Exploring Interrelationships Between Lifestyle and Demographic Factors Associated With Cognitive Functioning in Mid-to-Older New Zealanders

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Abstract

As the population ages, concerns around age-related conditions such as dementia rise. Characterised by severe cognitive impairment and thus significant reductions in cognitive functioning, beginnings of dementia can present in midlife and cause considerable challenges such as reduced functionality. The aim of the present study was to better understand the factors affecting cognitive functioning to inform a preventative focus.

The present cross-sectional study investigated relationships between socioeconomic status (represented by education, income, current occupational status, and a composite variable) and cognitive functioning (measured using the 'Kiwi' Addenbrooke's Cognitive Examination-Revised). This was assessed alongside sex and lifestyle-based modifiable risk (measured using a short-form Lifestyle for Brain Health (LIBRA) index). Data was sourced from the 2010 New Zealand Longitudinal Study of Ageing (NZLSA) cohort and included a subset of participants who had undertaken the voluntary cognitive assessments ($N = 869$, aged 48-75, 46.7% male, 26.4% Māori).

Preliminary analyses (Kruskal-Wallis and Mann-Whitney) indicated that lower education, lower income, non-employment, male sex, and higher LIBRA tertile (indicative of a less brain healthy lifestyle) were associated with lower cognitive functioning. However, hierarchical multiple regression modelling indicated that, once controlling for covariates, only higher educational attainment ($B = 1.48$, 95% CI = [1.16, 1.80], $p < 0.001$), female sex ($B = 1.26$, 95% CI = [0.62, 1.89], $p < 0.001$), and lower LIBRA scores ($B = -0.53$, 95% CI = [-0.84, -0.22], $p < 0.001$) (along with covariates of younger age and non-Māori ethnicity) remained independently related to higher cognitive functioning. While the main-effects model explained 19% of variance, interaction terms testing moderation between independent variables were insignificant and unable to improve model fit.

Findings suggest independent variables of education, sex, and lifestyle-based modifiable risk (LIBRA scores) all predict cognitive functioning individually, but not interactively. Thus, suggesting parallel and independent pathways of influences. Strategies to increase brain health should therefore support targeted interventions that address each factor directly and independently for healthier cognitive functioning. Future studies incorporating longitudinal data that utilises the full 12 factor LIBRA scale may be able to reveal more nuanced interactions and identify those most vulnerable.

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Chapter One: Introduction and Overview

This chapter will serve as an introduction and provide background for the present thesis. It will appraise the research concerning the current population in Aotearoa, New Zealand, provide discussion on the significant public health concerns of dementia, and also delve into an introduction of factors that may affect cognitive functioning within these populations.

A Global and Local Overview of the Ageing Population

The 'Silver Tsunami' and the 'greying population' are both terms that refer to the phenomenon of an ageing population. Over the past decades, this phenomenon has been recognised by many, with statements that the global population is experiencing a profound shift towards an older demographic (Dye et al., 2017; Gu et al., 2021; Pais et al., 2020). It is characterised by a sharp growth in the population of older adults aged 65 years and older. On a global scale, adults within this age group comprised 9.3% of the population in 2020, with expectancies of an increase to 15.9% by 2050 (Gu et al., 2021). The shift in proportions towards an older population is not just a coincidence but a product of factors such as a declining fertility rate (Beard et al., 2016; Gu et al., 2021) and modern advancements in public healthcare, and health technology (Gu et al., 2021). Overall, the changes in demographics signal a reshaping of society and suggest the need for structures that are able to better respond to the shifts in population proportion towards an older demographic.

Similar demographic trends are also apparent in Aotearoa, New Zealand (New Zealand), where over the past decades, significant shifts in the number of older adults, have resulted in numbers close to doubling from 0.44 million in 1998 to 0.74 million in 2020 (Parr-Brownlie et al., 2020). Within New Zealand, the older adult demographic accounts for approximately 15% of the population (Parr-Brownlie et al., 2020), thus reflecting global trends. Average life expectancies within New Zealand have risen to 80.0 years and 83.5 years, respectively for males and females (Statistics New Zealand, 2021). While this is an average of life expectancies across New Zealand, the isolated life expectancies for Māori (73.4 and 77.1 years, respectively for males and females) and Pasifika (75.4 and 79.0 years, respectively for males and females) are significantly lower (Statistics New Zealand, 2021). However, Māori life expectancy has now been steadily increasing (Dudley et al., 2019). Regardless, discrepancies between ethnic life expectancies (Blakely et al., 2005; Statistics New Zealand, 2021) are a major issue and are considered the result of health disparities and health inequities brought about through historical injustice, systemic racism, and present-day experiences, among others (Parr-Brownlie et al., 2020). Thus, the challenges of an ageing population in New Zealand are more than simply accommodating for larger numbers of older adults, but also about addressing inequitable health trajectories.

Implications of an Ageing Population and Middle Age Being a Critical Period

The demographic shift has presented unique sets of challenges for the health and well-being of older adults which need to be addressed. Although it may be a common misconception that living longer equates to better health for an extended period, this is, in general, not the case (Beard et al., 2016). This is because, in spite of increasing life expectancies, there is evidence to support increases in disability and disease burden among this population which affects quality of life (Chatterji et al., 2015). Consequently, advancing age and decreases in mortality are associated with decreases in functionality (Wood et al., 2005).

However, changes in functionality are not limited to older adults alone. The middle-aged adults, or adults between the ages of 45 and 64, also play a significant role in this shift, particularly due to many of the early signs of age-related changes and risk factors of health conditions being exhibited during this age period (Brown et al., 2020; Chatterji et al., 2015). Thus, an intervention or an administration of preventative health measures directed towards this group may result in significant and long-term outcomes. On the other hand, to visualise its necessity, although people are living longer, they are not necessarily gaining healthier life years (Chatterji et al., 2015). Thus, without taking preventative action, this age group could experience greater impairments at old-age than their predecessors (Brown et al., 2020).

Dementia: A Public Health Concern

As the population continues to age, the prevalence of neurodegenerative diseases such as dementia is also expected to rise (Takechi & Yoshino, 2023). This trend positions dementia as a significant public health concern, especially given the absence of an effective cure (Deckers et al., 2019a; Deckers et al., 2021; Zhang et al., 2022a). A point to note in the definition of dementia is its classification as an umbrella term. Thus, not every type of dementia is categorised as Alzheimer's disease (AD), however, AD is the most common type of dementia accounting for 60% of all cases followed by vascular dementia (VD) which accounts for 24 to 48% of all cases (Cherubini et al., 2010; Emrani & Sundermann, 2025; Mielke et al., 2014). Dementia is a condition consisting of symptoms such as decline in memory, changes in language and behaviour, and is essentially a state of progressive cognitive impairment (Cherubini et al., 2010). Therefore, people living with dementia become increasingly dependent on others for maintaining activities of daily life (Cherubini et al., 2010; Dyall, 2014), which has implications for quality of life and disability (Canavan & O'Donnell, 2022; Murman, 2015; Zhang et al., 2022b).

Dementia is often thought of as an issue that accompanies older age with a smaller portion (5%) of individuals at age 65 diagnosed with AD compared to those aged 85 years and above (40%) (Murman, 2015). However, the beginnings of dementia have been found to present themselves during midlife (Dyall, 2014). Within New Zealand, rates of dementia have also been observed to vary across ethnic groups. In 2011, 4% and 1.9% of those with a dementia diagnosis were those of Māori and Pasifika populations, respectively (Dyall, 2014). While these figures may seem low, it is important to note that only 60% of individuals received a formal dementia diagnosis (Dyall, 2014) which suggests potential underreporting. Almost a decade later, evidence also indicates that the most disadvantaged i.e. those that have an earlier onset of dementia (i.e. < 65 years) are those of Māori (19%), Pacific (18%) and Asian (16.8%) populations, respectively (Ma'u et al., 2021b). Thus, tackling these disparities and developing dementia care strategies that are culturally sensitive is a must and a crucial step to mitigate the impact of population ageing on the health and well-being of all New Zealanders. But first, to effectively combat dementia, it is critical to build knowledge within the New Zealand setting by first identifying conditions (such as cognitive impairment) that precede it, as well as the various factors that interact and affect its development.

Cognitive Functioning, Cognition Impairment, and its Implications

The decline in cognitive functioning is a common manifestation of older age but is also regarded as a critical component to maintain healthy ageing (the ability to sustain functional ability, both physically and mentally) (Beard et al., 2016). However, declines in cognitive functioning can begin from the age of 45 (Dye et al., 2017). Significant declines in cognitive functioning, referred to as cognitive impairment, is considered to be a hallmark of dementia (Roberts et al., 2010). In a systematic review conducted by Pais et al. (2020), it was found that cognitive impairment affected between 5.1% to 41.0% of people, globally. Although this range is large, the study results are of considerable importance due to the scarcity in reported prevalence of cognitive impairment, particularly within the New Zealand context.

Cognitive Impairment and its consequences are regarded as critical health care issues, particularly concerning the older population, and can include a reduced quality of life, loss of independence and lower life expectancy (Blazer et al., 2015). Not only does cognitive impairment have consequences associated with the individual such as a decreased quality of life, but, similarly to dementia, it has ripple effects on an individual's community (Blazer et al., 2015), along with costs associated with society (Takechi & Yoshino, 2023; Wang et al., 2023) which include but are not limited to medical, social care and family caregiver costs (Takechi & Yoshino, 2023). Thus, understanding the trajectory of declining cognitive functioning before it gets categorised as severe cognitive impairment and the associated changes that take place across the lifespan is a crucial process to develop interventions that may slow this trajectory. Essentially, it is important to better understand the nature and risk factors of lowered cognitive functioning due to its limited treatment options (Zhang et al., 2022a). Therefore, research within this field is important for working towards dementia prevention and is particularly important within regions such as New Zealand which consists of a large multicultural population.

Key Determinants of Cognitive Health

The pathways of cognitive health are complex. Biological mechanisms include oxidative stress (Deary et al., 2009; Fillit et al., 2002), neuronal loss (Fillit et al., 2002), hormonal dysregulation, and decline in immune function which are all possible core factors of cognitive decline (Deary et al., 2009). Genetic predispositions, particularly the APOE e4 allele, is a strong risk factor impacting brain health (Deary et al., 2009; Hugo & Ganguli, 2014). Additionally, inflammation is another key pathway where higher systemic inflammatory indices are linked to mild cognitive impairment (Mian et al., 2024). However, genetic and biological predispositions are only part of the larger picture. Social conditions and lifestyle behaviours also play a role in shaping cognitive trajectories which reflects the broader interaction and influence of social and environmental contexts on health outcomes. Accordingly, the present study will predominantly focus on the modifiable and contextual determinants of cognitive health. Specific factors include socioeconomic factors, sex, and lifestyle modifiable factors. Here, sex is conceptualised as a biological component within a biopsychosocial framework, interacting with social and behavioural contexts to influence cognitive outcomes. This approach recognises that while biology provides a foundation for individual differences, cognitive health is also shaped by social and environmental conditions.

Socioeconomic Status

Socioeconomic status (SES) is widely recognised as an influential factor affecting various aspects of health and well-being, including cognitive health (Dyall, 2014; Koster et al., 2005). SES can be understood to be a multidimensional measure of an individual's access to available resources (Wang et al., 2023; Zhang et al., 2015). Constructs of SES are not limited to individual-level SES factors such as education, income, and occupational status but can also include household income and area-based SES factors such as area-based socioeconomic deprivation (Röhr et al., 2024a).

In New Zealand, SES disparities remain substantial. Known for its diverse population and socio-cultural dynamics, these SES disparities may be due to several factors including social opportunity and are reflected in recent statistics. According to recent national statistics, approximately 8.5% of New Zealand households faced material hardship (i.e. poverty), while 36.1% of households stated their income to be barely sufficient to get by (Statistics New Zealand, 2024). These statistics indicate that the current New Zealand SES landscape is characterised by a mix of both affluence and poverty, but a large percentage of the population is disadvantaged and lives either on or below the poverty line which reflect broader structural inequities. This positions investigation of SES factors within the New Zealand landscape as a critical factor for brain health.

Sex

Sex has long been implicated to be a significant factor influencing aspects of health which includes cognitive health (Subramaniapillai et al., 2021). From a biological perspective, sex related differences in cognition may be partly attributed to hormones and their neural-preserving effects (Mielke et al., 2014; Subramaniapillai et al., 2021). However, biological factors alone cannot fully explain sex based differences in cognitive outcomes. A potential explanation of sex influences on health could be due to gender opportunities in economic resources. Current and historical differences between gender opportunities are well documented. In past decades, gender opportunities have risen, from women being unable to pursue much education to women in the present day overtaking men in terms of education and representing a significant part of the workforce (Bertrand, 2020; Jatrana, 2021). These gender opportunities can have implications for an individual's SES which then has implications for health and wellbeing (Jatrana, 2021; Stephens et al., 2022), including cognitive health (Hasselgren et al., 2020). Moreover, differences in health behaviours such as smoking and drinking are also present across the two sexes (Maylor et al., 2007; Mielke et al., 2014). Overall, differences across health behaviours can also contribute to cognitive health outcomes which underscores the necessity for sex to be examined alongside other lifestyle factors.

Lifestyle-Based Modifiable factors

In recent decades, lifestyle modifiable factors have gained increasing attention as key determinants in cognitive ageing. A wide range of modifiable behaviours have been identified as impacting cognitive functioning (Deckers et al., 2015; Livingston et al., 2020) with the recognition that they play a pivotal role in modulating cognitive outcomes across an individual's lifespan (Mian et al., 2024). This provides recognition that cognitive outcomes are shaped by more than just genetic predisposition. As the name suggests, the term 'modifiable factors' refers to aspects of lifestyle and behaviour which the individual has the ability to change or control to improve their health outcomes. This is in contrast to genetic predispositions, which makes lifestyle modifiable factors central to dementia prevention strategies. Modifiable factors can include but are not limited to the likes of diet, exercise, obesity, smoking, and alcohol consumption (Deckers et al., 2015; Ng et al., 2020). Collectively, in addition to others, modifiable factors form the basis of dementia prevention strategies by targeting risk that is changeable rather than irreversible pathology. Both global and local evidence suggest that past genetics, modifiable risk factors can account for significant proportions of dementia cases which indicates substantial space for prevention (Livingston et al., 2020; Ma'u et al., 2021a).

Summary

Overall, evidence indicates that cognitive functioning is a critical factor in healthy ageing. However, it is a multifactorial outcome that is shaped by more than primarily biological processes alone. Three primary determinants have been introduced and reviewed as impacting cognitive functioning substantially and include SES, sex, and lifestyle-based modifiable factors. Together these determinants can interact through a biopsychosocial framework which provides a foundation for understanding how intersectional (social, biological, behavioural) mechanisms shape cognitive health and dementia risk in the New Zealand population. By examining these factors collectively and exploring their interactions, it is possible to identify factors that interact to produce lower cognitive functioning. This can have implications for modifying dementia risk in vulnerable populations.

Chapter Two: Cognition

The following chapter will serve as an introduction to the topic of cognitive functioning and its fundamentality within human life. It identifies the various aspects of cognitive functioning and how its loss can have significant impacts. It also identifies cognitive functioning in the New Zealand context.

Cognition

Cognition is a fundamental aspect of being human. Although a difficult term to describe, it is said to include both crystallized (familiar and overlearned skills and resources) and fluid intelligence (problem solving of resources that are less-practiced and newer) and refers to an individual's ability to acquire, process and utilise information (Aajami et al., 2020; Harada et al., 2013). It is composed of various cognitive abilities/functions and domains such as attention, processing speed, memory, executive cognitive functioning and reasoning, language, and visuospatial abilities (Aajami et al., 2020; Blazer et al., 2015; Harada et al., 2013; Murman, 2015) and the sum of all cognitive functions is referred to as 'cognitive functioning' (Griva & Newman, 2021).

While cognitive functioning and functional status are treated as distinct constructs, there appears to be an association between cognitive ability and the capacity and ability to function (i.e. everyday activities) (Knight, 2000; Wood et al., 2005). Functionality refers to both motor function and being able to carry out activities of living (ADL) which include 'bathing, feeding, dressing and motor performance and instrumental activities' of daily living (IADL) which includes daily activities such as 'cooking, cleaning, finances, and shopping' (Knight, 2000, p. 1460). A loss in functionality has many implications, including the loss of independence which is categorised as a critical component in healthy ageing (Aajami et al., 2020; Blazer et al., 2015; Murman, 2015). Thus, optimal functioning within these domains is regarded as a crucial aspect of independent living, maintaining a good quality of life and the ability to sustain cognitive health (Blazer et al., 2015; Deary et al., 2009).

Cognitive Ageing

With age, people experience declines across various cognitive domains, a process that is referred to as 'cognitive ageing' (Blazer et al., 2015; Deary et al., 2009; Whalley et al., 2004). For instance, with age, Murman (2015) suggest most prominent changes occur across cognitive domains of attention, memory (reduced capacity for new learning, working, and prospective memory), executive function (reduced problem-solving, planning, and mental flexibility), language (reduced speech comprehension in certain settings i.e. background noise, and verbal fluency), and visuospatial abilities (reduced spatial orientation, and copying complex visual tasks). The patterns of changes across cognitive domains are not equal across all individuals and across all brain regions and many individual factors take place (Deary et al., 2009; Harada et al., 2013; Murman, 2015). Although cognitive changes naturally present themselves with age, the heterogeneous nature of the cognitive decline is due to differing biological and psychological factors and illnesses (Harada et al., 2013). However, it is critical to note that the gradual changes within cognitive functioning that take place with cognitive ageing differ from the cognition changes that are associated with neurodegenerative conditions such as dementia (Blazer et al., 2015). The declines within mental functions (such as, but not limited to, executive functioning and processing speed) (Deary et al., 2009), which can occur with age, are due to changes in the brain such as decreases in brain size, loss of grey matter and white matter volume, and neuronal loss (Murman, 2015). While many of these changes are also common in normal cognitive ageing, significantly higher losses and changes are present in individuals with cognitive impairment compared to individuals with cognitive ageing (Murman, 2015). Therefore, to a certain degree, a loss in cognitive functioning across some cognitive functions is to be expected with age. However, as its extent is not uniform, there is a need to understand other influences.

Cognitive Decline and Cognitive Impairment

Due to the multitude of factors impacting cognitive functioning and its gradual nature of decline with age, it may be difficult to determine the exact age at which cognition peaks and after which age it begins to decline. A study by Salthouse (2009), suggests that the peak age of cognitive functioning may be between the ages of 22-27 years, after which there may be a gradual decrease. Salthouse (2009) further report the occurrence of several cognitive changes (across domains of memory, processing speed, and visuospatial abilities) taking place before the age of 60. Similar observations have also been made by Murman (2015), who suggest that declines in fluid abilities may start from as young of an age as 20 and crystallised abilities may increase until the age of 60.

Cognitive decline is a broad term that ranges in its description. While it can include the general gradual decrease in cognitive functioning associated with age, it also includes more severe cognitive debilitations of neurodegenerative diseases such as dementia (Prakash & Jha, 2016). The term 'cognitive impairment', which is often used interchangeably alongside cognitive decline, refers to the decline in cognitive functioning such as the loss in memory and other decreases in abilities and cognitive function such as concentration and learning, greater than what is expected across an individual's age category (Liang et al., 2021; Pais et al., 2020). Cognitive impairment is a broad category and can imply any level of cognitive functioning from mild cognitive impairment (MCI) (which may not be noticeable in clinical evaluations) to severe cognitive impairment such as that observed in dementia (Pais et al., 2020; Zhang et al., 2022b). Although those with MCI may not meet the diagnostic criteria for dementia, they still function at a reduced cognitive quality beyond the expected range for normal cognitive ageing for their age group (Blondell et al., 2014; Liang et al., 2021; Mian et al., 2024). However, due to the similarities in risk factors (Roberts et al., 2010) and symptoms such as cognitive impairment being a core aspect, MCI can be difficult to distinguish from AD (Mian et al., 2024).

