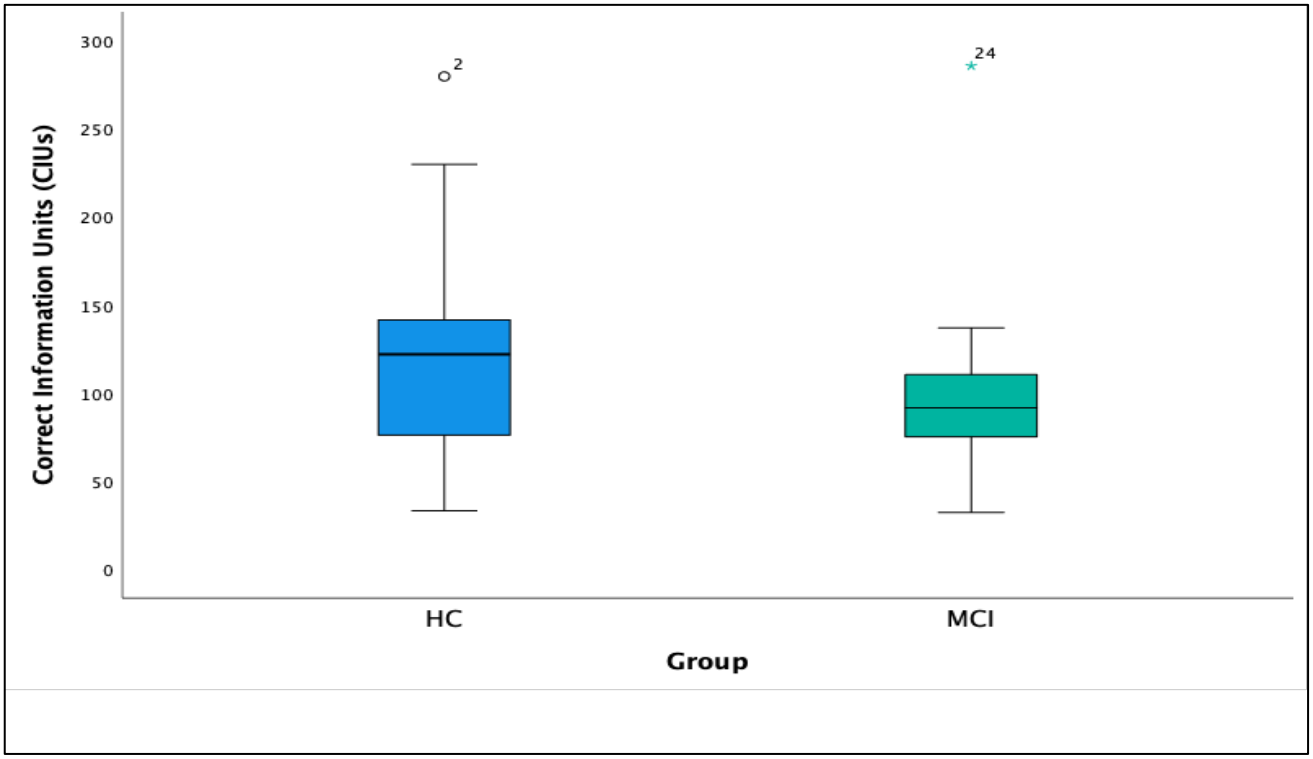
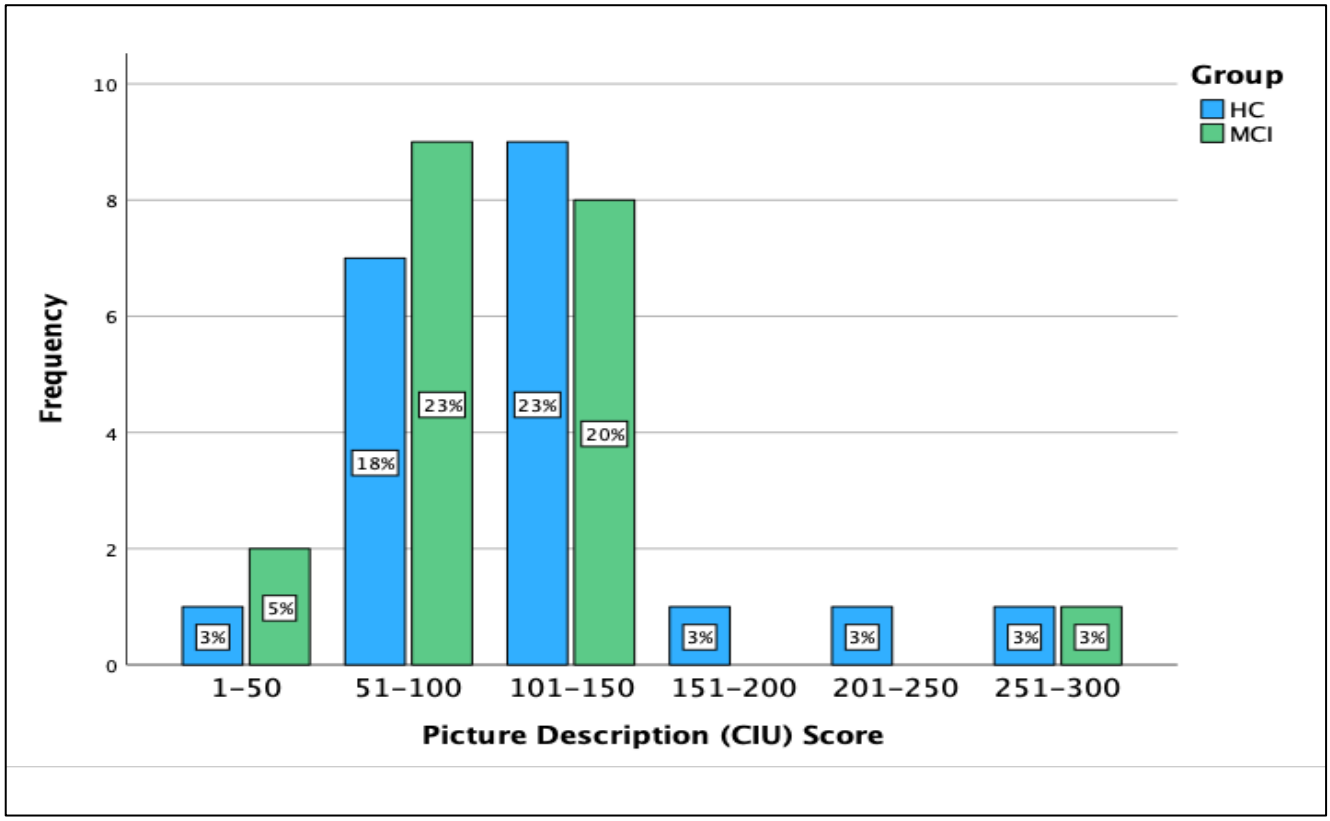


Figure 4.25 Frequency distribution of picture description (CIU) scores across groups



4.5 Differences in Cognitive-Linguistic Subtests Across Groups

The data analysed were mostly non-normal (Table 4.4). Despite normality across some of the subtests, the researcher chose to use non-parametric tests given the small sample size.

A log-transformation to enforce normality in the subtests that were non-normal was not warranted as the sample size was small and the amount of outliers meant the median was considered a more appropriate measure of central tendency than a log-transformed mean.

The non-parametric test the Mann Whitney U Test was used to examine differences in variables across both groups.

Table 4.4 Normality across subtests

Variable	Shapiro-Wilk (**p**)
Age	**<.001**
Picture Naming	**<.001**
Verbal Fluency (semantic)	.532
Verbal Fluency (phonemic)	.590
Reading	**<.001**
Repetition	**<.001**
Picture Description	**<.001**
List Learning	.038
List Recall	**.001**
List Recognition	**<.001**
Digit Span (forward)	.008
Digit Span (backward)	.042

Table 4.5 Mann Whitney U scores

Variables	**Mann Whitney U**	**Mean Rank**	***Z***	***p***
Picture Naming	71.50	26.93 (HC), 14.08 (MCI)	-3.576	**< .001**
Verbal Fluency (semantic)	112.50	24.88 (HC), 16.13 (MCI)	- 2.373	.018
Verbal Fluency (phonemic)	144.00	23.30 (HC), 17.70 (MCI)	-1.518	.129
Reading (single word)	190.00	21.00 (HC), 20.00 (MCI)	- 1.000	.317

Repetition	108.50	25.08 (HC), 15.93 (MCI)	- 2.644	**.008**
Picture Description	149.00	23.05 (HC), 17.95 (MCI)	-1.380	.168
List Learning	75.00	26.75(HC), 14.25 (MCI)	-3.389	**< .001**
List Recall	68.50	27.08 (HC), 13.93 (MCI)	-3.590	**< .001**
List Recognition	75.00	26.75 (HC), 14.25 (MCI)	-3.526	**< .001**
Digit Span (forward)	185.00	21.25 (HC), 19.75 (MCI)	-0.420	.675
Digit Span (backward)	153.00	22.85 (HC), 18.15 (MCI)	-1.308	.191

Statistically significant differences were identified for picture naming (*U*=71.50, *p*< .001), repetition (*U*= 108.50, *p*= .008), list learning (*U*=75.00, *p* < .001), list recall (*U*= 68.50, *p* < .001) and list recognition (U= 75.00, p < .001). There was no statistically significant difference across groups for verbal fluency semantic (*U*= 112.50, *p*= .018) and phonemic (*U*= 144.00, *p*= .129), reading (*U*= 190.00, *p*= .317), picture description (*U*= 149.00, *p*= .168), digit span forward (*U*= 185.00, *p*= .675) and backward (*U*= 153.00, *p*= .191). The results discussed above show picture naming, repetition, list learning, list recall and list recognition were all statistically significant in identifying differences in a group of HCs versus a group with MCI.