Although not all individuals with MCI progress to dementia, the risk has been shown to be 10 times higher (Zhang et al., 2022b) compared to those with normal cognitive functioning (Gauthier et al., 2006 as cited in Murman, 2015; Zhang et al., 2022b). Thus, it comes as no surprise that MCI is often referred to as a hallmark and the prodromal step to dementia (Blondell et al., 2014; Mian et al., 2024; Murman, 2015; Prakash & Jha, 2016; Yoshida et al., 2012), particularly due to the diagnosis of dementia as a state of severe cognitive impairment (Hugo & Ganguli, 2014). Due to this possible pathway it becomes crucial to investigate and recognise the factors that contribute to earlier or more rapid decline in cognitive functioning during midlife or older adulthood. The recognition of risk factors allows for early intervention which, in turn, could aid morbidity compression (Chatterji et al., 2015) and is particularly important given the current unavailability of a pharmacological or non-pharmacological cure (Deckers et al., 2019a; Deckers et al., 2021; Kumar et al., 2021 as cited in Canavan & O'Donnell, 2022; Hugo & Ganguli, 2014). When the above evidence is taken together, it suggests the importance of detecting risk factors before the progression into cognitive impairment. Thus, the importance of assessing factors impacting cognitive functioning.

Cognitive Functioning and Healthy Ageing

Having outlined the implications of cognitive decline and cognitive impairment, the focus now shifts to understanding cognitive functioning in the context of healthy ageing as well as factors that can help maintain it. Healthy ageing refers to the retention of functional ability (World Health Organisation, 2020). Aspects such as 'accumulated knowledge' including the likes of general knowledge and accumulated knowledge over the lifetime (Salthouse, 2009) and vocabulary, have been shown to increase with age (Fillit et al., 2002; Prakash & Jha, 2016; Salthouse, 2009). Essentially, aspects of crystallized intelligence (i.e. familiar skills and resources) are said to be preserved while decreases within fluid intelligence (i.e. problem solving of newer resources) are observed with progressing age (Murman, 2015; Prakash & Jha, 2016). Despite these trends, many individuals maintain relatively stable cognitive functioning well into later life, with variability occurring as a result of individuals and contextual factors such as cognitive reserve, education, and lifestyle (Whalley et al., 2004; Fillit et al., 2002; Prakash & Jha, 2016). Evidence to suggest the impact of contextual lifestyle factors and their role in cognitive functioning is present.

Protective factors for cognitive decline are also present and can include, but are not limited to, having a higher synaptic reserve (Murman, 2015), ongoing learning, increased and continued social engagement (Fillit et al., 2002), and being partnered (Feng et al., 2014; Larnyo et al., 2022; Liu et al., 2019; Sommerlad et al., 2018; Sundström et al., 2015; Zhang et al., 2022b). Overall, these findings highlight that cognitive functioning is shaped by more than biology alone. Therefore, while changes in some cognitive domains is a normal part of ageing, significant decline is neither universal nor inevitable. Rather, cognitive impairment is a reflection of the need for multifactorial approaches that can take place as preventative measures or to help manage an already present manifestation of cognitive decline. This underscores the need for attention to both individual characteristics as well as lifestyle factors that can be modified which will be explored further in the following sections.

Ageing and Wellbeing in the New Zealand Context

While the above global evidence highlights the importance of maintaining cognition with age, local research underscores similar concerns within New Zealand. There have been many large scale longitudinal studies that provide insight into ageing, its trajectories, and health disparities in New Zealand. Key longitudinal studies within the New Zealand context (incorporating present cohorts comprised of older adults) include the Christchurch Health and Development Study, Dunedin Multidisciplinary health and Development Study, LiLACS NZ, and the New Zealand Health, Work and Retirement Study (HWR), which includes sub-study's such as the New Zealand Longitudinal Study of Ageing (NZLSA), among others (Parr-Brownlie et al., 2020). These studies consist of extensive datasets and have tracked participants across decades to examine aspects such as health, psychological development, social factors (Parr-Brownlie et al., 2020) as well as inform studies that incorporate cognition as a component of health and ageing (Dyall, 2014; Poulton et al., 2015; Stephens et al., 2014; Towers & Stevenson, 2014). They are of critical importance to understand the influences of various factors on aspects of health and ageing within the unique New Zealand context.

To demonstrate how the New Zealand population differs, Stephens et al. (2014) compared cognitive functioning in older adults from New Zealand and the United States by using nationally representative datasets (i.e. NZLSA and the US Health and Retirement Study). Measurement of cognitive functioning occurred by using subscales of vocabulary, numeracy, orientation, serial 7s, immediate recall, and delayed recall. Of the participants (aged 49-84), 1,018 were drawn from the NZLSA dataset and 3,325 were drawn from the US Health and Retirement Study. It was found that older adults within New Zealand scored significantly higher on overall cognitive measures than those in the US. This translated to a percentage difference of 9% between the two national samples. Additional results demonstrated factors such as education, depression, exercise, alcohol consumption, diabetes, and stroke to all be significant predictors of cognitive functioning across both countries. However, these factors were only able to explain a small proportion of the overall difference between the two populations. Furthermore, the above variables included in the regression (in addition to age and sex) were able to collectively account for 14% of the total differences in cognition scores. The observed protective effects (i.e. higher cognitive scores) suggests differences within the New Zealand population compared to other populations. This highlights the importance of continued work focusing on the local population.

Differences within New Zealand and other OECD countries (such as the United States) may include the presence of a pension system and publicly funded cover for health and injury which have led to lowered old-age poverty as well as reductions in SES disparities in basic access to services (Towers & Stevenson, 2014). This is due to schemes such as the New Zealand Superannuation Fund, KiwiSaver, as well as establishing health strategies that aim to cushion the future age-related spending while aiming to improve care (Towers & Stevenson, 2014). In this setting, the income and cognition association may be attenuated in later life as compared to countries without universal pension or health cover. However, inequalities such as socioeconomic disparities have not diminished (Statistics New Zealand, 2024). Additionally, New Zealand also presents a distinctive gender landscape which places New Zealand in the top 15 of countries in terms of gender equalities i.e. Gender Empowerment Measure (Jatrana, 2021). When these unique contexts are taken together, it makes New Zealand and the studies conducted within its population especially valuable for generating evidence that is reflective of the realities and social structures of the country. This can then lead to the generation of policies that are more context specific to the New Zealand population.

Within this broader framework, New Zealand based studies have identified several determinants of cognitive health. These determinants include, but are not limited to SES (Röhr et al., 2024a; Stephens et al., 2022), modifiable factors (i.e. diabetes, depression, exercise) (Röhr et al., 2024b; Stephens et al., 2014), and even suggest ethnicity to be a component (Dyall, 2014; Zawaly et al., 2021) which particularly plays a role in an earlier onset of dementia (Ma'u et al., 2021b). Overall, the findings highlight that despite the protective factors within New Zealand, there are disparities that continue to play a role in shaping cognitive outcomes. Accordingly, the following chapters will explore some of these factors in more depth.

Additional Factors Affecting Brain Health

Ethnicity

Ethnicity has been identified as an important factor influencing cognitive health. However, its influences can be both direct and indirect. Studies have shown ethnic disparities in cognition (Díaz-Venegas et al., 2016; Schwartz et al., 2004) with education acting as a key protective factor that can mitigate these effects (Díaz-Venegas et al., 2016).

In New Zealand, ethnicity is representative of a salient determinant of poorer health outcomes due to the significant effects of colonisation as well as systemic inequities (Parr-Brownlie et al., 2020). Ethnicity is particularly significant given the disparities in dementia such as earlier onset (Ma'u et al., 2021b) as well as an increase in dementia rates due to increases in the Māori ageing population (Dudley et al., 2019). Furthermore, Zawaly et al. (2019), have found that Māori had lower cut-off scores on cognitive screening measures which was suggested to be a result of disparities in lower access to education and cultural bias. Given these factors, it is important to account for ethnicity-related differences in the present study.

Marital Status

Marital status has also been identified as a significant social factor influencing cognitive health. This may be as a result of protective effects through higher social engagement which could increase cognitive reserve (Sommerlad et al., 2018). For instance, factors such as being partnered can be a significant protective factor. In a study by Liu et al. (2019) which examined 7,508 older adults, those that were not partnered (i.e. divorced or widowed) were at a significant risk of cognitive impairment across cognitive domains of memory and orientation. Similar results have also been gained by Feng et al. (2014) which suggested a 2.5 times higher likelihood of lower cognitive functioning (measured using the Mini-Mental State Examination) in those that were not partnered (i.e. single) compared to those that were partnered (i.e. married). Data was gained through an analysis of 2,498 individuals above the age of 55 years who took part in the Singapore Longitudinal Aging Study. Additionally, gendered effects were observed such that the risk of cognitive impairment was significantly higher in men that were not partnered (5-6.2 times) compared to those that were. This effect was not observed in women. Across studies, the advantages of being partnered have been suggested to be a result of positive economic impacts, social engagement, and psychological pathways (i.e. lower anxiety and depression) (Feng et al., 2014; Liu et al., 2019; Sundström et al., 2015). An additional factor within the association between marital status and higher cognitive functioning may also be a result of the positive effects of marriage on health behaviours (Sommerlad et al., 2018; Sundström et al., 2015). Overall, marital status reflects a key social determinant in shaping cognitive ageing trajectories.

Chapter Three: Socioeconomic Status

This chapter will introduce the factor of socioeconomic status which is not easily modifiable. It will assess its impact on cognitive functioning as well as additional factors influencing this relationship. Finally, it will also introduce the theoretical underpinnings driving this potential association.

Socioeconomic status (SES) is considered to be a largely non-modifiable multifaceted construct consisting of economic and educational indicators (Wang et al., 2023; Zhang et al., 2015) with each indicator essentially reflecting an individual's social position (Wang et al., 2023). Through these avenues, SES is able to structure lifetime access to material and psychosocial resources, health care, and other opportunities for cognitive stimulation, all of which can shape risk and resilience for cognitive outcomes including cognitive impairment and dementia in later life (Dyall, 2014; Wang et al., 2023). There are many ways to conceptualise SES as it can operate across multiple levels such as individual, household, and the community. While individual level indicators can capture personal experiences and have been used extensively, other constructs of SES include area-based SES factors, such as neighbourhood deprivation indices which can also provide additional insights on cognitive functioning (Röhr et al., 2024a).

To understand the specific role of SES on an individual's cognitive functioning, there is a need to consult individual level theoretical frameworks that can provide insight into mechanisms and pathways. The Cognitive Reserve Theory developed by Stern (2009) can be used to help understand how SES can influence cognition. This hypothesises that those with higher cognitive ability, through factors such as higher education, and cognitively complex work (Deary et al., 2009; Marioni et al., 2012; Whalley et al., 2004; Zhang, 2006), as well as childhood intelligence are more likely to have lower risks of dementia (Deary et al., 2009; Whalley et al., 2004). Additionally, Marioni et al. (2012) determined through a longitudinal analysis of just over 13,000 older adults that a higher cognitive state through experiences across the lifespan and higher SES factors (such as education and occupation) along with higher social engagement can be protective and buffering factors against declining cognitive functioning. This occurs through the pathway of later onset for impairments which offers slightly better chances of cognitive recovery (but also a higher mortality once the process of severe cognitive impairment has begun) (Marioni et al., 2012). The work by Marioni et al. (2012) displays the critical role of a higher cognitive reserve in the delay of the cognitive impairment trajectory. Thus, inter-individual differences present in cognitive reserves and baseline cognitive ability can be determined as significant determinants in an individual's ability to buffer against structural brain changes and thus maintain cognitive functioning in later life (Deary et al., 2009).

In addition to the cognitive reserve theory, inequalities can also be understood through the Andersen behaviour theoretical model (1973). Within this model, access to healthcare can be a result of predisposing factors (such as age and education), the resources that they have (enabling factors such as income and access to services), and how much they believe the need is (need factors like health issues and disability) (Andersen & Newman, 1973). According to this, those with lower SES may have fewer resources but greater health needs and greater barriers to care which can lead to poorer health outcomes. While the Andersen model offers a strong individual-level framework, it is limited without the consideration of broader lifelong and structural determinants within communities

(McMaughan et al., 2020). Such structural determinants could include systemic inequities that are particularly relevant in New Zealand.

A newer framework that extends the foundations of the Andersen model is the Social Determinants of Health framework (World Health Organization, 2008). The Social Determinants of Health framework broadens the focus beyond individual-level access to care and incorporates the wider social, economic, and environmental conditions. The determinants which include education, gender, income, employment, housing etc. all shape the distribution of health opportunities and risks (World Health Organization, 2008). Within this framework, SES as well as other factors such as gender, is positioned as more than simply an individual attribute, but rather is a reflection of broader structural systems and policies that can generate inequities in health outcomes. When applied to cognitive functioning, this perspective is reflective of exposures to disadvantage and how they can interact to influence brain health.

Together, the Cognitive Reserve theory, the Andersen behaviour theoretical model, and the Social Determinants of Health framework suggest the influences of SES on cognition through both reserve-building pathways (education and complexity of cognitive demands) as well as indirect care and risk pathways (material resources and healthcare access). Building on these theoretical foundations, empirical studies have examined how SES and its indicators relate to cognitive functioning. This is critical in order to understand the influence of SES as a critical factor within cognitive functioning.

SES and Brain Health

Understanding how SES is conceptualised and the informing frameworks provides a necessary foundation to examine its relationship with cognitive functioning. Previous inclusions of SES have been as a covariate across many studies, however, the focus has now shifted to examine its effect as a factor. Studies have consistently associated lower SES with poorer cognitive functioning (Wang et al., 2023; Zhang et al., 2022b) with a meta-analysis declaring a higher risk of lower cognitive functioning and dementia (by 31%) for those with lower SES compared to those with higher SES (Wang et al., 2023). Recent multicentred studies have contributed to the understanding of the link between SES and cognition. For example, a cross-national study by Larnyo et al. (2022) that utilised data across five countries (China, Ghana, India, Russia, and South Africa), through meta-regression and a hierarchical multiple linear regression has extended the SES and cognition link. Cognitive functioning was measured through standardised scores across five tests (i.e. forward and backward digit span, immediate recall, verbal recall, and verbal fluency). Results of the study found SES factors of income and education to be significant predictors of cognitive functioning across diverse contexts. Within the study, even a single unit increase in either income (measured using household income quintiles) or education (measured using ordered categories of level of schooling) was found to be associated with an increase in cognitive functioning. The study also found other predicting factors (across data from some, but not all countries) of cognitive functioning such as older age, sex (males performed better in cognitive functioning scores), and lifestyle factors such as tobacco use, alcohol consumption and diet (higher consumption of fruits and vegetables), among others. A key strength of this study was its multifactorial approach that considered a wide range of variables reflective of a multifactorial nature of cognitive functioning. However, the cross-sectional nature of the study did limit causal inference, particularly as decline in cognitive functioning is a dynamic process. Furthermore, the study does not take into consideration that each country likely has its own cultural norms, varying healthcare systems, and education quality which may moderate the impact of SES on cognitive functioning and confound cross-country comparisons. For instance, in some nations, those with a lower SES may still be able to afford access to basic healthcare and education, whereas in other nations, it may correspond with severe deprivation. These differences could obscure the SES and cognition relationship and suggest that the association is not universally generalisable across diverse populations and may depend heavily on local structures.

Consistent with the main findings, a cross-sectional study by Zhang et al. (2022b) found that apart from age, lower SES was supported as being a significant predictor of lower cognitive functioning among 345 adults aged 65 years and older. Within the study by Zhang et al. (2022b), cognitive functioning was assessed using the Montreal Cognitive Assessment while SES was based on education, income, and occupation. The results of the study found higher cognitive impairment in those in the lower SES (58.97%) than in medium (45.69%), or in the higher SES group (27.68%). Additional factors such as marital status (being unmarried or without a partner), longer sleep durations, and depression, among others, were also identified as contributors to lower cognitive functioning. These findings reinforce the notion that SES is a key contributor to cognitive functioning but it operates alongside other social and health-related factors. It also portrays higher SES being a protective factor against a decline in cognitive functioning. A key strength of this study includes the incorporation of three indicators of SES which include education, income, and economic status. This composite approach provides a more nuanced understanding of SES compared to only single-variable indicators. However, it is also critical to note the recruitment of participants. Participants within the study included those that were in nursing homes which likely meant lower health among participants. Thus, while providing results that are complimentary to that of others, the study may not be generalisable to the general population let alone the New Zealand context.

While international research has consistently demonstrated the association between SES, its indicators and cognitive functioning, these findings are largely reflective of international contexts where social policy, healthcare access, and education quality may differ from those observed in New Zealand. This is due to the unique circumstances between New Zealand and other OECD countries such as its pension system and publicly funded health coverage which contribute to lower disparities in older age (Towers & Stevenson, 2014). However, inequalities have persisted. Socioeconomic disparities have presented themselves and are marked by more than a third of the population's household stating that their income is not sufficient for the present cost of living (Statistics New Zealand, 2024). Therefore evidence from New Zealand is critical to understand how socioeconomic conditions can influence those residing within the country. A study conducted by Stephens et al. (2022) (drawing on data from 729 New Zealanders) applied a life course model that linked childhood SES to late-life wellbeing. The findings showed that childhood SES was a critical component of wellbeing in later life with its effects mediated by factors such as education and occupation and wealth as an adult. However, this trajectory was not simple, as moderating effects were also observed. Key moderators included gender and ethnicity with non-Māori men showing the most consistent trajectory from childhood SES to later-life wellbeing. However, a weaker effect was observed for Māori men and women and non-Māori women. Overall, these results are suggestive of several factors such as gendered as well as ethnic differences. Although this study focuses on general health outcomes rather than cognitive functioning specifically, the mechanisms identified (i.e. education, occupation etc) are able to underpin cognitive health research. In this sense, the study provides contextual evidence for the present research which will extend these concepts into the domain of cognitive functioning.

Recent research by Röhr et al. (2024a) uses New Zealand data to demonstrate the value of this perspective. It was found that adults living in more socioeconomically deprived neighbourhoods exhibited lower cognitive functioning and higher rates of cognitive decline over two years. These findings suggest that research on area-based indicators, which extend beyond personal socioeconomic conditions, can be advantageous as they have been shown to contribute to brain health. The findings can also deepen the understanding of contextual influences on cognitive functioning and can be useful for policy implications. However, a critique of reliance on area-level proxies is that it can risk ecological fallacy and mask within-area variability. This may be especially true when considering SES alongside other individual level indicators (that more directly capture personal life experiences as well as individual level outcomes such as cognitive functioning) where individual level SES indicators may be more conceptually aligned.

Building on this conceptualisation, there is recognition that SES represents a collection of several SES factors rather than being a singular indicator, as they impact an individual interdependently (McMaughan et al., 2020). However, individual SES indicators can also act through non-identical mechanisms (Zhang et al., 2015). For example, education's reserve effect (Wang et al., 2023) in comparison to the resource effect observed for income (Larnyo et al., 2022) as well as occupation shaping job autonomy (Duncan & Magnuson, 2012). Together, these dimensions suggest that SES can have cumulative impacts on a person. However, each indicator can also be reflective of its own divergent pathway and therefore may impact cognitive functioning through diverging pathways.

Among the SES indicators, education has frequently emerged as the strongest predictor of cognitive functioning (Lee et al., 2003; Rodriguez et al., 2021), exerting a stronger effect than income and in some cases even counteracting the negative impacts that low income exerts (Rodriguez et al., 2021). When investigating the independent influence of education and income on cognitive functioning, Rodriguez et al. (2021) found both factors to contribute to cognitive functioning (measured using the 10 Word List Learning Test) in older adults. The results were derived by investigating data across the three longitudinal studies. However, while both education (based on highest educational attainment) and income (net value of household assets) influenced cognitive functioning, income had a weaker effect than education. The author reports that this can be a result of factors such as cognitive reserve, not engaging in health behaviours that can negatively impact cognition, as well as individual factors such as higher self-esteem (Rodriguez et al., 2021). This positions education as a strong and relatively stable component of SES, given its impacts on labour and workforce participation, income (Hasselgren et al., 2020; Rodriguez et al., 2021), its strong relation to cognitive reserve (Deary et al., 2009; Hasselgren et al., 2020; Wang et al., 2023), as well as its correlation with health literacy, and the uptake of a healthier lifestyle (Wang & Conwell, 2022; Zhang et al., 2022b) such as increased exercise and frequent health checkups (Park & Kang, 2008).

Income has also been identified to capture current material resources and the capacity to access services (Larnyo et al., 2022; McMaughan et al., 2020). However, while income can be shaped by earlier life factors (such as higher education) (Allin et al., 2009), it can vary with age as a result of retirement as well as institutional arrangements such as universal benefits. Regardless, higher income can lead to higher accumulations of wealth, particularly with age (Allin et al., 2009) and has been associated with cognitive functioning such that higher income can decrease the rate of cognitive decline (Marden et al., 2017). However, it is critical to note that within the results of a systematic review by Wang et al. (2023), while both lower income and education were associated with cognitive impairment and dementia, lower income by itself was unable to predict dementia. This confirms the differing pathways of influence even among SES indicators.

Another critical SES indicator is employment status which straddles both pathways as it reflects educational sorting while also providing opportunities for ongoing cognitive stimulation and social participation (Rodriguez et al., 2024). Evidence suggests that continued employment, particularly in later life is associated with slower cognitive decline, higher cognitive functioning as well as a reduced dementia risk (Bonsang et al., 2012; Takase et al., 2024). Complementarily, in a meta-analysis by Vélez-Coto et al. (2021), it was indicated that unemployment was significantly associated with lower cognitive functioning. This occurred through employment's positive influences on income security, cognitive stimulation as well as reduced stress of joblessness (Vélez-Coto et al., 2021). As such, employment status can capture ongoing engagement as well as income security in a way that occupational prestige alone may not. However, its use as a variable is not without limitations as it can conflate voluntary and involuntary retirement as well as diverse employment conditions. In instances where retirement is taken into consideration, Rodriguez et al. (2024) have found it to have positive influences on cognitive functioning such that its positive effects on cognitive functioning are observed to be larger than those who are still working. In the study population of 158,144 participants derived from the German National Cohort, it was found that not being in paid employment was also associated with lower cognitive functioning. Importantly, these effects were strongest when low income (also independently associated with lower cognitive functioning) co-occurred with unemployment. Although the anticipated pathways of influence were different (i.e. income affected finances while occupational status impacted cognitive stimulation), this highlights that socioeconomic disadvantage is not merely additive. Rather, socioeconomic disadvantage is both cumulative and interactive and can intersect to shape exposure and resources which collectively determine cognitive health. Therefore, when considering SES, it is beneficial to consider multiple SES indicators (together and separately) due to their complexities and interrelated effects on one another.

While the above evidence primarily highlights the main effects of SES and its indicators on cognition, there is also evidence to consider SES as a moderator within other pathways for cognition such as pathways involving health factors (Wang et al., 2023). To build on the presence of additional factors within the association between SES and cognition, Koster et al. (2005) found that biomedical risk factors (such as but not limited heart disease, diabetes, and hypertension) in older adults (70 - 79 years) were able to explain approximately 5% of the differences in declines in cognitive function observed between low and high SES. This suggests that higher SES may not always equate to cognitive health through better health outcomes. However, it is critical to note that there was a significant loss of follow up data which may have led to an underestimate of the true mediating role of health factors within this study. Implications of Koster's study include the presence of additional pathways which extend beyond biomedical risks such as cognitive reserve, care access and others.

From a broader Social Determinants of Health perspective, socioeconomic position can shape exposure to health risks. Marmot et al. (2008) highlight that differing health is not random, but rather a result of unequal access to determinants, for example, education. However, the basis of the above study aligns with the Andersen model where SES can shape both the exposure and the response to a health condition through access and enabling factors (Andersen & Newman, 1973; McMaughan et al., 2020), thus a need to test for SES as a potential moderator in pathways between lifestyle factors and cognitive functioning.

To test this, recent work by Heger et al. (2024) (also discussed at a later stage) found that a lower SES (measured through indicators of education and household income) was associated with lower cognitive functioning as well as with higher baseline modifiable lifestyle risk. However, SES did not moderate the modifiable lifestyle risk and cognition link. Their findings of no moderation highlight a key evidence gap, particularly given their SES measure was limited by missing income data (missing 41.8% of participants) and at times relying solely on education. The findings highlight limited explanatory precision when relying on individual SES indicators due to missing data. Testing moderation with a more comprehensive SES measure, such as a composite SES index as well as individual SES factors can directly address this gap.

When the above literature is taken together, there are strong suggestions that SES can be considered as having both main effects on cognitive functioning as well as potential interaction effects. However, the finding by Heger et al. (2024) reports no such effect. The inconsistencies between suggestions from previous research and the moderation study by Heger et al. (2024) could be reflections of methodological issues such as the reliance on incomplete SES measures. The evidence gap informs the rationale for the present study, which tests SES as a moderator using both individual as well as composite indices within a New Zealand setting.

Chapter Four: Sex

The chapter will introduce the non-modifiable factor of sex and its impact on cognitive functioning as well as additional factors influencing this relationship. It will also introduce the theoretical underpinnings driving this potential association.

Sex and gender are often used synonymously, particularly in research. However, it is critical to note that they are not synonyms. Sex refers to biological nuances and categorisation of individuals as either 'men' or 'women' based on chromosomal differences (Pryzgoda & Chrysler, 2000; Mielke et al., 2014). Gender, on the other hand, is a diverse and complicated topic whose definition may differ from the typical binary responses of 'male' or 'female'. Instead, gender is sometimes thought of as fluid, and is an amalgamation of differences in psychosocial aspects (Pryzgoda & Chrysler, 2000; Mielke et al., 2014). The present study uses the term 'sex' and focuses on its impact on cognitive functioning. However, it also acknowledges psychosocial mechanisms that are linked to gender. Studies that sometimes miscategorise and conflate sex with gender are also cited. Therefore it is acknowledged that a lack of conceptual clarity is itself a limitation in existing research as it does not take the interplay of biological and social influences into account.

Sex and Brain Health

Subramaniapillai et al. (2021) suggest that secondary to age, sex is one of the biggest risk factors of dementia. The higher presence of dementia (i.e. women having a higher rate of AD diagnosis) has been in part attributed to a higher life expectancies in women (Emrani & Sundermann, 2025; Hasselgren et al., 2020; Nebel et al., 2018). However, it is not as simplistic as simply living longer. From a biological standpoint, sex differences in cognitive functioning have been linked to hormonal influences (Maylor et al., 2007; Subramaniapillai et al., 2021). Lowered ovarian hormones, for example due to early menopause, have been associated with reduced cognitive functioning (Mielke et al., 2014; Subramaniapillai et al., 2021). However, much of research prioritises the biological explanations without sufficiently considering critical influences of contextual or structural factors.

Engel's (1977) biopsychosocial framework proposes that health cannot be a result of isolated biological processes but instead occur through interactive processes between biological, psychological, and social systems. This can position cognitive functioning to be a result of more than just biological sex differences. For example, biological factors such as hormonal fluctuations and genetic vulnerabilities can interact with psychological processes (e.g. cognitive reserve), as well as social structures (e.g. SES and gender norms). Therefore, cognitive functioning can be viewed as the product of interdependent biological, psychological, and social factors while at the same time drawing attention to the structural inequities that can amplify or buffer these biological vulnerabilities (which will be explored further).

When considering sex differences in cognitive functioning, longitudinal studies further suggest that women experience a faster rate of decline compared to men (Levine et al., 2021; Lin et al., 2015) which can help explain the paradox where although women are more frequently diagnosed with dementia, men may be more likely to develop MCI (Lin et al., 2015; Mielke et al., 2014). For instance, a study conducted by Lin et al. (2015) aimed to investigate sex differences in the progression of cognitive impairment in individuals with MCI. The study utilised an eight-year longitudinal data derived from the Alzheimer's Disease Neuroimaging Initiative to test the hypothesis that women were more likely to experience faster cognitive decline compared to men. It was found that although both sexes started with similar cognitive functioning scores, women demonstrated a faster rate of progression from MCI to AD compared to men even after controlling for factors such as age, education and genotype. The pattern of a faster cognitive decline in women was also observed by Levine et al. (2021). However, it is critical to note that while women experienced a faster cognitive decline within the study by Levine et al. (2021), they also presented with higher baseline cognitive functioning scores (as opposed to similar cognitive baseline scores observed in the study by Lin et al., 2015), which may have been indicative of higher cognitive reserve. Similar observances have been made in an earlier study by van Exel et al. (2001) who included 599 participants aged 85 and upwards, and measured cognitive functioning through Mini-Mental State Examination (MMSE), developed by Folstein et al. (1975). It was found that even though women had lower formal education, they still performed higher cognitively than men. Although this study was limited by being cross-sectional, it suggests that cognition is multidimensional and influenced by both biological and sociocultural factors. While women may have protective cognitive advantages earlier in life, potentially due to hormonal or reserve related mechanisms, these advantages may not prevent a more rapid cognitive decline in later life. Thus, these results indicate that despite men having higher risks for MCI, women are more vulnerable to rapid progression to AD resulting in the higher prevalence of women with AD (Lin et al., 2015).

A review of the literature suggests the presence of differing risk profiles and cognitive functioning trajectories for men and women thus demonstrating the need to examine additional factors impacting this observance. Further empirical evidence has been inconsistent with reporting global cognitive sex differences. Some studies have reported higher baseline global cognitive functioning in women than in men. Even when considering differences in cognitive functions, some report mixed results while others indicate men as having poorer cognitive functioning than women which is contrary to dominant beliefs. The study by Bloomberg et al. (2021) found that women outperformed men across the cognitive function of memory, with slower decline, while men performed better in the cognitive function of fluency compared to women in earlier rather than the later birth cohorts. However, when compared to women in the later birth cohort within those with higher education, women performed better in the cognitive function of fluency than men. These findings indicate that additional factors such as education can moderate the relationship between sex and cognitive performance and suggests that there is merit in examining cognitive functioning through a domain specific lens. This is because global cognitive measures may lead to obscurities in the meaningful sex related differences in cognitive functioning. Although this may be considered a strength of the study i.e. the inspection of sex related differences across cognitive domains i.e. the domains utilised are limited to memory and fluency. Thus, the results of the study may not be reflective of the overall advantages and differences across sex. Nevertheless, the study is still valuable and identifies additional factors such as education within the sex and cognition link that points to the influence of social opportunity structures on cognitive outcomes.

Similar identification of education as a moderator has also been identified by Nooyens et al. (2022) who primarily aimed to examine sex differences in cognitive functioning within a longitudinal study that followed participants for more than two decades. The results found that women performed better in cognitive functions of memory and information processing while men tested better in spatial tests of fluid intelligence. However, in the investigation of global cognitive functioning, there appears to be conflicting evidence such that data from one dataset presented no differences in global cognitive functioning between males and females, while the data from the second dataset presented significant differences where males had lower cognitive functioning than females. Subsequent analysis revealed that these differences could partly be a result of differing educational levels as well as birth cohort effects. That is, when education was taken into account, the female advantage became stronger which suggested that women's underperformance in earlier generations may have been a result of fewer educational opportunities. These findings show education emerging as a potential moderator and indicate additional mechanisms in the relationship between sex and cognitive functioning. However, a limitation of the study is that it did not account for the incidence of dementia during follow-up, which limits the ability to attribute the observed differences in cognitive decline purely to biological or social mechanisms as they may have occurred as a result of undetected dementia pathology. Nonetheless, the results imply that biological mechanisms alone cannot fully explain this relationship and instead can be impacted by social and educational circumstances that can influence engagement in cognition and opportunities to build cognitive reserve.

Building on this line of evidence, Zhang (2006) demonstrate that, alongside education, occupational status also contributes to sex related disparities in cognitive functioning. By including 8,805 participants aged 80 and upwards, it was found that both lower education and occupational attainment may play a key role in the increased risk of cognitive impairment in Chinese women. The observed gradients are likely reflective of historical gender norms and structural constraints that limited and prevented women's attainment of formal education and other resources which could have alleviated cognitive reserve (Zhang, 2006). Thus, Zhang, (2006) concluded that sex differences appear to be rooted in societal changes, power relations, and gender roles and inequalities which in turn influence lower SES outcomes, creating a disadvantage that can be observed in current health outcomes. Based on the consensus that SES factors contribute to higher cognitive reserve across the two sexes, it would be understandable to assume that older adult women may possess a lower cognitive reserve than men especially when considering the higher gender opportunities for education and occupation for men, historically (Mielke et al., 2014). However, this was not the case in the studies evidenced above which indicated incidences where women possessed a higher cognitive reserve as a result of higher baseline cognitive functioning scores. Another point to note is that the study by Zhang (2006) was conducted in China which may not be reflective of the New Zealand context where gender disparities (in education, labour force and wage-gap) are significantly lower than other countries (Jatrana, 2021) and labour force participation among older females has also increased steadily since 1986 (Gorman et al., 2012). This higher level of gender equality may have increased women's accessibility to opportunities such as higher education which has been identified as being protective factors against cognitive impairment and dementia (Bloomberg et al., 2021; Hasselgren et al., 2020). Within New Zealand, sex has predominantly been used as a covariate. For example, Stephens et al. (2014) included sex as a control variable when comparing NZLSA data with the US Health and Retirement Study, finding that men scored lower in cognition than women. However, the study did not explore the underlying mechanisms underlying these differences.

Considering the above research, it becomes apparent that sex, a biological factor, is often entangled with additional contextual factors, especially SES indicators. In particular, education has appeared to consistently emerge as a protective factor against cognitive decline as well as a determinant that can shape the sex-related variation (Bloomberg et al., 2021) through a higher cognitive reserve (Zhang, 2006). Even so, findings by Hasselgren et al. (2020) suggest that education alone is unable to fully explain these associations. Although they found no mediation effects of education on dementia risk, the study did highlight both education (a SES factor) and psychological distress as critical gendered influences. Within the study, females were found to have higher psychological distress compared to males which was, in turn, associated with a greater dementia risk, emphasising the role of psychosocial mediators. This suggests that differences in cognitive functioning across sexes being attributed to social factors (i.e. SES factors) alone may be a bit simplistic and additional factors may be at play. This is identified by Levine et al. (2021) who note that a limitation of their study was that it did not adjust for additional factors such as lifestyle factors i.e. depressive symptomology which also impact cognition. Additional factors elevating this sex and cognition link include reduced social engagement (being single or having minimal contact with family), reduced leisure activities in women (Zhang, 2006), and health conditions (e.g. higher depressive symptoms, diabetes, hypertension, social isolation etc) (Artero et al., 2008). However, elevated health risks (e.g. diabetes and stroke) are also observable in men, as well as both sexes sharing common risk factors such as age, low education and the presence of the APOE e4 allele (Artero et al., 2008). These findings indicate that sex related disparities in cognitive functioning are multifactorial and shaped by biological predispositions as well as structural inequities such as lower education rather than primarily biology or primarily structural inequities.

Health behaviours also contribute additional complexity. For example, while men tend to exercise more than women (Mielke et al., 2014; Nebel et al., 2018; Shang et al., 2023), they also represent a larger percentage of those who smoke which in turn has been associated with excessive drinking (Maylor et al., 2007; Mielke et al., 2014). Additionally, women are also suggested to generally exhibit more 'health-seeking' tendencies such as not partaking in smoking (Mielke et al., 2014; Okamoto et al., 2021; Shang et al., 2023) and consuming a healthier diet (Kautzky-Willer et al., 2016; Mielke et al., 2014; Okamoto et al., 2021). Patterns of partaking in behaviour that can develop into severe chronic conditions contribute to men being burdened with higher impacts of severe diseases (Okamoto et al., 2021). This is of importance due to the link between health behaviours and its impacts on cognitive impairment such as dementia (Okamoto et al., 2021). For instance, in a large retrospective study by Shang et al. (2023), which consisted of 429,340 age-matched participants, results were contrary to popular belief, i.e. men had a higher risk of dementia (both AD and VD) than women. These findings were largely explained by modifiable lifestyle behaviours such as smoking, diet, alcohol, and physical activity which substantially mediated sex differences indicated. In particular, the main contributors for younger onset dementia were lifestyle habits and health conditions while for older onset dementia, differences across sex were explained by health conditions (i.e. heart disease, diabetes, and hypertension) as well as biological markers. In short, the higher rate of health conditions which are often tied to lifestyle and behaviours, can play a large role in a greater risk of dementia in men compared to women. As a result of these health behaviours in conjunction with other factors playing a role, women may be more likely to have a higher life expectancy than men due to lower impacts of severe diseases (i.e. cardiovascular diseases, cancer etc) (Nooyens et al., 2022; Okamoto et al., 2021; Shang et al., 2023). Although contradictory to the higher report of dementia in men compared to women, the higher probability of reaching older age in women may lead to higher likelihoods of dementia risk observed in other studies (Nooyens et al., 2022; Okamoto et al., 2021). Thus despite higher life expectancies, higher disability is also observed amongst women and this is referred to as the 'health-survival paradox' (Okamoto et al., 2021, p. 2). Such behavioural and demographic dynamics reinforce why examining sex in isolation is insufficient as it does not consider the impacts of other factors such as lifestyle factors.

The above studies collectively reflect the complex nature of differences across both sexes in cognition i.e. as evidenced above, the sex differences in cognition can not be reducible to biological explanations alone. Overall, the evidence on sex differences in cognition is complex, multifaceted and shaped by biological as well as structural influences. It reflects the complex interplay between hormonal influences, socioeconomic opportunities and structural inequalities, health behaviours, and psychosocial stressors. While the literature suggests some inconsistencies with some showing female advantage while others show disadvantages, there appears to be some consistency which suggests that women may possess higher cognitive reserves but a faster decline of cognitive functioning thus leading to higher rates of AD pathology that is observed. This inconsistency highlights that there is a need for frameworks that account for multiple factors as well as intersecting influences on cognitive functioning. This aligns with Springer et al. (2012), who argue that meaningful explanations of sex differences requires the integration of multiple axes to formulate a unified framework.

Chapter Five: Lifestyle Modifiable Factors

This chapter will introduce the topic of modifiable factors. While modifiable factors are not limited to the ones listed in the following chapter, the listed factors are often considered synonymous with living and maintaining a healthy lifestyle and may be preventative mechanisms to reduce the risk for cognitive decline in old-age.

Modifiable Risk Factors

The development of severe cognitive impairment i.e. dementia, reflects both genetic predispositions and environmental factors. While the APOE e4 allele is recognised as a strong genetic risk factor associated with changes in brain structure and function (Bales et al., 2002; Hasselgren et al., 2020; Mielke et al., 2014), its presence can often be a notification for changes in the brain such as increases in the accumulation of amyloid proteins (Bales et al., 2002; Cody et al., 2022; Emrani & Sundermann, 2025). However, increases in the accumulation of amyloid proteins is not an isolated genomic process. It has also been linked to individually modifiable processes such as hypertension (Canavan & O'Donnell, 2022; Ungvari et al., 2021), and heavy alcohol consumption (Gong et al., 2021). This convergence suggests cognition may reflect the combined influence of biological vulnerabilities and lifestyle linked risks which highlights the importance of considering cognition from various approaches as opposed to only biological. This framing also supports the notion that severe cognitive impairment is not an inevitable outcome and its trajectory can be shaped through intervention. Recognising this is particularly important as cognitive functioning is a critical component of healthy ageing due to its associations with higher quality of life, independence, and life expectancy among others (Blazer et al., 2015).

Lifestyle-based modifiable risk factors have become central to dementia prevention discussions. Unlike non-modifiable factors such as age, genetics as well as SES (to a certain degree) and sex; modifiable risk factors, as the name suggests, are behaviours or conditions that individuals have the potential to control and change. There are many modifiable risk factors that have been associated with dementia which can include but are not limited to hearing impairment, traumatic brain injury, hypertension, physical inactivity, diabetes, high alcohol consumption, obesity, smoking, and depression (Livingston et al., 2020; Peters et al., 2019; Zhang et al., 2022a) as well as atrial fibrillation, gait speed, respiratory illness (Zhang et al., 2022a), sleep (Deary et al., 2009; Zhang et al., 2022b), heart disease (Liang et al., 2021), and even epilepsy (Prakash & Jha, 2016). An international 2020 Lancet Commission report by Livingston et al. (2020) synthesised data across several factors which may lead to lower rates in dementia. Through the report, 12 modifiable risk factors were presented. These risk factors include education, hypertension, hearing, smoking, obesity, depression, physical activity, diabetes, lower social contact, traumatic brain injury, alcohol, and air pollution. All of these factors have been suggested to have the ability to contribute to a reduction of two fifths of dementia cases and prevention practices have the capacity to contribute positively across the lifespan (Livingston et al., 2020). Recent New Zealand based studies have extended the international research of Livingston et al. (2020) by localising the dementia prevention framework consisting of the 12 modifiable risk factors to ethnic contexts (Ma'u et al., 2021a; Zawaly et al., 2021). Particularly notable is the study by Ma'u et al. (2021a) who calculated population attributable fractions for 12 modifiable dementia risk factors across the country for its four main ethnic groups (European, Māori, Pacific, and Asian). This was done using data from the New Zealand Health

Survey (2018/2019). The study showed that risk factors differed across ethnic groups with factors such as hearing loss and obesity being the most influential risk factors in the overall population while obesity and lower educational attainment were particularly significant for the Māori and Pacific population. These differences highlight the diversity of risk factors and their influence across different ethnic groups. Hence, showing the importance of prevention strategies being shaped to the realities of the New Zealand population. However, of the 12 identified risk factors, some appear to be more easily and readily modifiable at the individual level than others. For instance, while factors such as smoking, obesity, and physical activity may be modifiable through individual level interventions, factors such as air pollution are heavily dependent on societal structures and policy of environments. Therefore, the identified factors are mixed in representativeness at both the societal level as well as the individual level.