4.6 Conclusion

This chapter outlined the results of this research study. A sample of 40 participants was obtained over the time frame. The study protocol was tolerated by all participants. The following research questions were answered:

Can selected cognitive linguistic subtests discriminate between HC and MCI groups?

There was a statistical difference across groups in the subtests of picture naming, repetition, list learning, list recall and list recognition.

What are the differences in language characteristics between healthy controls and MCI using a devised informal speech and language assessment?

Almost all language specific subtests showed differences in characteristics. Higher mean scores were observed in picture naming, repetition at single word and sentence level, verbal fluency (semantic and phonemic) and CIUs in picture description in the HC group compared with the MCI group. The discussion and interpretation of these results will be discussed in the next chapter.

Chapter 5: Discussion

5.1 Introduction

This chapter will discuss the findings of this research study in relation to the current literature base. The clinical implications of the study alongside the strengths and limitations of the research will also be examined and explored. The aim of this study was to examine the differences in selected cognitive linguistic subtests used frequently in Speech and Language Therapists' (SLTs') assessment of people with mild cognitive impairment (MCI) versus a healthy control (HC) group. The second aim of the study was to examine the differences in language scores between participants in the healthy control group and those in the MCI group using a devised informal cognitive linguistic assessment. All of the tasks used in this study are used regularly by different members of the multidisciplinary team (MDT), including SLT. Useful qualitative and descriptive information can be achieved from these subtests which can impact and complement a clinician's diagnostic process but for SLTs it can be quite difficult to access quick screening tools which objectively predict the likelihood of MCI from linguistic measures. Most tools are not sensitive or specific enough. There is a need for diagnostic tools that can detect the presence of cognitive impairment and monitor its progression with ease and in a timely manner (Thomas et al., 2020).

5.2 Cognitive-Linguistic Assessment

For the purpose of this study, the components of the cognitive linguistic assessment were picture naming, repetition, verbal fluency, reading, picture description, list learning, list recall, list recognition and digit span forward and backward.

5.2.1 Picture Naming

Picture naming is widely used across cognitive linguistic and neuropsychological assessments. The picture naming assessment used in this study was a combination of lower frequency targets from many different SLT assessments, the Boston Naming Test (Kaplan, Goodglass & Weintrab, 1983), the Sydney Language Battery (Savage et al., 2013), the Quick Aphasia Battery (Wilson et al., 2018). Picture naming could successfully identify MCI versus HCs in this group. It is well established that semantic deficit is observed in the MCI population resulting in these naming difficulties. Previous research has identified picture naming to be one of the sensitive language markers in HCs versus MCI (Jokel et al., 2019). It has been identified as a quick screening tool most likely to identify semantic deficits in MCI versus HCs (Taler et al., 2019). This finding from this study has a significant clinical implication for picture naming as a potential screening method for MCI. It's a very quick screening tool and can be completed by many different members of the MDT. Future research for this subtest should examine whether lexical retrieval or perceptual difficulties are also underlying the picture naming deficits observed.

5.2.2 Repetition

Repetition of words and sentences of increasing length and complexity is a common assessment task in cognitive linguistic testing. In this study, repetition showed potential as a test that could identify MCI as a screening tool. The result reached statistical significance. Continuing research with a larger sample size will facilitate identification of whether this subtest reflects significant differences between the two cohorts of interest. The likelihood is that this test may discriminate between groups, as this would be in line

with previous research where sentence repetition was identified as having a significant difference in scores in HCs and MCI (Jokel et al., 2019).

5.2.3 Verbal Fluency

Verbal fluency (semantic or phonemic) did not achieve statistical significance in identifying MCI from HCs as has been documented previously (Jokel et al., 2019, McDonnell et al., 2020). Verbal fluency scores were higher in the HC group for both semantic and phonemic fluency. Given the semantic deficit commonly seen in Alzheimer's disease (AD) (Huff, Corkin and Growdon, 1986) and amnestic MCI, this task may have higher sensitivity in a group of solely amnestic MCIs.

5.2.4 Picture Description

The Cookie Theft picture (Goodglass, Kaplan & Barresi, 2001) was used as a prompt for a connected speech sample. This task was analysed using correct information units (CIU) (Nicholas & Brookshire, 1993), a similar concept to words per minute or information carrying units (ICUs). In this study the difference in CIUs in this picture description between HCs and MCI was not statistically significant. This is in contrast to other research where a connected speech sample indicated a decrease in CIUs with abnormal amyloid levels (Mueller et al., 2021). Again, maybe a more homogenous group of amnestic MCIs or MCI due to AD positive biomarkers may have revealed a different result. Despite this result as a potential screen for MCI versus HC, there continues to be a wealth of qualitative information achieved from these picture description tasks. In this study, word finding difficulty, dysfluencies and errors in speech were not assessed from the connected speech sample and the current research base has rated this type of linguistic and acoustic analysis

as highly sensitive in predicting MCI (Yeung et al., 2021). This type of analysis will be a next step in the larger research trial.

5.2.5 Reading

Reading at word level was not statistically significant in identifying MCI versus HC. This is similar to previous study by Jokel et al. (2019) which found that single word reading wasn't statistically significant in identifying amnestic MCIs versus HC compared to other linguistic tasks. Reading at single word level was included as surface dyslexia has been identified previously as a difficulty in cognitive impairment. This feature may be useful in a more advancing cognitive profile, in identifying AD dementia or some atypical presentations such as logopenic AD/ semantic dementia and may not be useful as a marker of MCI.

5.2.6 List Learning, List Recall and List Recognition

List learning, list recall and list recognition are commonly used assessments of working memory and are used in widely used neuropsychological tests such as the Addenbrooke's Cognitive Examination (ACE) III (Hsieh et al., 2013) and the Repeatable Battery for Assessment of Neuropsychological Status (RBANS) (Randolph, 1998). All of these subtests were found to be statistically significant in identifying MCI from the HC group. This result supports the use of these tasks as a screening tool alone

5.2.7 Digit Span

Digit span forward and backward were not statistically significant in identifying between groups in this study. These subtests have been used in combination with many other

subtests in identifying cognitive impairment across many different assessments. Examining the mean scores for differences among groups also gave the researcher minimal information as there were similar mean scores for both groups on this subtest. As an individual task, these subtests were shown to have little value in identifying differences across MCI and HC groups in this study.

5.3 Implications for Clinical Practice

The current study has potential for a number of clinical implications. Firstly, this study has highlighted the picture naming and repetition tasks as potentially successful in identifying the MCI group versus the HC group from a language perspective and list learning, list recall and list recognition from a cognitive perspective. There is a significant need for sensitive, quick, useful screening tools in identifying cognitive impairment. This is a promising finding in the field of memory assessment. The current literature base focuses on a combination of acoustic and linguistic variables and this research has the potential to identify some of the quick subtests that could be used alongside automated speech analysis. The study has characterised the profile of cognitive linguistic impairment in an MCI group. SLTs often find it difficult to identify subtle changes in someone's cognitive linguistic profile, this study aimed to facilitate this type of assessment. This should be useful for many different MDT members in screening for cognitive impairment where the use of a faster, more refined tool is needed. From an SLT's perspective, this assessment has significant clinical value in this regard. It provides a tool that will objectively identify those that may present with very minimal cognitive linguistic changes and who may often do well with assessments targeted for a more advanced profile.

Furthermore, this study has shown that cognitive linguistic assessments in a digital modality are a valid alternative to more traditional pen and paper screening. Digital assessments of cognition are fast becoming a reality in research settings and will eventually be part of our everyday clinical practice. All participants in this study tolerated the digital protocol well.