To further signify the importance of modifiable risk factors, Peters et al. (2019) have demonstrated through a systematic review of longitudinal studies that cognition and dementia are impacted by a dose-response relationship with risk factors. Individuals with even one risk factor (such as but not limited to vascular risk factors such as obesity and high blood pressure) have an increased risk of dementia by 20% while those with three risk factors were shown to have more than double the risk. However, the presence of protective factors (i.e. non-smoking, healthier diet etc) was able to reduce the risk of cognitive decline. These findings suggest that risk of cognitive impairment may be a result of an additive continuum where each additional risk or protective factor has the capacity to shift the trajectory of an individual's brain health. While Peters et al. (2019) were unable to determine which risk factors had the greatest impact, they were able to determine that risk of severe cognitive impairment is impacted by more than genetics alone. Such findings reinforce the notion that cognitive impairment is not an unavoidable consequence of ageing, but rather a condition which can be modified through appropriate interventions as there appears to be significant room for improvement. One such example of targeted intervention may be engagement in activities that may build cognitive reserve. For example, lifestyle changes have been shown to help in the reversal of cognitive impairment back to healthy cognitive functioning (Katayama et al., 2021). Katayama et al. (2021) followed 769 participants and their engagement across multidomain lifestyle activities, over the course of four years. Multidomain lifestyle activities were gathered using a self-report questionnaire and included activities such as IADL activities, cognitive, social, and productive activities. Evaluation of participants' engagement suggested one third of participants had reverted back from MCI to normal cognitive functioning. This reversion was the highest for participants that were partaking in multidomain activities compared to those that were not (i.e. inactive or discontinued multidomain activities). Although there is a presence of limitations such as lack of random selection of participants as well as losing close to half of the participants to follow-up, the results of the study showed the positive effects of starting new activities that also play a role in increasing cognitive activity. A strength of the study is gaining the knowledge that partaking in multidomain lifestyle activities such as but not limited to productive (e.g. gardening or house cleaning), social (e.g. hobbies and sports activities) and cognitive activities (e.g. reading a book or newspaper) helps the retention of normal cognitive functioning. Together, the findings reflect the significant effect of sustained, multifaceted lifestyle engagement which can act as protective factors as well as contributors to cognitive activity and cognitive resilience. It is important to note that the above study centers on activities that individuals can personally undertake, thus it highlights the importance of broader integrative frameworks that capture modifiable factors that can be amended. To capture these lifestyle influences quantitatively, multidomain indices have been developed.

Prognosing Cognitive Functioning: A Case for the Lifestyle for Brain Health (LIBRA) Index

Given the evidence that highlights the role of modifiable risk factors in influencing cognitive trajectories, it becomes essential to adopt frameworks that incorporate evidence-based factors. While models such as the Australian National University AD Risk Index (ANU-ADRI) and Cardiovascular Risk Factors, ageing and Dementia (CAIDE) and other cardiovascular disease risk models are available and have been linked to cognitive impairment (Harrison et al., 2014; Rosenau et al., 2024), the Lifestyle for Brain Health index (LIBRA) is a tool that is used to prognose cognitive impairment and dementia and can guide preventative interventions through the inclusion of several lifestyle factors that are modifiable (Deckers et al., 2019a; Vos et al., 2017). The 12 factors constituting the LIBRA index, illustrated in Figure 1 (Schiepers et al., 2018), include coronary heart disease, hypertension, hypercholesterolemia, high cognitive activity, healthy diet, renal dysfunction, diabetes, low-to-moderate alcohol consumption, smoking, physical inactivity, depression and obesity (Deckers et al., 2021). These factors, individually, have shown established associations with dementia, as evidenced by their derivation from an extensive literature review by Deckers et al. (2015) which was used to introduce the LIBRA index (Schiepers et al., 2018). They also share several overlapping mechanisms that may underlie their cumulative impact. For instance, inflammation and oxidative stress can contribute to effects on brain health through vascular damage and neurodegeneration (Canavan & O’Donnell, 2022). Changes within some of these factors (such as depression, smoking, physical inactivity, and vascular risk factors among others) have been suggested to have the potential to decrease AD prevalence by up to 8.3% (Norton et al., 2014 as cited in Harrison et al., 2014). However, it is critical to note that dementia prevention through modifiable factors appears to be much more pronounced. For example, Ma’u et al. (2021b) estimated that just under half of dementia cases in New Zealand are a result of modifiable risk factors.

Empirical studies support the lifestyle modifiable factors within the LIBRA and their ability to prognose dementia risk which essentially reflects brain health. Observations have been made by Neuffer et al. (2024) where even a single point increase in the LIBRA score has the potential to increase the risk of dementia by 15% and 9% (with no significant effect modification by APOE e4 allele). Similar observations of increases in dementia risk (13%) have been made by Deckers et al. (2019b) with increases in LIBRA scores. In the prospective cohort study by Deckers et al. (2019b) who investigated the interrelationship between the LIBRA index, SES indicators of wealth and education and its impact on dementia risk, across approximately six to seven years, it was found that higher LIBRA scores were associated with lower wealth as well as increased dementia risk. However, effects of both SES factors (i.e. wealth and education) were not equivalent such that the higher wealth tertile was associated with decreasing dementia risk, but this association was shown to be explainable by lifestyle habits and health conditions (encapsulated by the LIBRA). Lifestyle and health habits were able to explain over 50% of the wealth-related difference in dementia risk. This study suggests the opportunity to modify dementia risk even in those with an already present risk factor such as lower SES, through lifestyle modification. Thus, it shows the importance of considering lifestyle modifiable behaviours as the primary pathway through which SES shapes dementia risk.

While the LIBRA index has been shown to be associated with dementia risk, it has also been associated with differences in cognitive functioning. Several studies have built on the connection between LIBRA index and its ability to prognose dementia by evaluating its connection with cognitive functioning. Current literary evidence supports the associations between lower brain health potential (higher LIBRA scores) and higher risks of cognitive impairment (Cody et al., 2022; Deckers et al., 2019a; Deckers et al., 2019b; Deckers et al., 2019c; Neuffer et al., 2024; Röhr et al., 2024b; Vos et al., 2017). For example, in the same study investigating the association between LIBRA scores and dementia risk, Neuffer et al. (2024) have also identified associations between LIBRA scores and cognitive functioning. Cognitive functioning was considered as global cognitive functioning and measured using a combination of scores across multiple tests (i.e. the MMSE, Benton Visual Retension Test, Isaacs' Set Test, and the Trail Making Test). It was found that not only was a higher LIBRA score (lower potential for brain health) reflective of lower cognitive functioning but it was also associated with a steeper decline in cognitive functioning over 17 years both in the presence and absence of the APOE e4 allele. This suggests that irrespective of genetic risk, less brain healthy lifestyles are influential in increasing cognitive decline as well as strongly implying the interactions between genetic and environmental influences to guide an individual's outcome.

Importantly, the LIBRA index has shown value of use in a broader age range (i.e. middle-aged and older adults) (Röhr et al., 2024b). In a study by Röhr et al. (2024b), which investigated the LIBRA index and its associations with cognitive functioning in the context of New Zealand, the LIBRA index was found to be significantly associated with cognitive functioning. The study included longitudinal data from New Zealand and included 881 participants. Cognitive functioning was assessed using the 'Kiwi' Addenbrooke's Cognitive Examination-Revised ('Kiwi' ACE-R) as well as an eight-factor LIBRA index. The study assessed participants at both the cross-sectional as well as at a longitudinal level (with a two-year duration). At both time points, LIBRA scores, indicative of brain health, were negatively associated with cognitive functioning. While the study provided strong evidence that supports the relevance of modifiable lifestyle factors for brain health, a limitation of the study included the inability to include the full form of all modifiable factors within the LIBRA model. The inability to include all factors may have led to modified associations between lifestyle modifiable factors and cognitive functioning where the observed relationship may not have been reflective of the true association. Regardless, the association between lifestyle modifiable factors and cognitive functioning within the middle-aged population is particularly valuable as early signs of health conditions can often manifest within this age period (Brown et al., 2020).

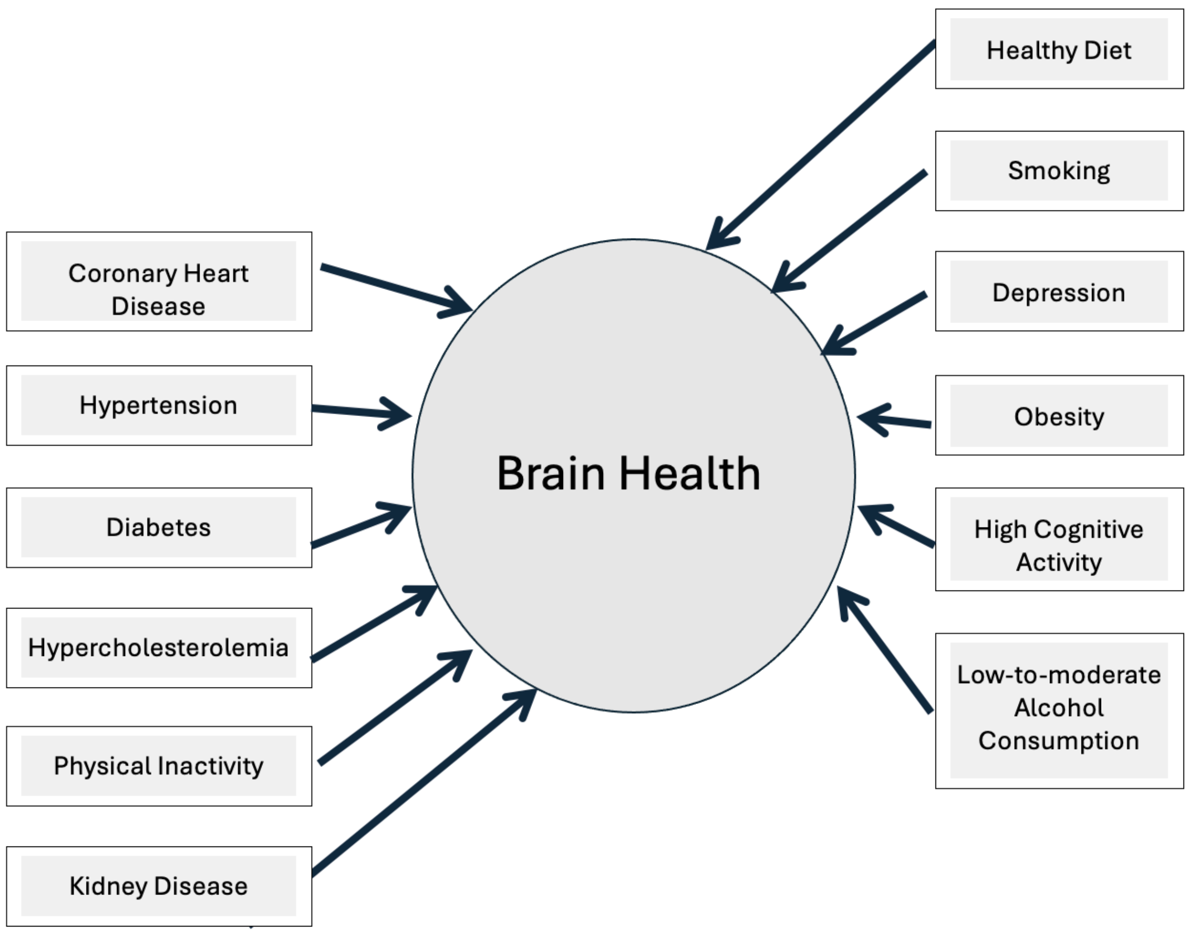
Within the lifestyle modifiable factors and cognition link, additional factors such as SES indicators and sex have also been thought to influence the association. Critical factors such as education and sex have been examined by Deckers et al. (2019c) using a 10 year longitudinal Dutch study with 2,347 men and women. In addition to higher LIBRA scores being reflections of lower cognitive functioning, it was also found that differences in verbal memory were present across the two sexes where women in the higher LIBRA group showed faster declines in cognition compared to women in lower LIBRA groups. Similar impairments were also observed for men in the higher LIBRA group. Men in higher LIBRA groups showed disadvantage by having lower baseline verbal memory than men in lower LIBRA groups. However, moderation effects by sex and education were not observed which suggests effects of lifestyle risks were consistent across sex and education levels.

Similar results of an individual effect of LIBRA has been observed in a more recent study by Heger et al. (2024). The longitudinal study that sought to investigate the link between lifestyle modifiable factors and cognitive functioning included an initial recruitment of participants between the ages of 24-81 years. It found that those with both higher LIBRA scores and lower SES (previously discussed) had lower cognitive functioning across processes of information processing and verbal memory as well as being linked to a faster cognitive decline trajectory. Although the exact age range of participants (past the initial recruitment age range) was unstated, a limitation of this study is the inclusion of participants beyond the validated age range of the LIBRA index which has been reported as being up to 75 years of age (Pons et al., 2018). This raises concerns about the applicability of the LIBRA index in the study's oldest-old population as the weighting of modifiable risk factors may not fully capture the risks and protective factors in later life. This may have reduced the validity of the LIBRA index and may have attenuated the observed association between lifestyle risk factors and cognition. Furthermore, within the same study, moderation effects were unobserved. However, these findings underscore the need to further evaluate modifiable risk with other factors such as broader structural contexts i.e. while lifestyle changes are able to buffer cognition, their feasibility and impact may be shaped by factors such as socioeconomic resources. Interactions between lifestyle modifiable factors and SES factors resonate with the biopsychosocial model which suggests the interplay between multiple factors (Engel, 1977; Spector & Orrell, 2010). These interacting layers can collectively influence the risk or resilience to cognitive decline. From this perspective, there is a possibility that lifestyle modifiable factors could either enhance or decrease cognitive functioning. However, its effects may be contingent on the socioeconomic environment in which they are present. To clarify this, there is a need to study LIBRA in conjunction with other factors to provide a more comprehensive picture of cognitive vulnerability.

Ongoing research continues to explore the pathways linking modifiable factors and cognitive functioning. The LIBRA index serves as more than a measure, but rather provides a framework for personalised and multidomain interventions that aim to preserve cognitive functioning. Interventions may include targeted risk factors identified within the LIBRA such as promoting physical activity, dietary modifications, and smoking cessation among others. For instance, Deckers et al. (2021) utilised the landmark Finnish Geriatric Intervention Study to Prevent Cognitive Impairment and Disability (FINGER) study to evaluate the effectiveness of lifestyle interventions aimed at diet, exercise, cognition, and vascular risk as opposed to general health advice across a two year period. The study included 1207 individuals aged 60-77 years who had a higher risk of dementia. Cognitive functioning was measured through the Neuropsychological Test Battery. The results of the study found higher LIBRA scores amongst men than women. The study also found that high-risk and intermediate risk tertiles of LIBRA scores were linked to lower brain health (lower cognitive functioning across the majority of cognitive domains and lower improvements in cognitive functioning after intervention) but, the intervention was found to be beneficial across all LIBRA scores rather than an observed moderation effect. The study did present with some limitations. For example, participants were drawn from those that had already completed previous health surveys. This presents with the possibility of selection bias whereby the participants recruited could be more health-conscious and already engaged with healthcare systems thus, unrepresentative of the general population, especially those that are more socioeconomically disadvantaged, or cognitive impaired. However, the presence of this study and its positive outcomes suggests implications of interventions on targeting specific risk factors identified in the LIBRA and its ability to effectively increase cognitive functioning, thereby potentially delaying or preventing the onset of dementia. Despite these advances, LIBRA as a framework as well as prevention and interventions based on it have received relatively little empirical attention in the New Zealand context.

Figure 1

Full-form Lifestyle for Brain Health Index



Note. Figure created to depict the full 12 factor LIBRA index described in Schiepers et al. (2018).

Chapter Six: Summary and Objectives of Present Study

Summary

The ageing population, both globally and locally, has necessitated a need to investigate a component of ageing, i.e. cognitive functioning. Importantly, cognitive functioning is also a critical component of dementia, a public health concern. Although some declines in cognitive functioning are inevitable with age, others are not. This variability underscores the need to investigate determinants impacting cognitive functioning.

Key factors impacting cognitive functioning include non-modifiable factors such as SES indicators, and sex, while modifiable factors include lifestyle modifiable factors, which are encapsulated in the LIBRA index. Non-modifiable factors such as SES indicators and sex help establish the structural and biological context which may impact cognitive functioning. SES can be accounted for through multiple indicators and it can shape cognitive outcomes through influences on cognitive reserve, material resources, and healthcare access, while sex based differences can reflect both biological mechanisms and socially constructed roles and opportunities. In contrast, modifiable factors such as physical activity, smoking, obesity, and vascular health represent opportunities for intervention and prevention. These lifestyle related risks and protective factors are summarised within the LIBRA index, a multidomain tool that quantifies the cumulative exposure to modifiable risks that have been linked to brain health. Being able to understand how these elements interact is critical as evidence increasingly suggests that cognitive outcomes are shaped not by singular influences but through the cumulative and interdependent effects of several factors. Furthermore, it provides critical insight into the biopsychosocial model which emphasises that health as well as cognitive health arises from the interplay between biological predispositions, psychological behaviours, and social-environmental contexts (Engel, 1977; Spector & Orrell, 2010).

Despite the growing body of research examining factors that influence cognitive functioning, there appears to be identifiable gaps and limitations in literature. Firstly, although existing research within the New Zealand context utilises large-scale datasets from longitudinal studies that include SES indicators and sex within it, they are often treated as covariates rather than independent and key factors. In instances where they are treated as variables of interest, they are predominantly undertaken internationally or are rarely examined alongside one another. For instance, studies such as those by Deckers et al. (2019b) and Heger et al. (2024) have both investigated interactive effects between SES and LIBRA in cognitive functioning and a study by Deckers et al. (2019c) builds on this investigation of interaction effect by adding sex as another independent variable. However, these studies have been completed internationally rather than utilising data from the New Zealand population.

Studies within the New Zealand context are of critical importance due to the unique cultural, social, and healthcare system differences as well as the earlier onset of dementia within Indigenous populations of New Zealand (Ma'u et al., 2021b). In the New Zealand setting, studies on cognitive functioning have also taken place. For instance studies by Röhr et al. (2024a), Röhr et al. (2024b), and Stephens et al. (2014) have all been conducted in the New Zealand context utilising some of the key factors identified within the present literature review (i.e. measuring SES, LIBRA, or measuring education and only part of the modifiable factors in relation to cognitive functioning, respectively). However, they do not measure all of the variables within the present study (i.e. SES and its indicators, sex, and lifestyle modifiable factors that are included within the LIBRA index).

Additionally, interaction effects i.e. two-way and particularly three-way interactions between these variables are underexplored, even though they may be able to provide a more realistic understanding of the effects and the interwovenness of various factors in shaping cognitive trajectories in real-world populations. Doing so overlooks their potential explanatory and moderating roles particularly in being able to identify vulnerable groups. Consequently, research examining the interplay between both modifiable and non-modifiable factors can provide valuable insight into individuals that are most vulnerable and at risk of lower brain health. These intersectional groups can then be used to inform equitable and evidence-based strategies to promote healthy cognitive ageing and thus allow for a chance at dementia prevention strategies.

Aims and Objectives

The purpose of the current study is to investigate the relationship between several factors (SES, sex, and lifestyle modifiable factors that are included within the LIBRA index) and their combined effects on cognitive functioning of mid-to-older New Zealanders. By investigating these variables as both independent predictors (rather than as covariates alone) and through their potential interactions, the study seeks to add to the body of research regarding cognitive functioning as well as dementia. It primarily builds on the work of the aforementioned studies that investigate interactions between several key factors both internationally and locally.

In line with the understanding that cognitive functioning is understood to be shaped by individual risk factors as well as their cumulative and intersecting influences (Spector & Orrell, 2010), the present study is grounded in a biopsychosocial framework. This framework recognises that cognitive functioning arises from the interaction of biological, psychological, and social influences (Engel, 1977). The framework provides an integrative foundation for examining how SES, sex, and lifestyle modifiable factors can collectively shape cognitive health. Therefore, this research assesses whether the relationship between one factor (e.g. lifestyle modifiable risk) and cognitive functioning is conditional on the level of another (e.g. education or sex). That is, if moderation effects exit. By testing such interactions, the present study aims to identify intersectional subgroups who may be at a higher risk of reduced cognitive functioning.

The study is explanatory in nature as it seeks to investigate the relationship between key factors and cognitive functioning, adding to existing research on cognition along with extending on previous works. However, the study also possesses aspects of exploratory research as it aims to address a gap in the research by exploring interactions within cognitive functioning in the New Zealand context. The below objectives will be achieved by engaging with cross-sectional data affiliated with a longitudinal study of ageing in New Zealand on mid-to-older New Zealand participants.

The objectives of the present study will include the following questions:

1. To investigate differences in cognitive functioning across SES.
2. To investigate differences in cognitive functioning across sex.
3. To investigate differences in cognitive functioning across lifestyle modifiable risk factors (encapsulated in the LIBRA index).

4. To explore interactions (including both two-way and three-way interactions) between SES, sex, and LIBRA and cognitive functioning.

Based on the literature review, the hypotheses for the above objectives include:

1. SES will be associated with cognitive functioning with lower SES presenting with lower cognitive functioning scores.
2. Sex will be associated with cognitive functioning scores with the female sex presenting with lower cognitive functioning scores
3. Lifestyle modifiable factors will be associated with cognitive functioning scores with higher LIBRA presenting with lower cognitive functioning.
4. Interactions (both two-way and three-way interactions) between the independent variables and cognitive functioning were expected to be significant, such that the relationship between each independent factor and cognitive functioning would be influenced by the other two independent variables.
    a. Higher education was expected to be associated with greater cognitive functioning, particularly among females. This reflects the evidence in the literature review which suggests education contributes to cognitive reserve.
    b. Higher education was also expected to buffer the negative association between higher LIBRA scores and cognitive functioning.
    c. Sex is expected to moderate the relationship between higher LIBRA and cognitive functioning. Differences are anticipated with adverse association between LIBRA and cognitive functioning to be stronger in males.
    d. Three-way interactions (between education, sex, and LIBRA) were also expected, such that the protective influence of higher education would be most pronounced among females with higher LIBRA risk.

Chapter Seven: Method

This chapter focuses on the research design, sample composition, procedures, and the variables of interest within the present study. It also discusses the steps taken for data preparation such as the detection of missing data, outliers, and other tests to ensure that the assumptions of multiple regression were met.

Research Design

The New Zealand Longitudinal Study of Ageing (NZLSA) is a sub-study and expansion of the biennial, government-funded longitudinal New Zealand Health, Work, and Retirement (HWR) study conducted by the Health and Ageing Research Team (Towers & Stevenson, 2014). The HWR first began in 2006, and was established at a period where exponential growth was being observed amongst the population of older adults (Towers & Stevenson, 2014). The HWR has been informed by other international studies such as the US Health and Retirement Study (HRS) as well as the English Longitudinal Study of Ageing (ELSA) (Gorman et al., 2012) as an avenue for public policy development in the local context (Towers & Stevenson, 2014). It aims to gather and provide nationally representative information on middle-aged and older-adults in New Zealand across aspects of health, wealth, work, retirement, housing, and many other aspects of ageing (Towers & Stevenson, 2014).

The NZLSA expands on the original HWR study by including data on the cognition of both middle-aged (48-64 years) and older adults (65-75 years). The inclusion of individuals under 55 years (i.e. those between the ages of 48-55 years) was a novel addition to the NZLSA which was funded by the New Zealand Foundation for Research, Science, and Technology for the 2010 and 2012 data waves (grant number MAUX0606) (Gorman et al., 2012). The present study will be an analysis of the subsample of participants from the NZLSA 2010 data wave which provides insight into the cognitive performances of a broader age range (middle to older age) of adults in New Zealand.

Sample

The participants in the NZLSA sample were randomly invited from the New Zealand electoral roll which requires all those with eligibility to vote to be registered (Towers, 2007). At the time of data collection for the present study, only 4% of New Zealanders were not registered on the electoral roll (Towers, 2007). Using those registered, and through processes of equal probability sampling, a nationally representative sample was achievable (Towers, 2007). Within the NZLSA sample, an oversampling of those of Māori descent (using the Māori descent indicator in the electoral roll database) was used to increase the subsample of the Māori group and ensure an adequate representation within the study (Towers, 2007; Towers & Stevenson, 2014). This was necessary to address the lower rates of participation observed in those belonging to an older Indigenous population (Gorman et al., 2012; Towers & Stevenson, 2014). For the 2010 NZLSA data wave, questionnaires were provided to 4,339 New Zealanders and responses were collected from 3,311 adults (Towers & Stevenson, 2014) who were aged 48 years and older.

Of those 3,311 participants who had completed the 2010 postal questionnaire, 1,001 agreed to take part in face-to-face interviews, a component of which included a cognitive assessment (Towers & Stevenson, 2014). Those that chose to take part in the face-to-face interviews were a volunteer sample, and consent was gathered through an item in the 2010 questionnaire which gathered participants willingness to complete a face-to-face interview.

Although the aim of the NZLSA sample was to remain as representative of the New Zealand population, the present study utilises the 2010 volunteer subsample (derived from the NZLSA 2010 participant pool) who chose to partake in the face-to-face interview (which included the cognitive assessment). The current study will include a sample of participants who satisfy the following: a) completed the postal survey, b) completed the face-to-face interview in 2010, and c) those that were 48 - 75 years as of 7th March 2010.

Procedures

The current study followed a positivist paradigm which utilised standardised quantitative survey methods. The methods employed in the current study included the use of the Tailored Design method coined by Don A. Dillman (Dillman, 2000 as cited in Towers, 2007, p. 7) as a way to increase response rates in the postal survey. To do so, a series of five points of contact were made. Firstly, potential participants were randomly selected from the electoral roll and were sent pre-notice letters which included information on the selection process and study procedures informing them that they would receive a questionnaire in a week's time. Then, they were mailed the questionnaire, an information sheet with their rights, expectations, and contact details along with consent forms and a free-post envelope. Next, after a three week duration, participants received a reminder (or a note of thanks) postcard. After another three weeks, a second questionnaire was sent to non-respondents. To encourage response, non-respondents received a follow-up reminder postcard, after five weeks, as a final contact.

Regarding the face-to-face interviews, an initial letter of appreciation was sent to all those who expressed interest for the face-to-face interviews when completing the postal survey. This letter included the interview process i.e. participants will be contacted and then contacted once again through a phone call to confirm consent. Following this consent, the participants were called to arrange meeting specifics (i.e. time, and location) and to confirm consent and availability. Once confirmed, the interview was facilitated by interviewers trained and managed by the Family Centre Social Policy Research Unit (Gorman et al., 2012). Interviewed participants were geographically spread across the country.

Measures

To answer the study aims, cognitive functioning was treated as the dependent variable. Factors indicative of SES as well as sex and lifestyle modifiable factors were treated as independent variables. While demographics were treated and used as covariates.

The NZLSA utilised two methods of data collection, i.e. the initial postal survey and the follow up face-to-face interviews. Data gathered from the face-to-face interviews included information which were new, additional or a reiteration of factors, such as cognitive functioning, ethnicity, marital status, educational qualifications, and income. Data from these face-to-face interviews were merged with data (on other factors included within the present research) gathered through the postal surveys. The measures utilised within this study are identified below.

Covariates

The identification and inclusion of these third variables in the data analysis is necessary to control for any potential confounding effect and to avoid or at least reduce risks of spurious associations.

Age.

To calculate the age, the year of participants' date of birth was subtracted from the date of the survey administration. Age was utilised in its continuous form rather than age bracketed categories.

Ethnicity.

Within the NZLSA study, participants were able to identify and select their ethnicity through response categories (Māori, New Zealand European, Samoan, Cook Island Māori, Niuean, Chinese, Indian, Tongan, and Other). For selections of more than one ethnicity, participants were asked to select their primary ethnicity identification. In the case of multiple ethnicity identification, ethnicity prioritisation rules were applied (Towers, 2007). For the purposes of data analysis, these responses were coded using a binary system with dichotomous categories (Māori = 0, non-Māori = 1). The choice to utilise a binary system was rooted in the availability of a small number of samples for most ethnicities which would result in a meaningful analysis difficult to conduct.

Marital Status.

Participants identified their relationship status by selecting categories from single, married, civil union, de-facto, divorced/ permanently separated, widowed, or other. For the purposes of data analysis, these categories were collapsed into two categories (single/no partner = 0, and married/partner = 1).

Independent Variable: Socioeconomic Status

In the current study, SES was represented by individual and amalgamated responses to items pertaining to education, income, and employment.

Education.

Participants in the study were asked to indicate their highest educational attainment with option categories being: no school qualification, secondary school qualification, post-secondary/trade, and tertiary education. For data analysis, options were scored 1- 4, respectively based on order of educational attainment.

Income.

To assess net personal annual income, participants were asked to identify their personal income from all sources in the past 12 months. Sources of income included, but were not limited to, payments by employers and self-employment, through investments, government benefits, no sources of income, and other. Participants were then requested to identify their total net personal income after all deductions (e.g. tax, KiwiSaver, union dues etc.) and its frequency. For data analysis purposes, income was left as an un-categorised continuous variable.

Employment.

Participants were asked to identify their current employment status. The nine selection options included: full-time paid employment (including self-employment, 35 or more hours per week), part-time paid employment (including self-employment, less than 35 hours per week), full-time student, retired with no paid work, full-time homemaker, unable to work due to health or disability issues, unemployed, seeking work, and other.

In the analysis, these categories were coded into an ordinal scale which reflected a greater workforce participation. In the ordinal scale, full-time employment received the highest score, followed by part-time employment and student status, while those who were retired, homemakers, unemployed, or unable to work due to health reasons were all assigned into the lower value category. For data analysis purposes, the eight options were condensed into the following 3 categories: Full-Time = 1, Part-Time = 2, and Other (Not Working, Studying, Retired) = 3. The decision to condense was based on the concept that those with full-time, and part-time paid employment had a higher workforce participation than those coded into the ‘other’ category.

Composite SES.

Due to the cumulative effect of SES factors (McMaughan et al., 2020), to analyse the SES of participants, a composite SES score was developed using each of the three variables, including education level, income, and employment status. For data analysis, each variable was first normalised (0 - 1 scale) to ensure that they were on a comparable scale. For example, for income this was achieved utilising the formula ((net personal income - minimum net personal annual income) / (maximum net personal annual income - minimum net personal annual income)). Normalisation allows for the adjustment of data values to a common scale (without any distortion of their range of values). This allows for a fair comparison between each variable across their differing units so that variables with larger ranges do not dominate the composite score. Thus, each variable being equally captured within a single measure.

The normalised scores for each variable (education, income, and employment status) where each variable was on a scale of 0 - 1, were then summed to create a composite SES which ranged between 0 and 3, with higher scores indicating higher SES. To categorise the participants into SES groups for analysis, the composite SES were divided into tertiles based on data distribution (using the 33^{rd} and 67^{th} data percentiles as cut points), thus providing balanced groups. The tertiles included low SES (the bottom third of participants), medium SES (the middle third of participants), and high SES (the top third of participants). This process ensures that each group contains an approximately equal number of participants with aims of a meaningful comparison across the SES groups.

While this approach allows for a multidimensional representation of SES through a composite SES score, it is also acknowledged that SES indicators may operate through distinct mechanisms and therefore may not be fully interchangeable (Rodriguez et al., 2024). As a result, individual indicators were also examined alongside a composite SES score.

Independent Variable: Sex

Within the 2010 NZLSA data wave, participants were required to select between dichotomous choices for their sex: male (0) or female (1). Additional gender selections were not offered in the 2010 NZLSA questionnaire, however this has been amended in subsequent questionnaires.

Independent Variable: LIBRA

The LIBRA, or the Lifestyle for Brain Health index, is a composite score developed as an estimation for dementia risk and thus dementia prevention (Pons et al., 2018; Schiepers et al., 2018; Vos et al., 2017). The original LIBRA index consists of 12 modifiable health and lifestyle factors (coronary heart disease, hypertension, hypercholesterolemia, high cognitive activity, healthy diet, renal dysfunction, diabetes, low-to-moderate alcohol consumption, smoking, physical inactivity, depression, and obesity), each with an assigned weight (Röhr et al., 2024b). The overall LIBRA score which can range from -5.90 to + 12.70, is a sum of weighted scores (reflecting relative risk) across each of these factors (Röhr et al., 2024b). Thus, while lower LIBRA scores can be an indicator of better brain health, higher LIBRA scores can be an indication of lower brain health potential as well as a higher risk of cognitive impairment and dementia.

Psychometric evaluations of the LIBRA index indicate psychometric properties of validity, highlighting its effectiveness in the prediction of brain health outcomes. For instance, there is evidence of the predictive validity of the LIBRA index such that higher LIBRA scores indicate a higher risk for dementia (Vos et al., 2017). However, this predictive validity is unavailable for those belonging to the oldest-old category (80-97 years) and nor does it suggest a definitive dementia diagnosis (Vos et al., 2017).

Overall, higher LIBRA scores have also been associated with low cognitive functioning, particularly for those in their mid, and earlier, older stages of their life (up to 75 years of age) (Pons et al., 2018). The LIBRA has been able to correctly allocate higher LIBRA scores to individuals presenting with MCI as opposed to those presenting with subjective cognitive complaints (Pons et al., 2018). This provides some evidence for construct validity. Although LIBRA was designed as a means for dementia risk prediction (Pons et al., 2018), it shows that higher scores align with a greater modifiable risk and thus poorer brain health thus showing construct validity.

Within the present study, information on 8 out of the 12 modifiable factors was available for evaluation. Information on hypercholesterolemia, cognitive activity, diet, and obesity were not available in the NZLSA and thus, the modified score differed from the original 12 factor model. The new scores for the modified model, also used by Röhr et al. (2024b), ranged from -1.00 to +8.70 and utilised weightings assigned to each factor (see Table 1). The score representativeness of the modified scores remained the same, in which higher scores were indicative of poorer brain health (and therefore higher potential of lower cognitive functioning and dementia)**.**

For data analysis, LIBRA scores were divided into three tertiles: low risk, moderate risk, and high risk similar to the study by Heger et al. (2024) and Vos et al. (2017). The cutoffs for the LIBRA categories were determined based on the distribution of LIBRA scores within the sample (specifically the 33rd and 67th data percentiles as cut points), to ensure that the data was more robust, data-driven, and reflected the natural distribution of the scores in the sample while also maintaining statistical rigor.

Table 1

Weightings assigned to the Modified LIBRA Index

Factor	Assessment	Weight
Coronary heart disease	Self-report (by responding "Yes") of diagnosis by a health professional (i.e. for "Heart trouble").	+1.0
Diabetes mellitus	Self-report (by responding "Yes") of diagnosis by a health professional (i.e. for "Diabetes").	+1.3
Chronic kidney disease	Self-report (by responding "Yes") of diagnosis by a health professional (i.e. for "Chronic kidney condition").	+1.1
Smoking	Self-report of current smoking status (i.e. If currently a smoker - "How many do you think you would smoke on an average day").	+1.5
Hypertension	Self-report (by responding "Yes") of diagnosis by a health professional (i.e. for "High blood pressure or hypertension").	+1.6
Low-to-moderate alcohol consumption	Self-report of frequency of alcohol consumption (i.e. "How often do you have a drink containing alcohol"). Assessment utilised the Alcohol Use Disorders Identification Test-Consumption Questions (AUDIT-C) were consumption of, or less than "two to four times per month" is indicative of heavy drinking (Bush et al., 1998).	-1.0
Physical inactivity	Self-report of activity levels (i.e. "the type and amount of physical activity involved in daily life) where physical inactivity was reported as engaging in less than once a week of moderate levels of activity (Röhr et al., 2024b; Stevenson, 2014).	+1.1
Depression	Self-reports of mood and behaviours in the past week. Assessment utilised the short-form (10-item) Centre for Epidemiological Studies Depression Scale (CES-D) where a score of, or greater than 10 was indicative of symptoms of depression (Andresen et al., 1994; Irwin et al., 1999).	+2.1
Obesity	Unavailable	+1.6
Hypercholesterolemia	Unavailable	+1.4
High cognitive activity	Unavailable	-3.2
Healthy diet	Unavailable	-1.7

Dependent Variable: Cognitive Functioning

Participants' cognitive functioning was measured using the 'Kiwi' Addenbrooke's Cognitive Examination-Revised ('Kiwi' ACE-R) which is provided in the appendix (Stevenson, 2014). The pathways of cognitive functioning can be predicted by multiple diagnostic tools including both the Addenbrooke's Cognitive Examination Revised (ACE-R) and the Mini-Mental State Examination (MMSE) (Bonilla-Santos et al., 2024; Yoshida et al., 2012). While the use of MMSE across literature is extensive, when comparing both diagnostic tools for cognitive functioning, Yoshida et al. (2012) concluded the ACE-R to be a higher quality tool than the MMSE in terms of assessment of cognitive domains/functions for the detection of MCI. Furthermore, Yoshida et al. (2012) also state the ACE-R to be a representative assessment of more cognitive abilities.

ACE-R scores vary from 0 to 100 with higher scores being indicative of higher cognitive functioning. The final ACE-R score is a reflection of scores across five cognitive domain tasks:

- Orientation and Attention (items to identify awareness of location and date, and tasks related to working memory). Examples of questions within this domain included "What is the date?", asking participants' current location as well as performing tasks spelling the word "world" both correctly and backwards. The maximum achievable score for this section was 18.
- Memory (items on recall/short-term, anterograde, and retrograde memory). This subsection of the cognitive test included questions to test both anterograde and retrograde memory. Examples of questions included asking participants the "Name of current Prime Minister?" as well a question on reciting a given address. The maximum achievable score for this section was 26.
- Fluency (generating names of words beginning with a given alphabet letter (i.e. "P"), and names of animals beginning with any alphabet letter in 60 seconds). The maximum achievable score for this section was 14.
- Language (items on writing, repetition of words, naming pictures, comprehension, and reading). For instance, participants were assessed on their ability to correctly name objects from pictures (i.e. a 'harp'). The maximum achievable score for this section was 26.
- Visuospatial abilities (items on copying drawings of shapes, drawing a clock, and writing). A question within this cognitive domain included asking the participant to "draw a clock face" with the clock hands pointing to the given time. The maximum achievable score for this section was 16.

The ACE-R also scores reasonably high across other psychometric properties such as sensitivity, specificity, reliability, and validity, particularly when compared to other tests of cognition (Bonilla-Santos et al., 2024). When compared to other tests of cognition such as the MMSE, the ACE-R was shown to be a more reliable detector of MCI by having higher sensitivity and specificity (Bonilla-Santos et al., 2024). The ACE-R is a sensitive and specific test battery, at a cut-off ACE-R score of 82, the ACE-R has a sensitivity of 0.84, and specificity of 1.00 while at a cut-off ACE-R score of 88, sensitivity is 0.94, and specificity is 0.89 (Mioshi et al., 2006). This shows that a score of 82 or lower is indicative of a higher likelihood of belonging to someone with severe cognitive impairment such as dementia. ACE-R and its culturally adapted versions have also been evaluated to have high internal consistency reliability through a satisfactory overall MacDonald's omega coefficient of 0.78 (Bonilla-Santos et al., 2024), and high alpha coefficients of 0.80 (Mioshi et al., 2006), and 0.90 (Yoshida et al., 2012). These studies demonstrate the effectiveness of the ACE-R in being able to assess cognitive functioning and accurately identify MCI, furthermore enhancing its applicability in global clinical settings.

To deliver the ACE-R to New Zealanders, the test was revised to be a culturally adapted version or the 'Kiwi' ACE-R. The 'Kiwi' ACE-R has retained the core elements of the original test while also accommodating for cultural differences thus reducing misinterpretation, being locally appropriate (i.e. using a local address and asking participants to name the current Prime Minister), and leading to a higher accuracy of results (Callow et al., 2015; Stevenson, 2014). To demonstrate its psychometric reliability, it has been shown to have concurrent validity (with MMSE) as well as a reliable alpha coefficient of 0.7 (Callow et al., 2015).