The cognitive linguistic app took on average 20 minutes to complete. This is in comparison to larger batteries which can take around 90 minutes to complete. This has huge benefits for SLTs and other MDT members working in a range of different settings.

Reading and verbal fluency subtests are ones that don't differ greatly between different types of assessments. However, picture naming and repetition tasks used were deemed difficult in comparison to some of the other tests used. The targets used were of lower frequency and imageability and words used for repetition were multisyllabic and complex in nature. This has use for clinicians in that this type of assessment can be used very easily and adapted to the level of cognitive impairment. The severity used for this assessment was due to the nature of the groups being assessed, MCI can be quite difficult to detect objectively as has been discussed.

The aim of this study was to understand the objective value of these assessments but unsurprisingly there was a wealth of other valuable clinical information as a result of the combined assessments whether they were found to be statistically significant or not. The purpose was in identifying screening tools but not to discredit the value of further

complete cognitive linguistic and neuropsychological assessments that give a complete profile and are recommended as best practice for cognitive linguistic assessment.

5.4 Limitations

As with all studies there were limitations to this study. One limitation consists of the sample size recruited. 20 participants were recruited in each group although the sample size intended by power analyses would have involved 26 participants in each group. This increased the possibility of a type II error. The researcher will continue to recruit to achieve the sample size advised and the data will be further reanalysed following this. It would have been preferable to achieve a more balanced age distribution among the groups also as the participants in the HC group were generally a younger cohort (median age of 59 years in the HC group versus the median age of 73.5 in the MCI group).

One of the gaps in the assessment used in the study was not examining visuospatial skills. Visuospatial tasks are used in almost all cognitive/neuropsychological tests but for the purpose of this study it was difficult to include a visuospatial task given the nature of the digital assessment. To include a visuospatial task for any future research using this app, the researcher will liaise with Canary Inc. around using a stylus to complete a clock drawing task on the tablet.

The repetition subtest was not marked with weighted scoring; a score of 1 was given to all words and sentences yet it could be argued that repeating phrases and sentences have

a higher predictive value in this cohort. Reduced repetition of increased length and complexity can often be seen in a person presenting with MCI.

Another limitation is that the MCI subtypes were not examined. Participants were classified as MCI only rather than amnestic/non-amnestic/single domain/multi domain. There may have been higher sensitivity in some measures with a group where all participants with MCI had positive AD biomarkers.

Reading aloud at paragraph level was not examined in this study. This data was however collected as part of the larger trial. It was not within the scope of this masters research to examine a read paragraph. Changes in speech chunking when reading aloud have been shown to predict MCI and AD (De Looze et al., 2018). However, the focus on this study was in areas that could be quickly assessed by a clinician and assessing read paragraphs involves in depth analysis. This is a goal for further publications in this study.

A limitation of completing digital speech assessments is the environment and other considerations involved. The researcher had to ensure a strong wifi connection for all assessments and a quiet space where there would be no interruptions for the recorded speech samples. This may not be feasible for some in clinic settings. The researcher also scored all items and collected responses using a data collection form. Ideally, going forward, the app will automatically score all items and provide a results output at the end of the assessment. Given that the current focus for the app developers was to receive speech data and to analyse the speech responses, their priority wasn't in scoring the cognitive linguistic variables. This will be an aim for future research.

5.5 Future Research

There are various directions for future research arising from this research that are part of the larger trial being completed at Tallaght University Hospital (TUH). One of the key areas for further research is to examine the use of speech and language characteristics using automatic speech and voice analysis in detecting cognitive impairment. This research is the first step for SLTs in Ireland examining the objectivity of subtests used frequently and investigate if the linguistic measures assessed are predictive of cognitive performance in MCI. Future research will examine and compare this type of manual analysis and raw scores to automatic speech analysis and how SLTs can contribute to the factors that should be included when using automatic speech analysis.

Another key area for future research is examining combined speech and gait tasks in identifying cognitive impairment. Research has shown that changes in gait speed during a dual task are indicative of cognitive performance, this can be assessed manually but can be time consuming and inaccurate. Similarly to speech, this type of data can be measured digitally and the combination of the digital speech and gait analysis in a dual task could improve the sensitivity and specificity of detecting cognitive impairment. Yamada et al. (2021) highlighted in their study the increased sensitivity in identifying cognitive impairment when combining modalities.

Furthermore, longitudinal monitoring of participants' speech is an area of interest for future research. This is an area which will be of huge clinical significance. Longitudinal monitoring is an important clinical part of managing people with MCI to assess for

progression. Digital monitoring remotely is a very viable way of achieving this. Research examining the changes in cognitive linguistic measures over three/six months in the MCI group would be of huge value.

Lastly, use of a digital speech and language assessment is novel in Ireland. It is imperative to understand the patient experience in its use. A patient satisfaction survey to receive feedback on this app, it's user interface and the use of digital assessment in general to further develop this assessment with the patient at the centre is of huge importance and an essential next step.

5.6 Conclusion

This study has tested the ability of a cognitive linguistic assessment and the different components involved in identifying MCI from a HC group. The cognitive linguistic differences between both groups were examined, picture naming, repetition and list learning/list recall/list recognition were among the strongest predictors of the MCI group. Connected speech sample analysed using CIUs may not be sensitive enough in identifying cognitive impairment and the next step of automated speech analysis appears to be the way forward for this task when attempting to use it as a quick screening tool. The results of this study indicate that picture naming, list learning, list recall and list recognition were the subtests which could successfully identify healthy controls versus those in the MCI group. Digit span forward and backward, verbal fluency (semantic and phonemic), reading single words, picture description and repetition tasks were not statistically significant in distinguishing between groups in this study. Scores achieved in all subtests apart from reading were higher in the HC group compared with the MCI group.

The main clinical implication for this study is the use of the most sensitive assessments from this cognitive linguistic assessment as a potential screening tool for identifying MCI. This includes picture naming, list learning, list recall, list recognition and potentially repetition. These subtests could be used in combination with a connected speech sample and analysed using automated speech analysis to ensure a sensitive screening tool that includes linguistic, acoustic and prosodic features.

This assessment was completed in digital form, this is a starting point for the future where cognitive screening can be completed quickly and even remotely as necessary. Linguistic, acoustic and prosodic features of a person's speech have been widely researched as potential screening tools for identifying cognitive impairment. This study is the first step in identifying which commonly used cognitive linguistic tasks may be used in combination with other acoustic or prosodic features of speech, automated speech analysis techniques or other behavioural markers e.g. gait.

Clinically, it can be difficult to objectively measure, as a SLT, subtle changes in someone's cognitive linguistic profile, however this study has the potential to facilitate this type of screening. Automated speech analysis alone has the potential to identify cognitive impairment as has been identified in the literature. However, combining other valid cognitive linguistic assessments may increase their predictive value.

Despite what we know about the benefits of timely diagnosis, less than 50% of those living with dementia in Ireland ever actually receive a diagnosis (Revez et al., 2018). This is a result of numerous factors including inequity in services nationwide, inconsistencies across diagnostic services and reduced awareness of dementia (HSE, 2023). Alongside a comprehensive service delivery model for dementia care in Ireland and adequate nationwide resourcing, we need increased dementia-related research and valid, quick, easily accessible screening tools to facilitate timely diagnosis and early intervention. This research study is one step in this process.

Reference List

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.). https://doi.org/10.1176/appi.books.9780890425787

American Speech-Language Hearing Association (ASHA). (2015). *Practice Portal: Dementia.* Retrieved from http://www.asha.org/PRPSpecificTopic.aspx?folderid=8589935289&section=Treatment

Bastardo, R., Pavão, J., Martins, AI., Silva, AG., Pacheco Rocha, N. (2022). A Scoping Review of Digital Solutions that Might be Used as Cognitive Screening Instruments of Community-Dwelling Older Adults. *Procedia Computer Science*, 196, 956-963.

Bayles, K. & Tomoeda, C. (1993). *Arizona battery for communication disorders of dementia(ABCD)*. Tucson, AZ: Canyonlands Publishing Inc.

Beauchamp, T. (2019). *The principle of beneficence in applied ethics*. (Spring 2019 ed.) Stanford Encyclopedia of Philosophy. Retrieved from https://plato.stanford.edu/archives/spr2019/entries/principle-beneficence/

Beauchamp, T. L., & Childress, J. F. (2013). *Principles of biomedical ethics* (7th ed.). Oxford: Oxford University Press.

Bellelli, G., Morandi, A., Davis, D.H., Mazzola, P., Turco, R., Gentile, S., Ryan, T., Cash, H., Guerini, F., Torpilliesi, T., Del Santo, F., Trabucchi, M., Annoni, G. & MacLullich, A.M. (2014). Validation of the 4AT, a new instrument for rapid delirium screening: a study in 234 hospitalised older people, *Age & Ageing*. 43:496-502.