For the present study, the sample was described using the 'Kiwi' ACE-R as a continuous variable and via standardised thresholds. While scores that are two standard deviations or below the mean can be categorised as 'cognitively impaired' (Callow et al., 2015; Yoshida et al., 2012), the present analysis categorised participants as 'cognitively impaired' if they scored 82 or below. While this is consistent with the ACE-R validation study by Mioshi et al. (2006), cognitively impaired individuals were not removed from the analysis as they were still reflective of the population as well as being part of the construct of interest.

Data Preparation

Exploratory analysis allowed for tests of normality as well as missing data, and outliers. Then descriptive statistics were used to summarise characteristics of the data. The inspection of these statistics allowed the visualisation of key variables and their distributions across the sample. All statistical analyses were completed using IBMS SPSS Version 26.

Missing data

Prior to the completion of any analyses, data was analysed to assess missing data. Each of the independent and dependent variables, and covariates were analysed. Most variables returned missing data percentages between 0.0% - 2.1%. Less than 5% of data points were missing which is typically considered insignificant (Dong & Peng, 2013) and indicates that the missing points could be handled through any method (Tabachnick & Fidell, 2019). A Little's MCAR test was completed which indicated that the data was not missing completely at random (x^2 = 25.92, df = 6, p = < 0.001). This suggested that some missingness was related to other observed variables. Nonetheless, based on the low percentages of missing data for each variable as well as the absence of consistent associations with the dependent variable, the overall pattern of the missing data was treated as predominantly missing at random (MAR). A listwise deletion was used to delete missing data and maintain data integrity as well as minimise the risk of artificially inflating relationships through imputation techniques.

Outliers

Detections and evaluation of outliers and other influential data points were made to ensure that they do not disproportionately affect the results. Univariate outliers in continuous data were identified through z scores values higher than 3.29 ($p < 0.001$, two-tailed) (Tabachnick & Fidell, 2019). Using these parameters, the 'Kiwi' ACE-R variable was identified to have 12 scores that were considered to be univariate outliers (scores < 78). The detection of these outliers was based on statistical deviation rather than clinical thresholds. Additionally, the LIBRA variable was identified as having 2 cases considered to be univariate outliers (7.10 and 7.40); income was identified as having 13 cases considered to be univariate outliers (income ranging between 158,908 to 362,293), and no outliers were identified for the age variable.

Multivariate outliers were examined using Mahalanobis Distance (MD) for continuous variables (LIBRA, age, income, and 'Kiwi' ACE-R). Alpha was defined as $p < 0.01$ (Tabachnick & Fidell, 2019). Eight multivariate outliers were detected to have a MD value of higher than x^2 critical value = 18.47 (ranging from 19.01 to 94.59). Upon further investigations of each potential univariate outlier, it was revealed that outliers had been correctly entered and had come from the intended population. Furthermore, the outliers identified for income were valid extreme outliers i.e. high income earners, and it is more than likely that the identified values may be cases that are observable in the normal population. The 8 multivariate outliers identified through MD, appeared to be a result of individuals with higher income. As the income variable is a building block of a composite SES score, a decision was made to keep them in the dataset to retain as much information as possible. While valid, this choice may have introduced additional variance and possibly reduced model precision. A final examination of residuals (completed using Cook's distance), found no cases with distance ≥ 1 (Tabachnick & Fidell, 2019), with the highest Cook's distance being 0.058. Thus, influential effects of individual cases on the regression analysis were not detected.

Assumptions of Normality

A normality check is crucial for the completion of several of the planned statistical tests. Assessments of normality for the variables using skewness, kurtosis, histograms, and normal probability plots showed several normality violations. These variables included income, LIBRA scores, age, along with the 'Kiwi' ACE-R total score which showed moderate to severe skewness and kurtosis thus indicating violations in the assumptions of normality (Tabachnick & Fidell, 2019). In particular, the 'Kiwi' ACE-R scores showed negative skewness (-1.78) and a high kurtosis (5.28) which suggests a left-tailed distribution. Similarly, income showed positive skewness (3.53) along with a high kurtosis (20.79) which indicates a long-tailed distribution with potential outliers (outliers were previously examined but a decision was made to keep them in the dataset to retain information and utilise the variable to complete a composite SES score). LIBRA and age had moderate skewness (0.54 and -0.13, respectively) and kurtosis of 0.09 and -0.80, respectively, but still deviated from normality. Visual inspections of histograms and Q-Q plots confirmed the above interpretations and deviations of the 'Kiwi' ACE-R scores clustering at the higher end.

Since most variables violated the normality assumptions, implementation of non-parametric tests was required. Before this decision, log transformations for each variable that violated normality were also performed. Although log transformations reduced skewness, transformations did not fully normalise the data, thus the need for non-parametric tests to be conducted on original data.

Assumptions of Linearity and Homoscedasticity

Further tests were also completed to ensure that the assumptions of multiple regression were met. The residual scatter plots (consisting of the dependent variable against the continuous independent variables) indicated no severe violations of homoscedasticity with a relatively even linear spread. There were, however, some slight deviations which could be indications of slight heteroscedasticity but these did not appear to be severe enough to undermine the planned regression analysis (Tabachnick & Fidell, 2019).

Table 2

Correlation Matrix for Relevant Variables

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
1. Age	1									
2. Sex	-0.09**	1								
3. Ethnicity	-0.03	-0.01	1							
4. Marital Status	-0.06	0.18***	0.09**	1						
5. Education	-0.18***	-0.03	0.08*	0.12***	1					
6. Income	-0.23***	-0.24***	-0.09**	0.11***	0.31***	1				
7. Employment Status	0.49***	0.08*	-0.01	-0.12***	-0.18***	-0.56***	1			
8. SES (Composite)	0.30***	0.01	0.07*	-0.01	0.52***	-0.14***	0.70***	1		
9. LIBRA (Continuous)	0.11**	-0.09*	-0.09*	-0.09*	-0.08*	-0.15***	0.22***	0.14***	1	
10. 'Kiwi' ACE-R	-0.26***	0.14***	0.11***	0.06	0.34***	0.19***	-0.18***	0.10**	-0.15***	1

Note: 'Kiwi' ACE-R = 'Kiwi' Addenbrooke's Cognitive Examination-Revised; SES = Socioeconomic status; LIBRA = Lifestyle for Brain Health. $N = 869$, $^{***}p < 0.001$, $^{**}p < 0.01$ level (2-tailed), $^{*}p < 0.05$ (2-tailed)

Multicollinearity

Multicollinearity was assessed using both Spearman's rank-order correlation analysis as well as through the calculation of Variance Inflation Factor (VIF) values and Tolerance statistics. Although the correlation matrix (Table 2) showed moderate correlations between SES (Composite) and its individual components, such as Education and Employment Status, this was a given considering SES (Composite) is an amalgamation of these factors. However, additional factors of Income and Employment Status showed a moderate to strong negative correlation and Age and Employment Status also demonstrated a moderate positive correlation (Akoglu, 2018) due to the coding scheme (higher scores in employment status meant lower workforce participation). Other correlations were also identified and are presented in Table 2. These correlations indicate potential multicollinearity as these variables share substantial overlap in what they measure.

Despite these correlations, there appeared to be no multicollinearity issues detected through the use of VIF values and Tolerance statistics. All VIF values returned to be well below the threshold of 10.0 (Kutner et al., 2004) with the highest VIF value being 1.04, along with all tolerance values exceeding 0.2; lowest tolerance level value being 0.96. Hence, no multicollinearity detected and these variables were retained for further analysis.

Statistical Analysis

The current analysis examined the associations of the independent variables of SES (and its predictors), sex, and LIBRA scores with the dependent variable of cognitive functioning (‘Kiwi’ ACE-R) as well as interactions between the independent variables. To independently compare differences of cognitive functioning (‘Kiwi’ ACE-R) across composite SES tertiles, sex, and LIBRA tertiles, non-parametric tests such as Kruskal-Wallis and Mann-Whitney were utilised, separately. These non-parametric tests accounted for the abnormal distribution of data and allowed for comparisons across each factor, with differences being analysed through mean rank differences. It is also important to note that while a composite SES score was created to evaluate the cumulative effect of each of the three SES factors, the factors were also considered as individual scores as a recognition of their somewhat differing pathways.

While all socioeconomic indicators (education, income, and employment status) were included as independent factors to capture the distinct aspects of socioeconomic position, interaction effects were only tested for education. This is because it is theoretically grounded in the cognitive reserve framework which suggests that education plays a buffering role in cognitive outcomes. Therefore, while income and employment status were retained as main effects, they were not included in interaction terms as their influences on cognition appears to be primarily additive.

To investigate interaction effects across all independent variables while controlling for covariates, a hierarchical multiple regression model was utilised and variables were added in steps (i.e. covariates, main variables, 2-way interactions, and 3-way interactions, respectively). First, the model included the covariates, followed by the independent variables. This was followed by interaction terms for each pair of independent variables in the third model. Finally, interaction across all relevant variables were identified in the fourth model. All continuous predictors were standardised prior to entry to reduce multicollinearity. The tables report unstandardised B and standardised β.

Chapter Eight: Results

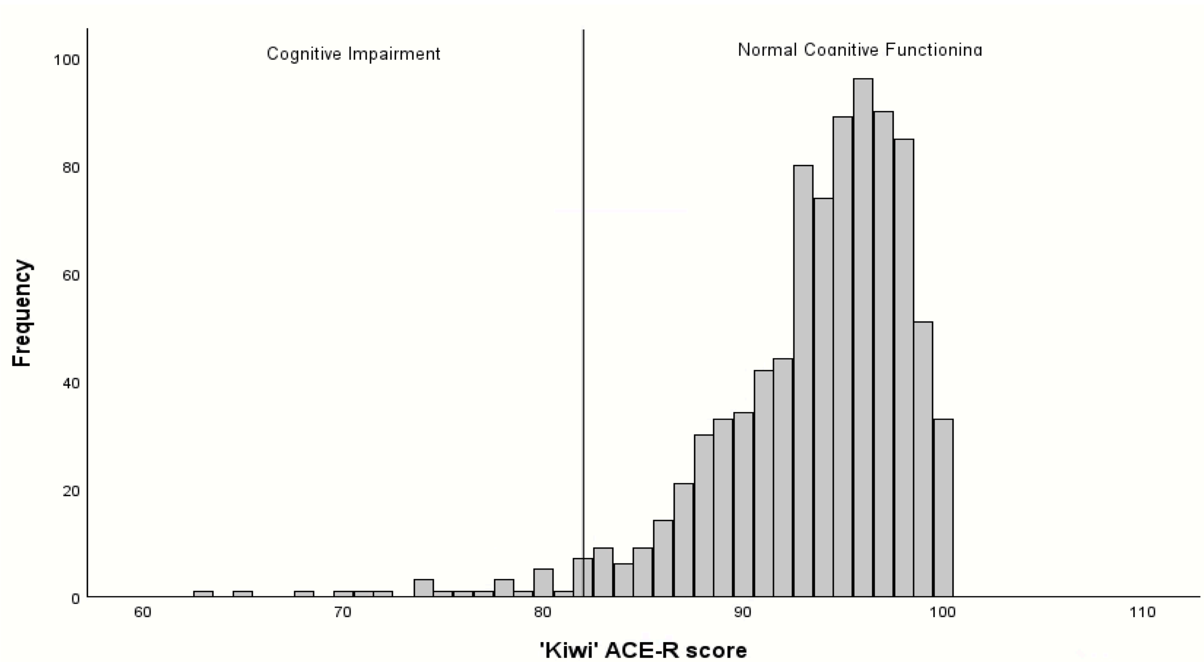
The final sample for the present study consisted of 869 participants (*N = 869).* Participants ranged from 48 to 75 years old in age with median age being 63.0 (*IQR* = 9.0) (Table 3). The majority of participants categorised themselves as non-Māori (73.6%, *N*= 640). Just over half were female and over two-thirds were married or had a partner. Descriptive statistics are summarised in Table 3 and in more detail below.

Sample Descriptives for Cognitive Functioning

Participants scored between 63 and 100 in the 'Kiwi' ACE-R test with the median score being 95.0. Within the sample of the present study, less than 4% of participants were classified as scoring in the 'cognitive impaired' levels of cognitive functioning. As a large majority of data points (Figure 2) were within 'normal' ranges for cognitive functioning, this variable (the 'Kiwi' ACE-R) was used in its continuous form for inferential statistics and throughout the analysis.

Figure 2

Distribution of Cognitive Functioning Based on 'Kiwi' ACE-R Scores in a New Zealand Sample



Note: This figure displays the distribution of cognitive functioning scores across New Zealand participants. The left side represents individuals with cognitive impairment (i.e. 'Kiwi' ACE-R scores of or below 82), while the right side indicates those with normal cognitive functioning (i.e. those with 'Kiwi' ACE-R scores above 82).

Table 3

Descriptive Summary of Participants

Variables	Participants (*N* = 869) Frequency	%	Median	IQR
Age (48-75)			63.0	9.0
Sex				
Female	463	(53.3)		
Male	406	(46.7)		
Ethnicity				
Māori	229	(26.4)		
Non-Māori	640	(73.6)		
Marital Status				
Single/no partner	245	(28.2)		
Married/partner	624	(71.8)		
SES				
Education				
No Qualifications	140	(16.1)		
Secondary School	195	(22.4)		
Post-secondary certificate/diploma	339	(39.0)		
University Degree	195	(22.4)		
Income ($)			$32,726.0	$35,050.3
Employment				
Full-Time	321	(36.9)		
Part-Time	199	(22.9)		
Other (Not Working/Studying/Retired)	349	(40.2)		
SES (Composite)			1.17	
Low SES	289	(33.3)		
Medium SES	290	(33.4)		
High SES	290	(33.4)		
LIBRA (scale)			1.60	2.1
Low Risk	227	(26.1)		
Moderate Risk	345	(39.7)		
High Risk	297	(34.2)		
Cognitive Functioning (‘Kiwi’ ACE-R)			95.0	6.0
Normal Cognitive Functioning	840	(96.7)		
Cognitive Impairment	29	(3.3)		

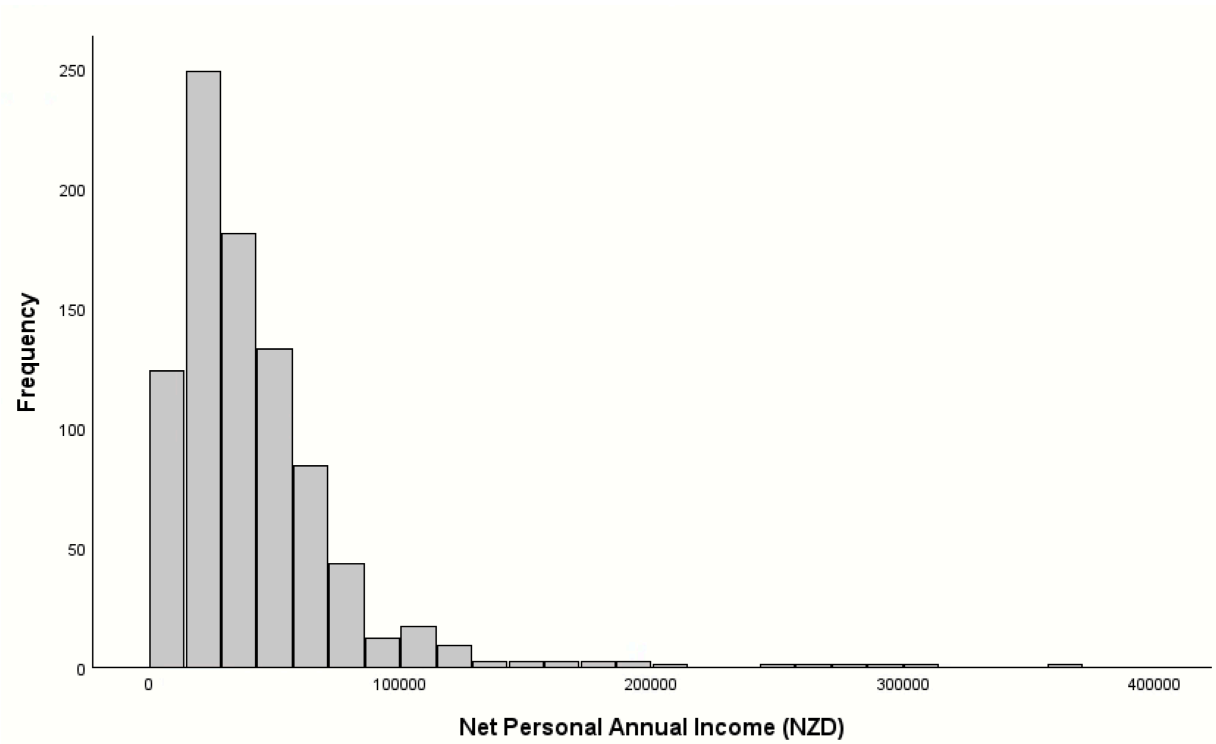
Note: Cognitive Impairment included ‘Kiwi’ ACE-R scores that were below 82 which is consistent with prior literature. *IQR* = Interquartile Range; SES = socioeconomic status; LIBRA = Lifestyle for Brain Health; ‘Kiwi’ ACE-R = ‘Kiwi’ Addenbrooke’s Cognitive Examination-Revised.

Sample Descriptives for SES and SES factors

Composite SES consisted of an amalgamation of participants' highest level of education, net annual income, and current employment status and had a median score of 1.17. The most common educational level was post-secondary certificate/diploma (39.0%), while 16.1% reported no formal qualifications. Employment status was varied, with around two-fifths no longer in any employment i.e. they were either retired, studying, or otherwise not working. Median net annual personal income level was $32,726.0 (*IQR* = $35,050.3) which reflected the variability across the sample. This variability has been displayed in Figure 3.

Figure 3

Distribution of Income in a New Zealand Sample



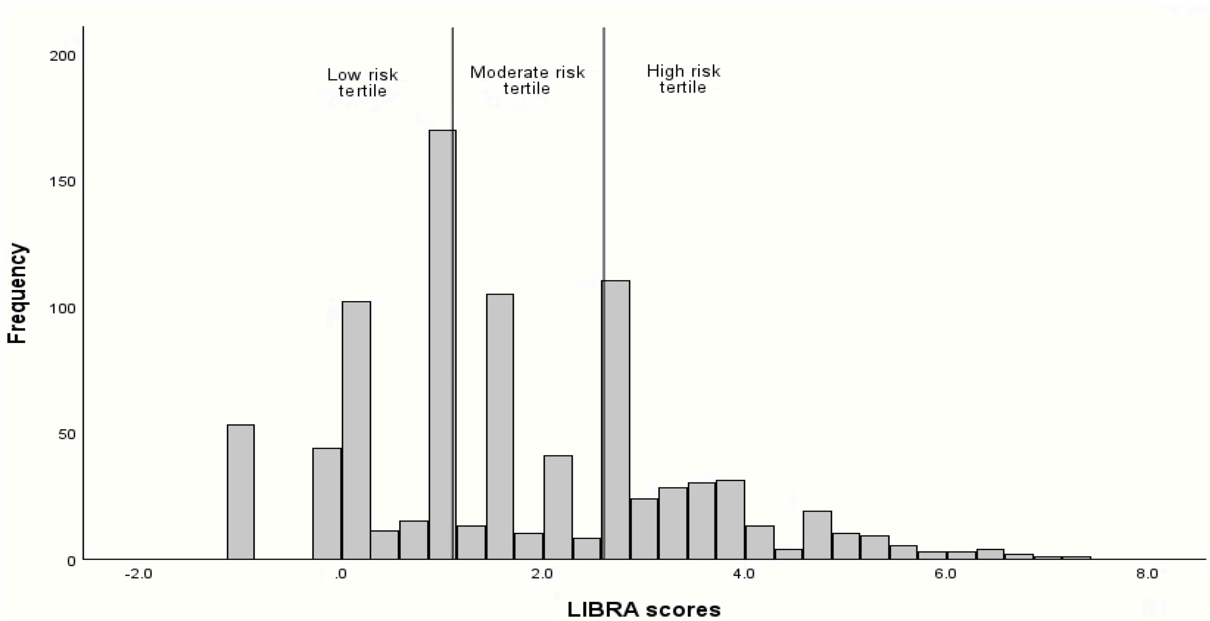
Note: This figure displays the distribution of net personal annual income across New Zealand participants.