Berg L. (1984). Clinical Dementia Rating. *The British journal of psychiatry : the journal of mental science*. 145, 339.

Berube, S., Nonnemacher, J., Demsky, C., Glenn, S., Saxena, S., Wright, A., Tippett, D. C., & Hillis, A. E. (2019). Stealing Cookies in the Twenty-First Century: Measures of

Spoken Narrative in Healthy Versus Speakers With Aphasia. *American journal of speech-language pathology*, 28(1S), 321–329.

Blaxter, L., Hughes, C. & Tight, M. (2010). *How to Research* (4th ed.) UK: Open University Press.

Bourgeouis, M. S. & Hickey, E. (2011). *Dementia: From diagnosis to management-a functional approach.* New York, NY: Taylor & Francis.

Calzà, L., Gagliardi, G., Rossini Favretti, R., & Tamburini, F. (2021). Linguistic features and automatic classifiers for identifying mild cognitive impairment and dementia. *Computer Speech & Language*, 65, 101-113.

Damian, A. M., Jacobson, S. A., Hentz, J. G., Belden, C. M., Shill, H. A., Sabbagh, M. N., Caviness, J. N., & Adler, C. H. (2011). The Montreal Cognitive Assessment and the mini-mental state examination as screening instruments for cognitive impairment: item analyses and threshold scores. *Dementia and geriatric cognitive disorders,* 31(2), 126–131.

Dooley, S. & Walshe, M. (2020). Management of Cognitive Communication Difficulties in Dementia: A Cross Sectional Survey of Speech and Language Therapists. Retrieved from http://dementianetwork.ie/management-cognitive-communication-difficulties-dementia-cross-sectional-survey-speech-language

De Looze, C., Kelly, F., Crosby, L., Vourdanou, A., Coen, R. F., Walsh, C., Lawlor, B. A., & Reilly, R. B. (2018). Changes in Speech Chunking in Reading Aloud is a Marker of Mild Cognitive Impairment and Mild-to-Moderate Alzheimer's Disease. *Current Alzheimer Research*, 15(9), 828-847.

Dubois, B., Slachevsky, A., Litvan, I., & Pillon, B. (2000). The FAB: a Frontal Assessment Battery at bedside. *Neurology*, 55(11), 1621–1626.

Eyigoz, E., Mathur, S., Santamaria, M., Cecchi, G., & Naylor, M. (2020). Linguistic markers predict onset of Alzheimer's disease. *EClinicalMedicine,* 28, 100583.

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods,* 39, 175-191.

Filiou, R.-P., Bier, N., Slegers, A., Houzé, B., Belchior, P., & Brambati, S. M. (2019). Connected speech assessment in the early detection of Alzheimer's disease and mild cognitive impairment: a scoping review. Aphasiology, 34(6), 723-755.

Fisher, A. G. (1997). *Assessment of Motor and Process Skills*. (2nd ed.) Fort Collins, CO: Three Star Press.

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. *Journal of psychiatric research*, 12(3), 189–198.

Galvin, J. E., Roe, C. M., Powlishta, K. K., Coats, M. A., Muich, S. J., Grant, E., Miller, J. P., Storandt, M., & Morris, J. C. (2005). The AD8: a brief informant interview to detect dementia. *Neurology*, 65(4), 559–564.

Gavett, B. E., Poon, S. J., Ozonoff, A., Jefferson, A. L., Nair, A. K., Green, R. C., & Stern, R. A. (2009). Diagnostic utility of the NAB List Learning test in Alzheimer's disease and amnestic mild cognitive impairment. *J Int Neuropsychol Soc*, 15(1), 121-129.

Gibb, M. & Begley, E. (2017). A Guide to Memory Clinics in Ireland. (4th ed.). Dublin: Dementia Services Information and Development Centre.

Goodglass, H., Kaplan, E., Barresi, B. (2001). *Boston Diagnostic Aphasia Examination-Third Edition (BDAE-3)*. San Antonio: Pearson.

Health Service Executive (2020). Estimated Dementia Prevalence. Retrieved from http://dementiapathways.ie/permacache/fdd/cf3/792/e223695cf65ee173882bdc394de3a8fc.pdf

Helm-Estabrooks, N. (2001). *Cognitive linguistic quick test: CLQT.* USA: Psychological Corporation.

Hoffmann, I., Nemeth, D., Dye, C.D., Pákáski, M., Irinyi, T. & Kálmán, J. (2010). Temporal parameters of spontaneous speech in Alzheimer's disease. *International Journal of Speech-Language Pathology*, 12:1, 29-34.

Howitt, D. & Cramer, D. (2017). *Research methods in psychology* (5th ed.). UK: Pearson.

Hsieh, S., Schubert, S., Hoon, C., Mioshi, E. & Hodges, J.R. (2013). Validation of the Addenbrooke's Cognitive Examination III in Frontotemporal dementia and Alzheimer's disease. *Dement Geriatr Cogn Disord*. 36, 242-250.

Huff, F.J., Corkin, S., & Growdon, J. H. (1986). Semantic impairment and anomia in Alzheimer's disease. *Brain and Language*, 28(2) 235-249.

Irish Association Of Speech And Language Therapists. (2016). *IASLT Position Statement. Speech And Language Therapy Provision For People With Dementia*. Dublin: IASLT.

Jokel, R., Seixas Lima, B., Fernandez, A., & Murphy, Kelly J. (2019). Language in Amnestic Mild Cognitive Impairment and Dementia of Alzheimer's Type: Quantitatively or Qualitatively Different? *Dementia and Geriatric Cognitive Disorders Extra*, 9(1), 136-151.

Kaplan, E., Goodglass, H. & Weintraub, S. (1983). *Boston naming test.* Texas, USA: Pro-ed.

Kremen, W. S., Elman, J. A., Panizzon, M. S., Eglit, G. M. L., Sanderson-Cimino, M., Williams, M. E., Lyons, M. J., & Franz, C. E. (2022). Cognitive reserve and related constructs: A unified framework across cognitive and brain dimensions of aging. *Frontiers in aging neuroscience,* 14, 834765.

König, A., Satt, A., Sorin, A., Hoory, R., Toledo-Ronen, O., Derreumaux, A., Manera, V., Verhey, F., Aalten, P., Robert, P. H., & David, R. (2015). Automatic speech analysis for the assessment of patients with predementia and Alzheimer's disease. *Alzheimer's & dementia*, *1*(1), 112–124.

König, A., Zeghari, R., Guerchouche, R., Duc Tran, M., Bremond, F., Linz, N., Lindsay, H., Langel, K., Ramakers, I., Lemoine, P., Bultingaire, V., & Robert, P. (2021). Remote cognitive assessment of older adults in rural areas by telemedicine and automatic speech and video analysis: protocol for a cross-over feasibility study. *BMJ open*, 11(9), e047083.

Laake, P. & Benestad, H.B. & Olsen, B.R. (2015). *Research in Medical and Biological Sciences: From Planning and Preparation to Grant Application and Publication*. UK: Elsevier.

Lanzi, A. M., Saylor, A. K., & Cohen, M. L. (2022). Survey results of speech-language pathologists working with cognitive-communication disorders: Improving practices for mild cognitive impairment and early-stage dementia from Alzheimer's disease. *Am J Speech Lang Pathol*, 31(4), 1653-1671.

Lavrakas, P.J. (2008). *Encyclopedia of survey research methods*. Thousand Oaks, CA: Sage Publications, Inc.

Martinez-Nicolas, I., Llorente, T. E., Martinez-Sanchez, F., & Meilan, J. J. G. (2021). Ten Years of Research on Automatic Voice and Speech Analysis of People With Alzheimer's Disease and Mild Cognitive Impairment: A Systematic Review Article. *Front Psychol*, 12, 620251.

McCullough, K. C., Bayles, K. A., & Bouldin, E. D. (2019). Language Performance of Individuals at Risk for Mild Cognitive Impairment. *J Speech Lang Hear Res*, 62(3), 706-722.

McDonnell, M., Dill, L., Panos, S., Amano, S., Brown, W., Giurgius, S., Small, G., & Miller, K. (2020). Verbal fluency as a screening tool for mild cognitive impairment. *Int Psychogeriatr*, 32(9), 1055-1062.

McKhann, G. M., Knopman, D. S., Chertkow, H., Hyman, B. T., Jack, C. R., Jr, Kawas, C. H., Klunk, W. E., Koroshetz, W. J., Manly, J. J., Mayeux, R., Mohs, R. C., Morris, J. C., Rossor, M. N., Scheltens, P., Carrillo, M. C., Thies, B., Weintraub, S., & Phelps, C. H. (2011). The diagnosis of dementia due to Alzheimer's disease: recommendations from the National Institute on Aging-Alzheimer's Association workgroups on

diagnostic guidelines for Alzheimer's disease. *Alzheimer's & dementia : the journal of the Alzheimer's Association*, 7(3), 263–269.

Mueller, K.D., Koscik, R.L., Hermann, B.P., Johnson, S.C. & Turkstra, L.S. (2018). Declines in connected language are associated with very early mild cognitive impairment: Results from the Wisconsin Registry for Alzheimer's Prevention. *Front. Aging Neurosci*. 9, 437.

Mueller, K. D., Van Hulle, C. A., Koscik, R. L., Jonaitis, E., Peters, C. C., Betthauser, T. J., Christian, B., Chin, N., Hermann, B. P., & Johnson, S. (2021). Amyloid beta associations with connected speech in cognitively unimpaired adults. *Alzheimers Dement*, 13(1), e12203.

Nasreddine, Z. S., Phillips, N. A., Bédirian, V., Charbonneau, S., Whitehead, V., Collin, I., Cummings, J. L. & Chertkow, H. (2005). The Montreal Cognitive Assessment, MoCA: a brief screening tool for mild cognitive impairment. *Journal of the American Geriatrics Society,* 53, 695-699.

National Dementia Office. (2023). *Model of Care for Dementia in Ireland*. Tullamore: National Dementia Office.

National Institute for Health and Care Excellence. (2018). *Dementia: assessment, management and support for people living with dementia and their carers*. [NICE guideline no. 97] Retrieved from https://www.nice.org.uk/guidance/ng97/resources/dementia-assessment-management-and-support-for-people-living-with-dementia-and-their-carers-pdf-1837760199109

Nicholas, L. E., & Brookshire, R. H. (1993). A system for quantifying the informativeness and efficiency of the connected speech of adults with aphasia. *Journal of speech and hearing research*, *36*(2), 338–350.

Ohman, F., Hassenstab, J., Berron, D., Scholl, M., & Papp, K. V. (2021). Current advances in digital cognitive assessment for preclinical Alzheimer's disease. *Alzheimers Dement*, 13(1), e12217.

Ostrand, R & Gunstad, J. (2021). Using automatic assessment of speech production to predict current and future cognitive function in older adults. *J Geriatr Psychiatry Neurol*. 34(5), 357-369.

Paplikar, A., Varghese, F., Alladi, S., Vandana, V. P., Darshini, K. J., Iyer, G. K., Kandukuri, R., Divyaraj, G., Sharma, M., Dhaliwal, R. S., Kaul, S., Saroja, A. O., Ghosh, A., Sunitha, J., Khan, A. B., Mathew, R., Mekala, S., Menon, R., Nandi, R., . . . Consortium, I. N. C. T. B. (2022). Picture-naming test for a linguistically diverse population with cognitive impairment and dementia. *Int J Lang Commun Disord*, 57(4), 881-894.

Randolph, C., Tierney, M. C., Mohr, E., & Chase, T. N. (1998). The Repeatable Battery for the Assessment of Neuropsychological Status (RBANS): Preliminary clinical validity. *Journal of Clinical and Experimental Neuropsychology, 20*(3), 310–319.

Revez, A., Timmons, S., Fox, S., Murphy, A., O'Shea. E. (2018). *Dementia Diagnostic Services for Ireland: a literature review.* Tullamore: National Dementia Office.

Richardson J. T. (2007). Measures of short-term memory: a historical review. *Cortex; a journal devoted to the study of the nervous system and behavior*, *43*(5), 635–650.

Robin, J., Harrison, J. E., Kaufman, L. D., Rudzicz, F., Simpson, W., & Yancheva, M. (2020). Evaluation of speech-based digital biomarkers: review and recommendations. *Digit Biomark*, 4(3), 99-108.

Robin, J., Xu, M., Kaufman, L. D., & Simpson, W. (2021). Using digital speech assessments to detect early signs of cognitive impairment. *Front Digit Health*, 3, 749758.

Royal College of Speech and Language Therapists. 2014. *Speech and Language Therapy Provision for People with Dementia*. London, UK: RCSLT.

Saccasan, N., & Scerri, C. (2020). Dementia knowledge, attitudes and training needs of speech-language pathology students and practitioners: A countrywide study. *Int J Lang Commun Disord*, 55(6), 955-970.

Sanborn, V., Ostrand, R., Ciesla, J., & Gunstad, J. (2022). Automated assessment of speech production and prediction of MCI in older adults. *Appl Neuropsychol Adult*, 29(5), 1250-1257.

Savage, S., Hsieh, S., Leslie, F., Foxe, D., Piguet, O., & Hodges, J. R. (2013). Distinguishing subtypes in primary progressive aphasia: application of the Sydney language battery. *Dementia and geriatric cognitive disorders, 35*(3-4), 208–218.

Stephan, B.C.M., Minett, T., Muniz Terrara, G., Mathews, F.E., & Brayne, C. (2015) Dementia Prediction for People with Stroke in Populations: Is mild cognitive impairment a useful concept? *Age & Aging*, 44(1), 78 -83.

Stommel, M. & Wills, CE. (2004). *Clinical Research Concepts and Principles for Advanced Practice Nurses*. US: Lippincott Williams & Wilkins.

Sung, JE., Choi, S., Eom, B., Keun Yoo, J. & Hyang Jeong, J. (2020). Syntactic complexity as a linguistic marker to differentiate mild cognitive impairment from normal aging. *Journal of Speech, Language & Hearing Research*, 63(5), 1416-1429.

Swinburn, K., Porter, G. & Howard, D. (2004). *Comprehensive aphasia test.* London: Taylor & Francis.

Taler, V., Monetta, L., Sheppard, C., & Ohman, A. (2019). Semantic Function in Mild Cognitive Impairment. *Front Psychol*, 10, 3041.

Timko, R.M. & Hoff, J. W. (2001). *Clinical Ethics: Due Care and the Principle of Nonmaleficence*. US: University Press of America.

Thomas, J. A., Burkhardt, H. A., Chaudhry, S., Ngo, A. D., Sharma, S., Zhang, L., Au, R., & Hosseini Ghomi, R. (2020). Assessing the Utility of Language and Voice Biomarkers to Predict Cognitive Impairment in the Framingham Heart Study Cognitive Aging Cohort Data [Research Support, N.I.H., Extramural Research Support, U.S. Gov't, Non-P.H.S.]. *Journal of Alzheimer's Disease*, 76(3), 905-922.

Tröger, J., Baykara, E., Zhao, J., ter Huurne, D., Possemis, N., Mallick, E., Schäfer, S., Schwed, L., Mina, M., Linz, N., Ramakers, I. & Ritchie, C. (2022). Validation of the remote automated ki:e speech biomarker for cognition in mild cognitive impairment: verification and validation following DiME V3 Framework. *Digit Biomark*, 6,107-116.

Varkey B. (2021). Principles of Clinical Ethics and Their Application to Practice. Medical principles and practice. *International Journal of the Kuwait University, Health Science Centre*, 30(1), 17–28.

Volkmer, A. (2013). *Assessment and therapy for language and cognitive communication difficulties in dementia and other progressive diseases.* Guilford, UK: J&R Press.

Wear, H. J., Wedderburn, C. J., Mioshi, E., Williams-Gray, C. H., Mason, S. L., Barker, R. A., & Hodges, J. R. (2008). The Cambridge Behavioural Inventory revised. *Dementia & neuropsychologia*, 2(2), 102–107.

Whelan, R., Barbey, F. M., Cominetti, M. R., Gillan, C. M., & Rosická, A. M. (2022). Developments in scalable strategies for detecting early markers of cognitive decline. *Translational Psychiatry*, 12(1), 473.

Wilson, S. M., Eriksson, D. K., Schneck, S. M., & Lucanie, J. M. (2018). A quick aphasia battery for efficient, reliable, and multidimensional assessment of language function. *PloS* one, *13*(2), e0192773.

Wisler, A. A., Fletcher, A. R., & McAuliffe, M. J. (2020). Predicting Montreal Cognitive assessment scores from measures of speech and language. *Journal of Speech Language & Hearing Research*, 63(6), 1752-1761.

World Health Organization. (2017). *Global action plan on the public health response to dementia 2017–2025*. World Health Organization.

Yamada, Y., Shinkawa, K., Kobayashi, M., Caggiano, V., Nemoto, M., Nemoto, K., & Arai, T. (2021). Combining multimodal behavioral data of gait, speech, and drawing for

classification of Alzheimer's disease and mild cognitive impairment. *J Alzheimers Dis*, 84(1), 315-327.

Yeung, A., Iaboni, A., Rochon, E., Lavoie, M., Santiago, C., Yancheva, M., Novikova, J., Xu, M., Robin, J., Kaufman, L. D., & Mostafa, F. (2021). Correlating natural language processing and automated speech analysis with clinician assessment to quantify speech-language changes in mild cognitive impairment and Alzheimer's dementia. *Alzheimers Res Ther*, 13(1), 109.