Sample Descriptives for LIBRA

Scores on the LIBRA index (reflecting dementia risk) ranged from -1.00 to +7.40, with a median of +1.60. Based on tertiles, participants were classified as either low (26.1%), moderate (39.7%), or high risk (34.2%) as displayed in Figure 4. Some imbalance across the tertiles was present as a result of several tied values where large numbers of participants had the same LIBRA scores.

Figure 4

Distribution of LIBRA Scores Across Risk Tertiles in a New Zealand Sample



Note: This figure displays the distribution of LIBRA scores across New Zealand participants, with the data divided into three risk tertiles: low, moderate, and high risk.

Bivariate Correlations

Table 4 shows the results of Spearman's rank tests which were conducted to examine the associations between the 'Kiwi' ACE-R and continuous independent variables as well as age. Cognitive functioning ('Kiwi' ACE-R) was negatively correlated with age and LIBRA, and positively correlated with income. This suggests that older age, and higher lifestyle modifiable risk were linked to lower cognitive scores, while higher income was associated with higher cognitive scores. However, the strength of the relationships were regarded as being weak (Akoglu, 2018). The findings indicate multiple interrelated effects of demographic and lifestyle factors on cognitive functioning with no single variable having a significantly large influence.

Other relationships included positive correlations between age and LIBRA while negative correlations between age and income, and income and LIBRA were also present. While statistically significant, all of these effect sizes were considered to be weak (Akoglu, 2018).

Table 4

Correlation Matrix for Relevant Continuous Variables

	1.	2.	3.	4.
1. Cognitive Functioning (‘Kiwi’ ACE-R)	1			
2. Age	-0.26***	1		
3. Income	0.19***	-0.23***	1	
4. LIBRA (Continuous)	-0.15***	0.11**	-0.15***	1

Note: ‘Kiwi’ ACE-R = ‘Kiwi’ Addenbrooke’s Cognitive Examination-Revised; LIBRA = Lifestyle for Brain Health. N = 869, $^{***}p < 0.001$, $^{**}p < 0.01$ level (2-tailed), $^{*}p < 0.05$ (2-tailed)

Bivariate Analyses

SES and Cognitive Functioning

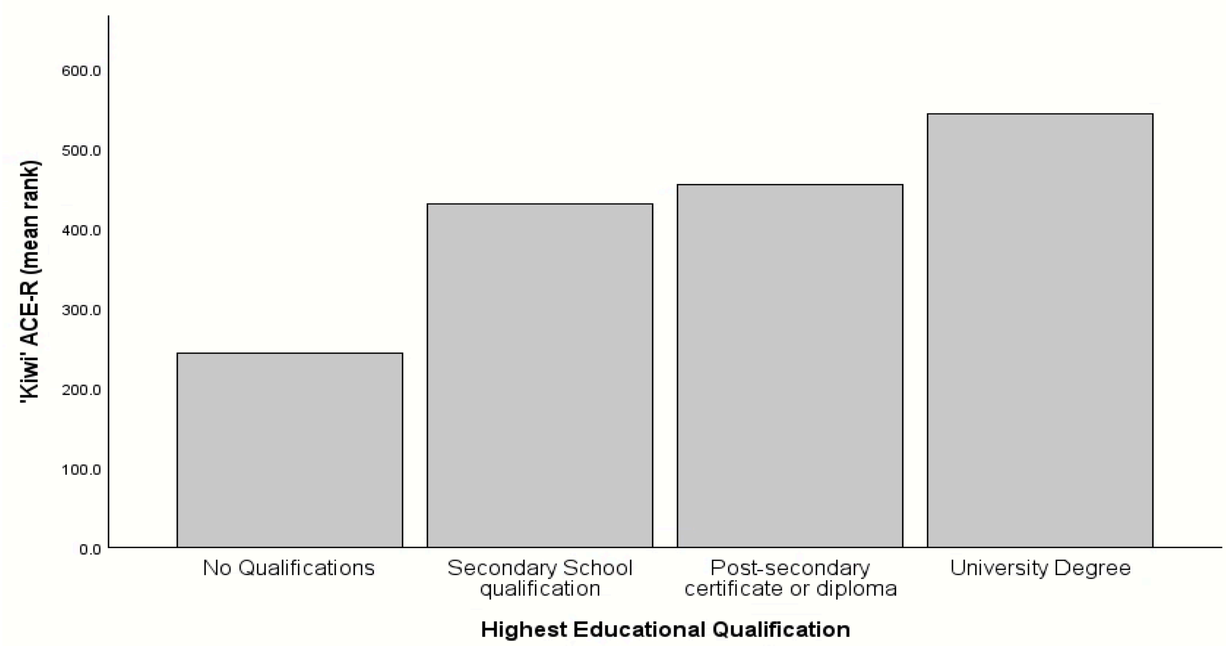
A Kruskal-Wallis H test was conducted to examine the differences between SES composite tertiles (low, medium, and high). It was found that the mean ranked cognitive functioning scores appeared slightly higher in the high SES tertile (mean rank = 455.95) than in the low (427.67), and the medium SES tertile (421.36). However, these differences were not statistically significant, $H(2) = 3.14$, $p = 0.21$. This indicated that the overall SES composite was not meaningfully associated with cognitive functioning and as a result, SES was further explored at the individual SES component level to provide more information.

Education.

Utilising the Kruskal-Wallis H test, a significant effect was found between variables of education and cognitive functioning, $H(3) = 120.92$, $p < 0.001$. The post-hoc pairwise comparisons showed participants with tertiary education had significantly higher ‘Kiwi’ ACE-R scores than those with lower levels of education. Participants with a university degree had a higher mean rank cognitive functioning (mean rank = 542.63) than those with post-secondary certificate or diploma (mean rank = 455.23), secondary school qualification (mean rank = 430.13) and no qualifications (mean rank = 242.90, see Figure 5). Significant differences were observed between no qualification and secondary school qualification ($U = 187.23$, $z = -6.76$, $p = < 0.001$), no qualification and post-secondary certificate or diploma ($U = 212.33$, $z = -8.45$, $p = < 0.001$), no qualification and university degree ($U = 299.73$, $z = -10.82$, $p = < 0.001$), secondary school qualification and university degree ($U = 112.50$, $z = -4.44$, $p = <0.001$), and post-secondary certificate or diploma and university degree ($U = 87.40$, $z = -3.89$, $p = < 0.001$). No significant difference was observed between secondary school qualification and post-secondary certificate or diploma ($U = 25.10$, $z = -1.12$, $p = 0.26$). The moderate association of education with cognitive functioning ($r_s = 0.34$, $p < 0.001$) can be observed in Table 2.

Figure 5

Average 'Kiwi' ACE-R (mean rank) by Education



Note: This figure displays the mean rank cognitive functioning ('Kiwi' ACE-R scores) across participants' highest educational qualification.

Income.

Spearman's rank-order correlation was conducted to assess the relationship between income and cognitive functioning ('Kiwi' ACE-R) scores. The results (Table 4) showed a significant positive correlation ($r_s = 0.19$, $p < 0.001$) which indicated higher income levels were associated with higher cognitive functioning. However, the correlation was small, suggesting a modest relationship between the two variables.

Employment Status.

Employment status also showed a significant effect, $H(2) = 30.65$, $p < 0.001$ in the Kruskal Wallis H test. Participants that were employed full-time or part-time had significantly higher mean rank cognitive functioning (mean rank = 476.67) and (mean rank = 468.13), respectively than those not in full-time or part-time employment (mean rank = 377.78). Significant difference was observed between part-time and other as well as full-time and other (($U = 90.34$, $z = 4.07$, $p = < 0.001$) and ($U = 98.89$, $z = 5.11$, $p = < 0.001$), respectively). However no significant difference was observed between the part-time and full-time samples ($U = 8.54$, $z = 0.38$, $p = 0.71$). Employment status had a small negative association with lower cognitive functioning in those that were not employed full-time or part-time ($r_s = -0.18$, $p < 0.001$) (Table 2).

In summary, as there were no significant differences in cognitive functioning across composite SES tertiles, the null hypothesis was retained. This null finding is notable as it suggests that a multidimensional composite may obscure the meaningful effects that could appear if the composite SES was divided into its individual factors. Analyses of the individual factors (education, employment, and income) making up the composite SES scores provided clearer associations and as a result were carried forward to the hierarchical multiple regression model for further testing.

Sex and Cognitive Functioning

To assess whether cognitive functioning differed by sex, a Mann-Whitney U test was conducted. Results indicated that females had a higher cognitive functioning mean rank (mean rank = 468.58) compared to males (mean rank = 396.71), $U = 78{,}441.50$, $z = -4.23$, $p < 0.001$. Although this is a statistically significant result, the difference was modest as the medians differed by only one point and the score distributions were largely overlapping (see Table 5). This suggests that while sex differences in cognitive functioning were detectable in this sample, the effect size (Table 2) was small ($r_s = 0.14$, $p < 0.001$) and may warrant cautious interpretation.

Table 5

Cognitive Functioning ('Kiwi' ACE-R) by Sex (Mann - Whitney U test)

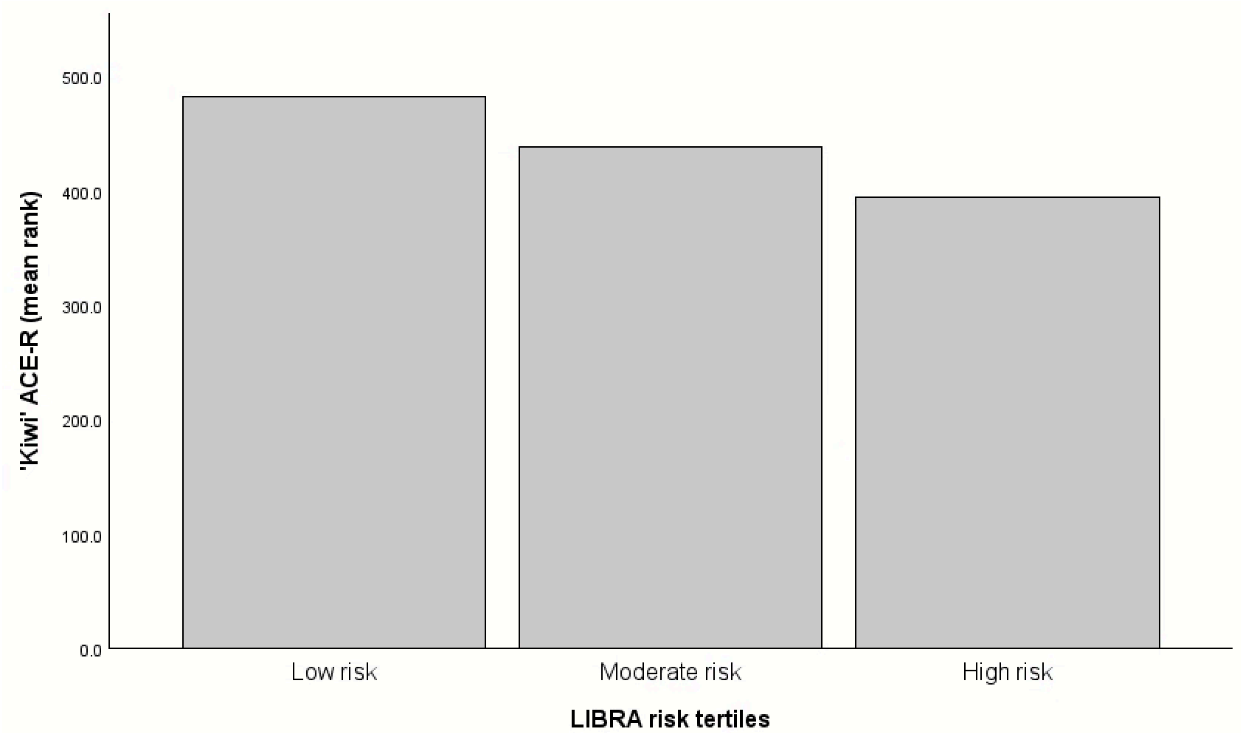
Sex	Median	Range	IQR	Mean Rank	U
Male	94	68 - 100	6	396.71	
Female	95	63 - 100	5	468.58	78,441.50

LIBRA and Cognitive Functioning

A Kruskal-Wallis H test revealed statistically significant differences in cognitive functioning across LIBRA tertiles, $H(2) = 15.84$, $p < 0.001$. Participants in the lowest risk tertile had significantly higher cognitive scores (mean rank = 481.90) than those in the high risk group (mean rank = 394.52), observed in Figure 6. Comparisons between low and moderate ($U = 42.91$, $z = 2.01$, $p = 0.05$), moderate and high ($U = 44.47$, $z = 2.25$, $p = 0.03$), and between low and high risk tertiles ($U = 87.38$, $z = 3.96$, $p = < 0.001$) were all observed to be significant. This confirms that higher LIBRA risk was consistently associated with lower cognitive functioning even though the effect size (r_s = -0.15, $p < 0.001$) (Table 2) was very modest.

Figure 6

Average 'Kiwi' ACE-R (mean rank) by LIBRA scores



Note: This figure displays the mean rank cognitive functioning ('Kiwi' ACE-R scores) across LIBRA risk tertiles.

Covariates and Cognitive Functioning

Age.

To investigate the association between age and cognitive functioning, a spearman's rank-order correlation was done. Table 4 shows the significant negative correlation (r_s = -0.26, $p < 0.001$) which suggests higher age was associated with lower cognitive scores.

Ethnicity.

To assess differences across ethnicity, a Mann-Whitney U test was employed. The test indicated that non-Māori participants had significantly higher cognitive functioning (mean rank = 451.90) compared to Māori participants (mean rank = 387.76), U = 84, 098.50, z = 3.33, $p < 0.001$.

Marital Status.

A Mann-Whitney U test indicated that married/partnered participants had slightly higher cognitive functioning (mean rank = 444.82) than single/no partnered participants (mean rank = 409.98). However, this difference was not statistically significant (U = 82,569.50, z = 1.85, p = 0.065).

Multivariate Analyses

A hierarchical multiple linear regression model was conducted to examine the association between cognitive functioning (as measured by the ‘Kiwi’ ACE-R) and the variables of education, income, employment, sex, and LIBRA scores. Covariates of age and ethnicity were also included within the model. While marital status was initially considered as a covariate, due to insignificance at the bivariate level, marital status was not included in the hierarchical multiple linear regression model. Similarly, although SES was initially a multidimensional construct (education, income, and employment), only individual SES components were carried forward to be tested in the hierarchical multiple regression model. However, as stated previously, while all SES indicators (education, income, and employment status) were tested for main effects, the interaction effects were only tested for education. This was based on theoretical relevance as well as prior bivariate analyses, correlations, and non-parametric results. The hierarchical multiple linear regression produced four models and the results are presented in Table 6.

The first model, produced using covariates of age and ethnicity, significantly predicted cognitive functioning and explained 7% of the variance. Among the covariates, both younger age and being non-Māori were independently associated with higher ACE-R scores.

The second model introduced the main variables of education, income, employment, sex, and LIBRA in addition to the covariates. The inclusion of these variables substantially improved model fit and were able to explain 19% of the variance. Within this model, education, sex, and LIBRA (as well as covariates of age and ethnicity) all emerged as significant independent variables of cognitive functioning with higher education, female sex and lower LIBRA risk scores being linked to higher cognitive functioning scores. Specifically, within this model (which was the most explanatory), each additional level of education was associated with approximately a 1.5-point increase in ACE-R scores, whereas each one-unit increase in LIBRA corresponded to an approximate decrease of 0.5 points in the ACE-R scores. However, their relative explanatory power differed. Education demonstrated the strongest unique association with cognitive functioning which was more than twice that of sex and close to three times that of LIBRA therefore having the largest proportion of unique variance in the ‘Kiwi’ ACE-R scores. Variables such as income and employment status were not independently associated with cognitive functioning performance once other variables were controlled for. This suggested that education accounts for the majority of the SES related variance in cognitive functioning making it the strongest SES related variable.

The third model examined the two-way interactions to test whether the associations between cognitive functioning and education affected the sex or LIBRA and cognitive functioning link. The inclusion of these interaction terms was not able to improve model fit and no significant moderating effects were detected.

The fourth model extended the analysis to test three-way interactions among education, sex, and LIBRA (e.g. education x sex x LIBRA). No statistically significant results were seen in these interactions and interactions did not account for any additional variance in cognitive functioning.

Across all models, the most consistent variables of higher cognitive functioning were younger age, non-Māori ethnicity, higher educational attainment, female sex, and lower LIBRA scores. Overall, the hierarchical multiple regression model was able to explain approximately 19% of the variance in cognitive functioning.

Table 6

Hierarchical Multiple Regression with Factors Associated with Cognitive Functioning ('Kiwi' ACE-R)

Variable	Model 1			Model 2			Model 3			Model 4		
	B	β	95%	B	β	95%	B	β	95%	B	β	95%
Age (48 - 75 years)	**-1.23**	**-0.25*****	**(-1.55, -0.91)**	**-0.80**	**-0.16*****	**(-1.16, -0.45)**	**-0.84**	**-0.17*****	**(-1.19, -0.48)**	**-0.84**	**-0.17*****	**(-1.20, -0.49)**
Ethnicity (ref = Māori)	**1.21**	**0.11****	**(0.44, 1.94)**	**0.82**	**0.07***	**(0.13, 1.51)**	**0.80**	**0.07***	**(0.11, 1.49)**	**0.82**	**0.07***	**(0.13, 1.52)**
Education	-	-	-	**1.48**	**0.29*****	**(1.16, 1.80)**	**1.59**	**0.32*****	**(1.13, 2.05)**	**1.57**	**0.31*****	**(1.11, 2.03)**
(ref = no school qualification)												
Income (NZD)	-	-	-	0.24	0.05	(-0.11, 0.59)	0.22	0.04	(-0.13, 0.58)	0.22	0.04	(-0.13, 0.58)
Employment (ref = Full-time)	-	-	-	0.02	0.00	(-0.42, 0.45)	0.02	0.00	(-0.42, 0.46)	0.02	0.00	(-0.41, 0.46)
Sex (ref = male)	-	-	-	**1.26**	**0.13*****	**(0.62, 1.89)**	**1.80**	**0.18***	**(0.04, 3.57)**	**1.78**	**0.18***	**(0.02, 3.55)**
LIBRA (-1.00 - +8.70)	-	-	-	**-0.53**	**-0.11*****	**(-0.84, -0.22)**	**-1.16**	**-0.23***	**(-2.08, -0.23)**	**-1.40**	**-0.28***	**(-2.64, -0.15)**
Education x Sex	-	-	-	-	-	-	-0.21	-0.06	(-0.83, 0.41)	-0.21	-0.06	(-0.83, 0.41)
Education x LIBRA	-	-	-	-	-	-	0.23	0.13	(-0.08, 0.54)	0.32	0.18	(-0.12, 0.76)
Sex x LIBRA	-	-	-	-	-	-	0.04	0.01	(-0.57, 0.65)	0.51	0.07	(-1.21, 2.23)
Education x Sex x LIBRA	-	-	-	-	-	-	-	-	-	-0.17	-0.07	(-0.79, 0.43)
R^2	0.07			0.19			0.19			0.19		
Adjusted R^2	0.07			0.18			0.18			0.18		
$\triangle R^2$	-			0.12***			0.00			0.00		

Note: 'Kiwi' ACE-R = 'Kiwi' Addenbrooke's Cognitive Examination-Revised; SES = socioeconomic status; LIBRA = Lifestyle for Brain Health.
$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$.

Chapter Nine: Discussion

This chapter focuses on providing a summary of results, interpreting findings, comparison with existing literature, as well as presenting strengths and limitations of the present study and future directions. The purpose of the present cross-sectional study was to examine the interrelationship between SES indicators, sex, LIBRA, and cognitive functioning (through global cognitive functioning scores) in mid-to-older adults. The study contained elements of both explanatory and exploratory research and results were gained from the analysis of the 2010 survey data from the NZLSA.