Zigmond, A. S., & Snaith, R. P. (1983). The hospital anxiety and depression scale. *Acta psychiatrica Scandinavica*, 67(6), 361–370.

Appendices

Appendix A Ethical Approval TUH

Approval Date: 22 July 2021 Submission Number: 95

Submission Title: GAS-Cog: Analysis of gait and speech characteristics as objective measures of cognitive performance in healthy aging, mild cognitive impairment, and mild dementia- a feasibility. Submission Date: 13/04/2021 07:52

Dear Professor Kennelly,

On behalf of the Chair and members of the SJH/TUH Joint Research Ethics Committee I wish to inform you that your study has received **FULL APPROVAL.** Your study can now proceed.

The following comments were made:

Title

3.2.1 What is the anticipated start date of this study?

3.2.8 Please select the method of randomisation

4.1.1.3 Please outline who will be the data controller of the coded study data

4.1.1.12.3.2 Please justify why video/audio recordings will be retained. How long will they be retained for? What safe-guards will be in place to protect the recordings and the participants identity?

4.1.1.12.3.2 Please justify why video/audio recordings will be retained. How long will they be retained for? What safe-guards will be in place to protect the recordings and the participants identity?

Comment
It is understood that the anticipated start date will be amended.

An error in the form gives this response, understood to be "N/A". The Data Controller is typically understood to be the institution/organisation. Typo: facial

Note: item not specified in the attached consent form (although referenced in the PIL).

Project ID: 0138

The following documents were reviewed and approved:

Document Type

Principle Investigator C.V.
GP Letter
Healthy Control Information Leaflet Healthy Control Consent Form Participant Information Leaflet Participant Consent Form

File Name

sean.kennelly_02.20_clinical_trial.CV GAS_cog study GP letter
GAS_Cog. PIL GAS_Cog.Consent_Form GAS_Cog. PIL GAS_Cog.Consent_Form

Please note that ethical approval for this study is only active under the following conditions:

1. *Applicantsmustsubmitanannualreportforongoingprojects.*
2. *Applicantsmustsubmitanendofstudydeclaration/endofstudyreportuponcompletionofthestudy.*
3. *AlladverseeventsmustbereportedtotheJREC.*
4. *Allchanges(minorandsubstantial)todocumentation/studymustbesubmittedtotheJRECusingtheamendmentrequestformandthechangesmust*

   be tracked/highlighted clearly. Approval from the JREC is required before implementation of the changes.

It is the responsibility of the researcher/research team to ensure all aspects of the study are executed in compliance with the General Data Protection regulation (GDPR), Health Research Regulations and the Data Protection Act 2018.

Yours sincerely,

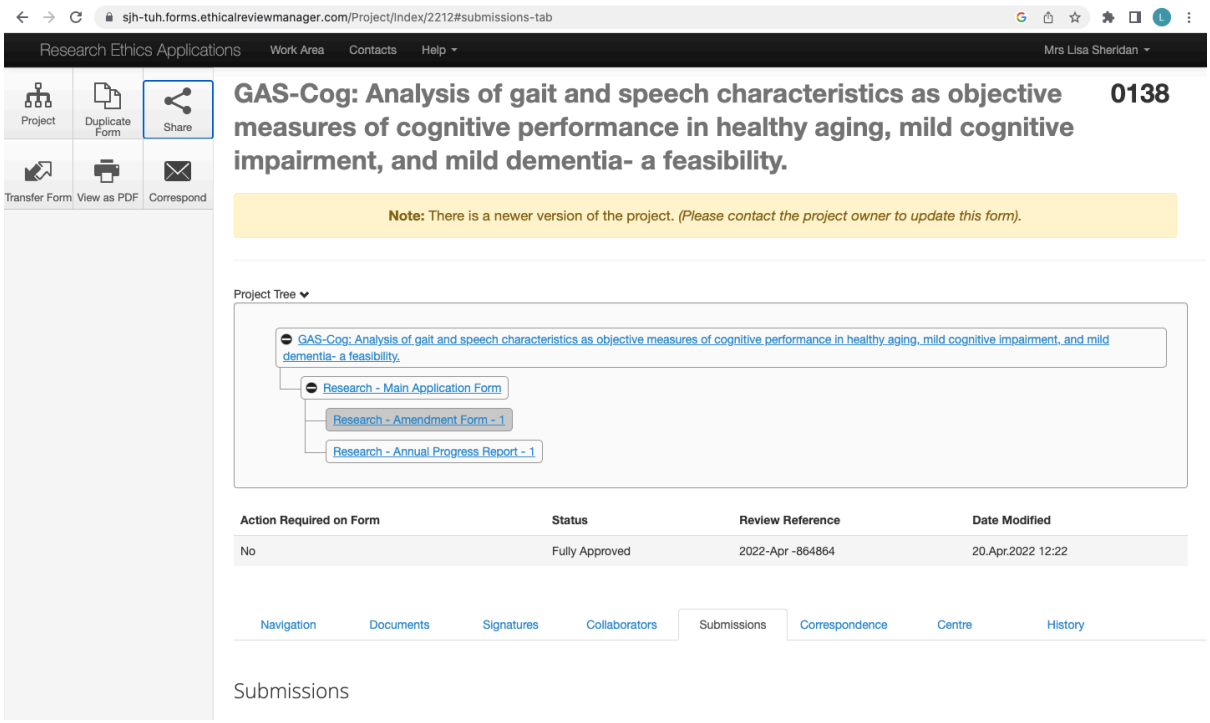
Ms Chita Murray

Research Ethics & Clinical Trials Manager,

SJH/TUH Joint Research Ethics Committee

The SJH/TUH Joint Research and Ethics Committee operates in compliance with and is constituted in accordance with the European Communities (Clinical Trials on Medicinal Products for Human Use) Regulations 2004 & ICH GCP guidelines.

Appendix B Ethics Amendment Form (electronically approved via electronic system)



Appendix C: Data Protection Impact Assessment (DPIA) approval

Tallaght University Hospital | Ospidéal Ollscoile Thamhlachta

An Academic Partner of Trinity College Dublin

Data Protection Impact Assessment (DPIA)

Purpose of Data Protection Impact Assessment The central focus of the DPIA is **data protection**. Its purpose is to identify the privacy and data protection impacts of any product, research or services to be offered. It helps identify the **personal data** (and, where applicable, special category personal data) to be processed and the potential risks to that data. This is to allow the risks to be assessed and to take the appropriate actions to prevent or, at the very least, minimise the risk of those impacts. DPIAs are required by the General Data Protection Regulation in some instances, particularly where a new product or service is likely to result in a high risk to the rights and freedoms of natural persons.

Instructions

DPIAs are not required in all instances. If your project contains corporate data, for example, a DPIA is not required.

In Section 1, you are asked a number of questions. This is to determine if a DPIA is required. If you answer 'yes' to at least one of these, you require a DPIA and must complete the rest of the form.

Threshold assessment - is a DPIA required?

Article 35 of the General Data Protection Regulation (GDPR) requires the Tallaght University Hospital (TUH) to conduct a DPIA if the introduction of a product, research or services processes personal data. A DPIA must be conducted if you intend to include any of the following:

Please enter Y or N as applicable.	**Y**	N

Transfer of data outside European Economic Area (EEA) countries Processing of vulnerable person's data or children's data Data shared with, or accessed by, third parties Personal data used to evaluate performance Data processing on a large scale Processing of large volumes of special category personal data* Outsourcing of patient samples to third parties for analysis Processing of genetic and/or biometric data. **Research study title**

Analysis of speech characteristics as objective measures of cognitive performance in healthy aging, mild cognitive impairment, and mild dementia- a feasibility study.

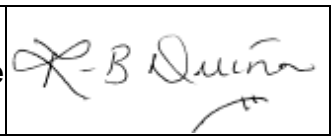
Signatures

DPO Review and Advice:

I confirm that I have read and reviewed the information in this document. Based on the information presented to me, I assess the risk as 'low'. I base this on the following: (i) the level of personal detail collected is minimal; (ii) it is pseudonymised with the key held by TUH; (iii) anonymous data is only accessible by the service provider; (iv) access to information is limited to TUH and the service provider; and (v) it is not transferred within or outside the EEA.

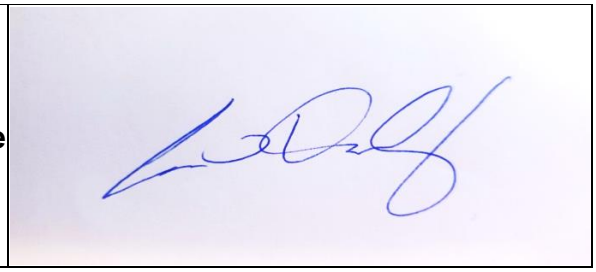
Overall Study risk rating
DPO Name Dr Ruth-Blandina Quinn

Date 25 January 2022 High ☐ Medium ☐ Low☒

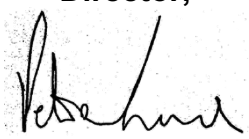
Signature	

DPIA prepared by:
Name Gavin O'Duffy
Title Chief Business Officer, Canary Speech

Date 26th January 2022

Signature	

DPIA Sign-off by EMT Director at Tallaght University Hospital Name Peter Lavin
Title Clinical Director, Medical Directorate

Signature Date 31.01.2022 

DPO advice overruled/not accepted ☐ by whom_____ Explain reason for rejection:

Appendix D Participant Information Leaflet

Tallaght University Hospital | Ospidéal Ollscoile Thamhlachta

An Academic Partner of Trinity College Dublin

PARTICIPANT INFORMATION LEAFLET

Analysis of speech and gait characteristics as objective measures of cognitive performance in healthy aging, mild cognitive impairment, and early-stage dementia- a feasibility study

We would like to invite you to take part in a research study to be carried out at Tallaght University Hospital to understand how we can use assessment of speech (How we talk) and gait (How we walk) as measures of cognitive (memory and thinking) performance. Your decision to take part is entirely voluntary. Before you decide whether or not to take part, you should understand the benefits and risks of the study. This is called "informed consent". If you choose not to take part, this will have no effect on your medical care or treatment. This information sheet explains what taking part would involve. Please read it carefully, discuss it with others if you wish, and ask if anything is unclear or if you would like more details.

PART 1 – THE STUDY

Why is this study being done?

The purpose of the study is to examine elements of gait, speech and language characteristics that may be used as objective measures of cognitive performance and potential indicators of cognitive decline, thereby facilitating timely access to diagnosis and potential therapies. As well as measuring these by traditional assessments, we will assess the use of more novel artificial intelligence enabled devices to support identification of cognitive change.

Why am I being asked to take part?

You have been chosen to participate because you are aged 50 or over and are in either one of the following groups: 1) you have no cognitive difficulties; 2) you have been given

a diagnosis of mild cognitive impairment or 3) you have been given a diagnosis of mild dementia. You also meet the criteria set by the researcher.

Do I have to take part? What happens if I say no? Can I withdraw?

You do not have to take part in this study. Participation in this study is entirely voluntary. If you decide not to participate this will not affect your current or future medical care. You can change your mind about taking part in the study and opt out at any time even if the study has started. If you decide to opt out, it won't affect your current or future medical care. You don't have to give a reason for not taking part or for opting out.

If you wish to opt out, please contact the research team (contact details at the end of this leaflet), and we will be able to organise this for you. If you decide later that you do not wish for your confidential data to be processed as part of the study, you can email or phone us at any time.

How will the study be carried out?

This study will take place in the Age-Related Healthcare department in Tallaght University Hospital. A maximum of seventy-five adults will participate in this study. After a minimum time period of three days of having received this information leaflet and the consent form, researchers will contact you to discuss the study and to answer any questions. If you are happy to be involved, the consent form will be signed and an appointment will be made for you to attend the Age Related Healthcare department in Tallaght University Hospital. Assessments of speech, language, gait and cognition will then be completed.

What will happen to me if I agree to take part?

If you agree to take part in this study an appointment will be made for you to attend the Age-Related Healthcare department in Tallaght University Hospital. We will take note of your medical diagnoses, medications, and record some basic physical performance measures (Height, weight, grip strength). We will also perform some brief walking tests on a special mat with sensors called a GAITRite mat, and we will also assess how you walk using a video enabled device called GaitKeeper. This will take 10 minutes in total, and the videos will be stored on a secure hard drive which only the research team have access to. Following this we will do some brief memory tests including a Mini Mental State Examination (MMSE) and a computerized cognitive assessment (CANTAB) which takes about 25 minutes in total. Following a break you will have an assessment of your speech and language which will take about 35 minutes. This part of the assessment will be recorded using a digital voice recorder and these recordings will be stored on a secured hard drive which only the research team can access. Following a standardized training session you will also be asked to engage in digital speech/voice analysis by completing a brief 5-minute self-administered speech assessment on a smart phone application that has been developed by our co-investigators Canary Speech. This phone/tablet application will be downloaded to your personal phone or that of someone you are in regular contact with who is willing to support the study. Total testing time will not exceed 90 minutes.

This detailed assessment will then be repeated at 3-month and 6-month intervals.

Participants will complete the brief self-administered speech/voice assessment via the Canary Speech phone/tablet application every two weeks for 6 months and will be supported in doing this by the study team.

Are there any benefits to me or others if I take part in the study?

The study will not directly benefit you but your contribution will help us to gain valuable information about the characteristics of speech and gait and how reliable they are as objective measures of cognitive performance. This may inform future recommendations for treatment and research.

Are there any risks to me or others if I take part in the study?

There are no anticipated risks associated with this research study.

What will happen if something goes wrong when I'm taking part in the study?

If you have a concern about any aspect of this study, you should ask to speak to the researchers who will do their best to answer your questions (contact details at the end of this leaflet). This study is fully insured by the hospital.

Will I be told the outcome of the study? Will I be told the results of any tests or investigations performed as part of this study that relate to me?

We will write to you and let you know the overall outcome of the study. The results will be presented at national and international conferences and will be published in scientific journals. All published information will be confidential and you will not be identified personally. The results of the study will also inform further development for applications of this type with Canary Speech.

PART 2 – DATA PROTECTION

What information about me (personal data) will be used as part of this study? Will my medical records be accessed?

The following personal data will be collected: name, age, gender, weight, height, literacy, frailty status, grip strength, hearing, vision, comorbid illness, cognitive diagnosis. Your medical records will be accessed for some of this information. Your name will not be noted with the above information so you cannot be identifiable. Each participant will be assigned a number at the beginning of the study and it will be used throughout the study.

Your personal information will remain confidential. Your name will not be used, published or discussed by the researchers.

What will happen my personal data?

Your personal information will remain confidential. Your name will not be used, published or discussed by the researchers. The data from this study will be used for the purposes of this study only. Only Tallaght University Hospital staff will have access to your clinical notes and only data relevant to the study question and outlined in this application will be recorded. Participants will be issued a trial number separate to their hospital ID and other identifiers. Only TUH staff will have access to the key for these identifiers, and this will be stored on a secure encrypted hard drive. Data will be stored on encrypted hard drives and servers located in Tallaght University Hospital. Other members of the research team outside of Tallaght University Hospital will only have access to the trial number as the identifier.

Your data will be used in accordance with GDPR articles 6 (6(1)(e)) and 9 (9(2)(j)) until the point of withdrawal. Data will be stored for five years, in line with the Data Protection Law (2018), after which time it will be destroyed.

Who will access and use my personal data as part of this study?

The principal investigators and co-investigators will have access to data from this study. The researchers will need to know your age, gender, medical diagnoses and any other relevant medical information, however this data will be made anonymous. Your name will not be noted with this information so you cannot be identifiable. The data will be kept in Tallaght University Hospital only.

Will my personal data be kept confidential? How will my data be kept safe?

Yes, your personal information will remain confidential. Your name will not be used, published or discussed by the researchers. Each participant will be assigned a number at the beginning of the study and it will be used throughout the study. The data from this study will be used for the purposes of this study only. All data will be anonymous and stored on encrypted hard drives and servers in a research office in Age Related Healthcare department in Tallaght University Hospital. Data will be stored for 5 years, in line with the Data Protection Law (2018), after which time it will be destroyed. Any data presented at medical conferences or published in medical journals will be anonymised.

What is the lawful basis to use my personal data?

The lawful basis for the use of your data is in accordance with GDPR articles 6 and 9 – specifically:

6(1)(e): Processing is necessary for the performance of a task carried out in the public interest or in the exercise of official authority vested in the controller

9(2)(j): Processing is necessary for archiving purposes in the public interest, scientific or historical research purposes or statistical purposes in accordance with Article 89(1) based on Union or Member State law which shall be proportionate to the aim pursued, respect the essence of the right to data protection and provide for suitable and specific measures to safeguard the fundamental rights and the interests of the data subject.
Personal data

What are my rights?

As a participant you have the right to:

1. Access the data being held on you
2. Restrict the use of your data
3. Correct inaccuracies
4. Have information deleted
5. Data portability
6. Object to profiling

PART 3 – COSTS, FUNDING & APPROVAL

Will it cost me anything if I agree to take part?

It will not cost you anything if you agree to participate in this study.

Who is funding this study? Will the results study be used for commercial purposes?

Funding for this study has been given by Canary Speech Incorporated, this is an investigator led study, Canary Speech have sponsored this research. Researchers are not being paid to recruit participants.

Has this study been approved by a research ethics committee?

Yes, this study has received approval from Tallaght Hospital/ St. James' Hospital Joint Ethics Committee. The committee can be contacted at ResearchEthics@tuh.ie.

PART 4 – FUTURE RESEARCH

Will my personal data and/or biological material be used in future studies?

Following participation in this study, you will not be contacted again by the researchers. It is possible that the "coded" data collected in this study might be useful for other research taking place in the future in the area of dementia. We would like to ask you to consent to future use of your coded data in this research. Any researchers accessing this data will make sure that your data is protected to the same standard as this study. You may decide if you wish to have your data used in the future or not.

PART 5 – FURTHER INFORMATION

Where can I get further information?

If you have any questions, please contact:

- Lisa Sheridan, Senior Speech and Language Therapist, Tallaght University Hospital at 01-4142776/ Lisa.Sheridan@tuh.ie
- Ruth Ennis, Research Coordinator , Age-Related Healthcare, Tallaght University Hospital at 01-4143221/ Ruth.Ennis@tuh.ie

What happens if I wish to make a complaint?

If you wish to make a complaint you can contact any of the following:

- Lisa Sheridan 01-4142776/ Ruth Ennis 01-4143221
- Data Protection Officer: dpo@tuh.ie
- Research Ethics Committee: researchthics@tuh.ie

Appendix E Consent Form

CONSENT FORM

GAS-Cog: Analysis of gait and speech characteristics as objective measures of cognitive performance in healthy aging, mild cognitive impairment, and early-stage dementia- a feasibility study

To be completed by the **PARTICIPANT**:

I have read and understood the information leaflet.	YES □	NO □
I have had the opportunity to discuss the study, ask questions about the study and I have received satisfactory answers to all my questions.	YES □	NO □
I have received enough information about this study.	YES □	NO □
I understand that I am free to withdraw from the study at any time without giving a reason and this will not affect my future medical care.	YES □	NO □
I agree to allow the researchers use my information (personal data) as part of this study as outlined in the information leaflet.	YES □	NO □
I understand that the purpose of this study is to examine elements of gait, speech and language characteristics that may be used as objective measures of cognitive performance and potential indicators of cognitive decline.	YES □	NO □
I agree to be contacted by researchers as part of this study.	YES □	NO □
I understand that my GP will be informed that I am participating in this study.	YES □	NO □
I consent to take part in this research study having been fully informed of the risks, benefits and purpose of the study.	YES □	NO □
I give my explicit consent to have my data processed as part of this research study.	YES □	NO □

Participant's Name (Block Capitals):	
Participant's Signature:	
Date:	

To be completed by the **RESEARCHER**:

I have fully explained the purpose and nature (including benefits and risks) of this study to the participant in a way that he/she could understand. I have invited him/her to ask questions on any aspect of the study.	YES □	NO □
I confirm that I have given a copy of the information leaflet and consent form to the participant.	YES □	NO □

Researcher's Name (Block Capitals):	
Researcher's Title & Qualifications:	
Researcher's Signature:	
Date:	

Appendix F GP Letter

Tallaght University Hospital

GAS-Cog: Analysis of gait and speech characteristics as objective measures of cognitive performance in healthy aging, mild cognitive impairment, and mild dementia- a feasibility study.

Professor Seán Kennelly MB, PhD, FRCP (Lond), FRCPI,
Consultant Physician in Geriatric and Stroke Medicine,
Director of Memory Assessment and Support Service,
Department of Age-Related Healthcare,
Tallaght University Hospital

Dear GP,

Your patient, (insert name and DOB), has consented to participate in the above titled study.

As part of this study, participants will have a computerised cognitive assessment, a speech and language assessment and a gait assessment. Every two-weeks a short language assessment will be recorded remotely. At three-months and six-months the baseline gait, speech and language, and cognitive assessments are repeated in the gerontechnology research laboratory in the department of Age-Related Healthcare in Tallaght University Hospital.

Participation in this study will not affect any care or treatment the patient is due to receive at any point. Participants are free to withdraw from the study at any time.

More detailed information about the study and contact details for the study team are provided in the attached participant information sheet. If you require any additional information about any part of the study please contact the study team directly.

Kind regards,

Professor Sean Kennelly
Lisa Sheridan, Clinical Specialist SLT
Principal Investigators

Appendix G Data Collection Form

Tallaght University Hospital | Ospidéal Ollscoile Thamhlachta

An Academic Partner of Trinity College Dublin

Data Collection Form

Participant Identifier: _____

Group: Healthy Control □ MCI □ Mild dementia due to AD □

Time at beginning of protocol: _____

1. **Demographics:**

Age: _____ Gender: Male □ Female □ Other □

Years of education: _____

Hearing: WNL □ Difficulty identified □ Hearing aids: Yes □ No □
Vision: WNL □ Difficulty identified □ Glasses: Yes □ No □

Date of cognitive diagnosis: _____ CSF biomarkers: Yes □ No □

2. **Baseline Cognitive Screen:**

MoCA Score: _____

3. **Baseline Comprehension Assessment:**

CAT Sentence Level: _____
CAT Paragraph Level: _____

4. Cognitive Communication Assessment using Canary App

List learning:

List	*Trial 1*	*Trial 2*	*Trial 3*	*Trial 4*
Knee				
Parcel				
Fabric				
Orange				
Story				
Meadow				
Tyre				
Dust				
Honey				
Bottle				
Score	/10	/10	/10	/10

Digit Span Forward:

Item	*Response*
29	
826	
6543	
51327	
321842	
6723695	
14853627	
916825374	
Score	/8

Digit Span Backward:

Item	*Correct response*	*Response*
13	31	
174	471	
8635	5368	
61843	34816	
539417	714935	
4739126	6219374	
93467258	85276439	
753921861	168129357	
Score		/8

Verbal Fluency: (animals)

1-15 secs	*15-30 secs*	*30-45 secs*	*45-60 secs*	*Total*

Verbal Fluency: (s words)

1-15 secs	*15-30 secs*	*30-45 secs*	*45-60 secs*	*Total*

Picture Naming:

Item	*Response*	*Comment*
Crab		
Pineapple		
Trumpet		
Crocodile		
Drum		
Unicorn		
Funnel		
Stethascope		
Asparagus		
Rhinocerous		
Score	/10	

Perseveration □ Phonemic paraphasias □ Semantic paraphasias □ Delays □

Reading:

Item	Response
Cough	
Sew	
Dough	
Choir	
Yacht	
Score	/5

Repetition:

Item	*Response*
Nose	
Window	
Radio	
Computer	
Butterfly	
Stethoscope	
Prosperity	
Hieroglyphics	
The dog chased the bird	
They chose to paint the room purple	
The popular architect created masterpieces	
The man and woman drove through the countryside at night	
The detective sought information following the catastrophe	

The ambitious journalist paved the way for further endeavours	
Score	/14

List recall:

Item	
Knee	
Parcel	
Fabric	
Orange	
Story	
Meadow	
Tyre	
Dust	
Honey	
Bottle	
Score	/10

List Recognition:

Bottle	**Tyre**
Chair	Pencil
Fabric	**Dust**
Orange	**Story**
Elbow	Flower
Rose	**Knee**
Cloud	Piano
Parcel	Sun
Kite	**Honey**
Meadow	Crown
Score	/20

Picture description:

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

Number of ICUs: _____
Word finding difficulties □ Hesitations □ Delays □ Dysfluencies □

Overall impression:
Cognitive communication deficits identified: Yes □ No □
Mild □ Moderate □ Severe □

5. Gait Assessment

Single task: Trial 1 _____ cm/sec Trial 2 _____ cm/sec
Dual task: Trial 1 _____ cm/sec Trial 2 _____ cm/sec

Appendix H Log of Edits

Date	Edit made
15/03/22	Volume/brightness on tablet reverting to original after each use, documented volume and brightness level to remain as standard throughout the study
11/04/22	User interface updated as buttons for participants too small/ not clear; changed to large “Listen Here” button
11/04/22	Previous audio items in digit span remain in “play” mode when moved to next task, updated so previous items stop immediately when you move to the next task
13/06/22	Digit span and repetition task recording not starting immediately following audio, potential for speech to be missed, updated so that recording begins immediately as audio finishes
13/06/22	Increased brightness from windows in study room on one wall impacting tablet view, area for testing moved to other wall for optimal testing environment
13/06/22	Time increased for picture description response from 1 minute to 2 minutes
13/06/22	Connection dropping with app during testing resulting in lost data, app developers created new version which combated this issue