Summary

The present study drew on a large, community based sample of mid-to-older New Zealand adults (N = 869), with participants who ranged from ages between 48 to 75 years (median = 63). Towers and Stevenson (2014) report that the NZLSA sample was broadly representative of the New Zealand population with deliberate over-sampling of Māori. Overall the NZLSA sample (45% male, 55% female) and the present study's sample (46.7% male, 53.3% female) was near consistent with the sex distribution of the 2006 national population (48% male, 52% female) (Towers & Stevenson, 2014). However, participants were more educated and affluent than the wider population with 21-26% (in the NZLSA sample) and 22.4% (in the present study) holding tertiary qualification compared to 6-12% nationally, and only 17% (in the NZLSA sample) and 29.7% (in the present study) reporting annual incomes below $20,000 compared to 44-49% in the national population (Towers & Stevenson, 2014). These differences indicate that the NZLSA reflects a somewhat wealthier subset of the New Zealand population.

Findings at the bivariate level showed that the overall SES composite was not associated with cognitive functioning ('Kiwi' ACE-R scores). However, relationships between the individual SES indicators of education, income, and employment status were all associated with cognitive functioning ('Kiwi' ACE-R) scores. For example, higher educational attainment, higher income, and being in full-time employment were all significantly associated with better cognitive functioning scores. In contrast, sex and higher LIBRA scores (indicative of a higher modifiable risk for dementia) were also significantly associated with cognitive functioning i.e. females and a lower LIBRA tertile scored higher in cognitive functioning).

Furthermore, in the multivariate analysis, the hierarchical multiple regression model utilised key variables of cognitive functioning which included education, income, occupational attainment, sex, LIBRA scores, and covariates of age and ethnicity. Education presented itself as the strongest SES related indicator. Having a higher educational attainment, being female, and having a lower modifiable risk/higher brain health potential as well as covariates of younger age and non-Māori ethnicity, were all significantly associated with better cognitive functioning. Although interaction terms were also tested, no significant moderation effects were observed, nor did they significantly improve the model. These results will be revisited individually in relation to the literature.

Associations Between SES and Cognitive Functioning

The first research question aimed to identify differences in cognitive functioning across SES. It was hypothesised that SES would be associated with cognitive functioning such that lower SES would present with lower cognitive functioning scores. This hypothesis was predominantly supported. At the bivariate level, all three SES indicators of education, income, and employment were positively associated with cognitive functioning. This pattern is of significance and is consistent with international evidence that links cognitive health to socioeconomic conditions through mechanisms such as access to resources, opportunities for cognitive stimulation, and accumulation of cognitive reserve (Deary et al., 2009; Rodriguez et al., 2021; Wang et al., 2023; Zhang et al., 2015). Therefore, it is unsurprising that when considered individually, higher education, higher income, and employment status corresponded with better cognitive functioning performance. These associations are in alignment with theoretical frameworks such as the Cognitive Reserve theory which emphasises the role of both educational and occupational experiences in building resilience against cognitive impairment (Rodriguez et al., 2021; Zhang et al., 2022b), as well as potentially the Andersen Behaviour Model which is able to highlight the role of socioeconomic resources and their ability to shape access to care and health behaviours (Andersen & Newman, 1973)

Of the three SES factors, education emerged as the strongest correlate of cognitive functioning. The results showed a graded effect where participants with a higher education (i.e. university degree) had the highest 'Kiwi' ACE-R scores, followed by those with post-secondary qualifications, secondary school qualifications, and finally those with no formal education. This is consistent with previous research that suggests higher education to be associated with cognitive performance and lower dementia risk (Koster et al., 2005; Larnyo et al., 2022; Marioni et al., 2012; Wang et al., 2023) with Rodriguez et al. (2021) identifying its predominant role in cognitive functioning. The influence of education on cognitive performance may be a direct result of building reserve and indirect result of health literacy (Rodriguez et al., 2021), which may play a role in enhancing the ability to adopt health-promoting behaviours. Together, the pathways of both direct cognitive reserve and indirect behaviour, can explain why education may exert a protective effect and consistently predict cognition cross-nationally (Larnyo et al., 2022), including within New Zealand where education has been shown to have different lifecourse effects on different ethnic groups (Stephens et al., 2022). This places education as both a powerful protective factor as well as a key factor in inequality. The current results support the cognitive reserve hypothesis which argues that formal learning across the lifespan provides resilience against decline and may play a supporting role in increased chances of recovery (Marioni et al., 2012; Stern, 2009). However, it should be noted that the reliance on education as the dominant SES proxy can have limitations. Education is predominantly implied to be a stable earlier life experience (Hasselgren et al., 2020), while income and employment capture socioeconomic experiences of mid-to-late life. However, it is important to note that the current study is employed cross-sectionally, therefore causality cannot be inferred and the protective effect of education on cognitive trajectories over time is only assumed based on other longitudinal studies, but cannot be confirmed. It should also be noted that participants in the present study were generally more educated and wealthier than the wider New Zealand population (Towers & Stevenson, 2014) which may have influenced the present findings. The higher educational attainment could have elevated average cognitive functioning scores and reduced the variability within the sample that could have led to potentially attenuating the strength of the observed association. Thus, while education has emerged as the strongest SES indicator, this relationship should be interpreted with caution.

Similarly, income was positively correlated with cognition at the bivariate level. Consistent with global evidence that higher economic resources provided protective effects against cognitive decline (Larnyo et al., 2022; Marden et al., 2017; Rodriguez et al., 2021; Wang et al., 2023), this also aligns with the Andersen behaviour theoretical model. Within this model, income can function as an enabling factor that reduces barriers to care as well as health promoting resources (Andersen & Newman, 1973) which can help clarify why higher income was associated with higher cognitive functioning. Beyond access, income also shapes lifestyles such that those with lower income may not be able to take part in mentally stimulating activities due to lower resources and lower disposable income which may have impacts on cognitive reserve (Larnyo et al., 2022). However, income's explanatory power weakened in the multivariate regression model resulting in a non-significant result. This could be reflective of both methodological and contextual factors. Methodologically, income was treated as a continuous variable which although could have allowed for fine-grained variation, it may not have fully captured the non-linear effects that could have arisen as a result of New Zealand's financial support systems. Contextually, this outcome may have been a result of the variability across the life course, particularly in older adults where the presence of a universal superannuation system could alter financial circumstances and reduce variability by providing a baseline of financial security for retirees (Towers & Stevenson, 2014). Consequently, this could have attenuated the variability in later life income and could have also weakened the association between current income and cognitive outcomes observed in the multivariate regression analysis. This could mean uneven influences of income in the present sample due to the presence of both middle and older aged adults.

In the bivariate analyses, employment status was also positively associated with cognitive functioning. Employment status was captured through the measurement of labour force participation. Therefore, it may link to different mechanisms than that captured by occupational prestige. Instead, it focussed on whether individuals engaged in paid work. International evidence has suggested that continuing to work later in life sustains cognition via stimulation, social participation, and income security (Bonsang et al., 2012; Takase et al., 2024). Conversely, while there is a link between non-employment and lower cognitive functioning (Bonsang et al., 2012; Rodriguez et al., 2024; Takase et al., 2024; Vélez-Coto et al., 2021) this may have mixed meanings for the present sample. It is important to note that among older adults, non-employment can reflect retirement rather than socioeconomic disadvantage alone. For some, retirement may be voluntary and accompanied with engagement in other cognitively enriching activities. This is reflected in the study by Rodriguez et al. (2024) where retirement was associated with higher cognitive functioning even when compared to those in employment. However, for others, unemployment may reflect hardship or health-related limitations. These mixed pathways could have obscured meaningful distinctions between retirees, unemployed individuals, and those unable to work due to health reasons thus diluting the effect of employment on cognitive functioning as observed through the non-significance in the multivariate regression analysis.

When these indicators were combined into a composite SES index, no significant differences in cognitive functioning were observed which was contrary to the results found by Zhang et al. (2022b). Although composite measures are often intended to capture cumulative socioeconomic position, collapsing distinct but potentially uneven SES indicators into a single score risks concealing meaningful variation. While education is able to directly contribute to cognitive reserve, income provides material resources and access to health care (Wang et al., 2023), and employment offers an avenue to engage in potential cognitive engagement as well as sustain income (Rodriguez et al., 2024). Averaging these dimensions could mask the potentially dominant role of education and the more context dependent influences of income and employment that may be present within the New Zealand setting. Thus, these mechanisms may not converge as neatly within composite indices which may be a contributor to the null findings observed at the composite level but result in significant patterns at the individual component level. This may mean that collapsing distinct but interrelated indicators into a single index could mask the nuanced pathways of influence that may not be interchangeable. Although a critique by Mcmaughan et al. (2020) suggests that an individual factor of SES is unable to embody SES and studies that include individual factors within statistical models do not take multicollinearity into account. Within the present study, no multicollinearity issues (through VIF values and Tolerance statistics) were identified which suggests that despite the overlap, each variable provides some distinct information.

In theory, the significance within individual SES predictors broadly aligns with the wealth-health gradient (McMaughan et al., 2020; Zhang et al., 2022b) as well as the Social Determinants of Health framework which suggests that a stratified access to resources can yield graded differences in health outcomes (Marmot et al., 2008) but the results also suggest that different indicators may exert uneven influence across settings. Due to the insignificance observed within the composite SES, it was decided not to include it in the multivariate regression analysis. Rather, the multivariate model consisted of individual SES indicators. Taken together, the results indicate that SES should be addressed dimension by dimension rather than as a composite, as not all dimensions appear to exert equal weight on cognitive functioning. The findings underscore the need for caution as the loss of significance of individual components in the multivariate model could be a result of multiple factors which have been identified earlier. An additional factor could be the presence of mediation and overlap. Education operates as a significant determinant that has influences on both employment as well as income which may result in the absorption of the variance that may have instead been attributed to employment and income. Overall, this shows the complexity of SES as a construct, that although there are multiple SES constructs, not all contribute equally or independently. Importantly, the findings reinforce the idea that cognitive functioning is not solely biological but also structural and can be shaped by inequalities such as access to education, work opportunities, and economic resources. The persistence of education emerging as the most consistent component of SES in cognitive functioning reinforces its role as a critical factor for cognitive reserve which situates it at a critical point for intervention. Therefore, the present findings support recommendations made elsewhere (e.g., Livingston et al., 2020; Stephens et al., 2022), that efforts to improve educational access and quality may offer an effective formula to sustain cognitive functioning and reduce dementia risk.

Associations between Sex and Cognitive Functioning

The second research question examined whether there were any differences in cognitive functioning across sex. It was hypothesised that the female sex would be associated with lower cognitive functioning. However this was not supported by results. The bivariate results indicated that females scored significantly higher on cognitive functioning than males which was evident in the ranked distribution of scores. Yet, the median scores between groups remained similar. This suggests that while there was a difference in cognitive functioning across the sexes where females demonstrated a small cognitive advantage, the difference was very modest. However, it is important to note that this advantage was able to persist even after controlling for other independent variables and covariates in the regression analysis.

The literature provides mixed evidence for direction of favour for higher cognitive function. However, the present results align with strands of international literature that demonstrate the cognitive advantages possessed by females. While the results are supported by Nooyens et al. (2022), and van Exel et al. (2001) which suggest female participants possessing cognitive advantages in some domains, it complicates earlier claims that suggest that females are more frequently diagnosed with dementia, particularly AD (Emrani & Sundermann, 2025; Hasselgren et al., 2020; Mielke et al., 2014; Nebel et al., 2018; Subramaniapillai et al., 2021). As discussed in the literature review, this apparent contradiction within the results where there appears to be a female advantage in overall cognition are consistent with findings that women may begin later life with stronger cognitive reserve but paradoxically face greater dementia prevalence due to a faster rate of cognitive decline later in life (Levine et al., 2021). Considering this, it would therefore be of interest to track the present study's participants longitudinally to see how sex relates to cognitive functioning and confirm if cognition does in fact decline with age at a steeper rate in the female sex within the New Zealand context.

The New Zealand context is especially relevant for interpreting these findings. Compared to many countries, New Zealand ranks highly in regard to gender opportunities and equalities indicating the presence of lower gender disparities (Jatrana, 2021). The lack of gender disparities likely positions New Zealand to have increased access to education, labour force, and reduced wage-gap across both sexes. These structural conditions may have facilitated an increased access to additional cognitive reserve building resources for women which could have partially accounted for the observed female advantage within the present study. Thus, higher gender equity could have amplified female's opportunities to build and sustain cognitive reserves that translate to measurable cognitive advantages. In this study, while no moderation effects were observed, education emerged as a significant variable in cognitive functioning which reinforces the protective role of reserve against cognitive impairment (Bloomberg et al., 2021; Nooyens et al., 2022; Zhang, 2006). The increased access to SES resources for women in more recent cohorts (relative to older generations) may therefore explain the modest cognitive gains that have been observed here. Based on this, it may be acceptable to assume that studies on successive cohorts may provide different results which may present an even greater female advantage in cognitive functioning, as has been observed by Bloomberg et al. (2021). However, it is important to note that while Bloomberg et al. (2021) observed later birth cohorts of women to perform better than men, cognitive functioning was measured across its individual domains. While investigation across individual cognitive domains was not completed in the present study, this may be an important consideration for future studies investigating sex related differences.

There are also suggestions that sex differences in later life cognitive health are not purely biological or purely social but reflect a layered interaction between both. In New Zealand, women have been found to report better self-assessed health yet also score higher on psychological distress compared to males with comparable socioeconomic resources (Jatrana, 2021). This mirrors the broader evidence that women are more likely to engage in health-seeking behaviours (Mielke et al., 2014) which could mitigate risks and support healthier cognitive ageing trajectories while at the same time also facing greater psychosocial stressors. Alternatively, it may also suggest differences in health perception with women possibly rating their own health more positively on self-report measures, regardless of the underlying health status. However, it is worth noting that the present study uses the LIBRA index (which will be discussed in more detail) to gather health related data and is based on the presence or absence of a diagnosed condition rather than subjectivity. Accordingly, the modest female cognitive advantage observed in this study is likely to be a cumulative result of multiple influences that shape cognitive functioning which may compound on top of physiological advantages.

Another aspect that could have informed the relationship between sex and cognition , includes biological influences. Cognitive functioning has been identified to be influenced by hormonal changes in females (Subramaniapillai et al., 2021). For instance, the protective role of estrogen (Mielke et al., 2014) prior to menopause, could also contribute to the sex differences observed in cognitive functioning (Subramaniapillai et al., 2021). This interplay between biology and reserve enhancing experiences could explain why even in a sample that includes both peri and post-menopausal ages, females were able to maintain significantly higher cognitive scores i.e. the inclusion of peri-menopausal females could have inflated cognitive functioning scores. Thus, the higher scores in cognitive functioning for females could be a result of biological, behavioural, and sociostructural advantages that have accumulated over a life course. These potential mechanisms were beyond the scope of the present study. Nonetheless, their interactions should be considered and measured in future studies that include investigations on aspects of menopause with cognitive functioning.

Collectively, the results suggest the multifactorial nature of sex differences in cognition. As suggested in the literature review, sex cannot be treated as a biological construct alone nor can biology be excluded from its explanation (Hasselgren et al., 2020**;** Jatrana, 2021). Overall, while the results are modest, they highlight the distinctive contribution of sex in cognitive functioning

Associations between Lifestyle Modifiable Factors and Cognitive Functioning

The third research question aimed to assess the relationship between lifestyle behaviours and cognitive functioning. It was hypothesised that lifestyle modifiable factors (encapsulated in the LIBRA) would be associated with cognitive functioning scores, with higher LIBRA presenting with lower cognitive functioning. This was supported by results and was assessed using tertiles from a modified LIBRA index. The modified LIBRA index included 8 out of 12 modifiable factors (i.e. coronary heart disease, hypertension, renal dysfunction, diabetes, low-to-moderate alcohol consumption, smoking, physical inactivity, and depression). Based on the bivariate analysis, cognitive functioning significantly differed across LIBRA tertiles. Those in the lowest LIBRA tertile performed better than those with higher LIBRA scores (i.e. those with lower brain health potential had lower cognitive functioning scores). These results are consistent with the theoretical underpinnings of the LIBRA index as well as studies (Heger et al., 2024; Neuffer et al., 2024; Röhr et al., 2024b) that suggest higher LIBRA scores to be associated with a higher risk of cognitive impairment.

Pairwise comparisons confirmed that significant differences in cognitive functioning were observed across all LIBRA tertiles which indicates that each risk group increase in lifestyle related risk corresponds with lower cognitive functioning. While differences between adjacent groups i.e. low-moderate and moderate-high were present, the largest and most robust difference emerged between the low risk and high risk LIBRA group. This reflects a graded decline in cognitive functioning as risk accumulated (i.e. strongest reduction in cognitive functioning occurs at the highest accumulation of risk) rather than a sharp threshold. The observed pattern of incremental increases is consistent with Deckers et al. (2019a) and Neuffer et al. (2024). From a prevention perspective, this reinforces the importance of reducing cumulative risk across the continuum as well as prioritising individuals with the greatest burden of lifestyle risk which would generate the greatest benefits.

Furthermore, although moderation by education and sex in relation to LIBRA was explored in the multivariate analyses (presented below), the present findings indicate that even when controlling for other factors, lifestyle modifiable factors alone are significantly associated with cognitive functioning. The observed pattern aligns with its sensitivity in capturing lifestyle-based influences on cognition in this cohort. Notably, the present association between lower brain health potential (higher LIBRA scores) and lower cognitive functioning was apparent regardless of the LIBRA index missing four modifiable factors in the NZLSA study from which data was derived from. This supports its utility as a tool for identifying current cognitive vulnerability in addition to potentially predicting long term dementia risk as suggested by previous studies (Deckers et al., 2019b; Neuffer et al., 2024). From a practical perspective, these results highlight that the LIBRA index is a valid tool for both research and public health. This is portrayed in the analyses by Deckers et al. (2021) which demonstrates that multidomain lifestyle interventions are effective across all levels of LIBRA risk. This positions the LIBRA index as a valuable framework for capturing lifestyle modifiable factors and identifying groups with the most potential to increase brain health as well as showing how interventions can help reduce future dementia burden. However, inspection of the weighting pattern suggests that certain risk domains contribute disproportionately to the total LIBRA score. In particular, several unavailable lifestyle factors such as high cognitive activity and healthy diet carry strong protective weightings. The omission of these factors due to unavailability likely resulted in an underestimation of the protective influence of healthier lifestyle behaviours and may have biased the overall LIBRA score toward risk rather than resilience. Therefore, to confirm the findings of the present study, there is a need to assess the index in its full form alongside the factors in the present study which may result in a true reflection of the association.

Overall, the results indicate that the LIBRA index can function as a valuable framework for identifying and addressing risk for cognitive decline. Since most of its components are modifiable, interventions that are aimed at reducing lifestyle modifiable risk through physical activity, smoking cessation, and management of vascular risk factors to name a few, hold the promise for enhancing both brain and physical health. Although there have been newer additions to the LIBRA index such as hearing impairment, social contact, and sleep, which has been named as LIBRA2, its current structure also showcases utility in the identification of lower cognitive functioning (Rosenau et al., 2024) and thus its ability to guide future preventive strategies. In the local context, New Zealand has well-established public health systems and health promotion strategies in place, and to add to it, the LIBRA can serve as a valuable screening and intervention tool to reduce future burden of dementia. This can be by offering a structured and evidence-based method to guide prevention efforts. However, there may be opportunities for cultural adaptation to ensure that it resonates across diverse communities and addresses equity considerations. For instance, while the LIBRA index accounts for several lifestyle modifiable factors, it does not account for structural determinants of health such as systemic racism, colonisation, or inequitable access to healthcare, all of which may influence the feasibility of lifestyle change. This raises questions about its cultural generalisability, particularly in a diverse context such as New Zealand. Questions on its generalisability arise given the study by Ma'u et al. (2021a) which suggested that differing modifiable risk factors hold different weights of impact on the four major ethnic groups in New Zealand. Due to these differences, it is important to cater to individual communities rather than the overall population as not all communities have the same genetics or access to lifestyle modification opportunities.

These findings also support a biopsychosocial model which emphasises that cognition is impacted by the combined influence of biological vulnerabilities and lifestyle factors rather than genetics alone. To elaborate, the LIBRA index encompasses both biology vulnerabilities as well as lifestyle factors. By integrating multiple domains, such as behavioural, cardiovascular, and psychological health, the LIBRA index is able to capture this multidimensionality and reflects how multiple exposures are able to offer a more comprehensive picture and collectively shape cognitive outcomes than single modifiable factors alone. This approach reflects findings from the wider literature, where individual risk factors have been shown to contribute additively to cognitive functioning (Peters et al., 2019). Together these findings reinforce that cognition is a reflection of cumulative exposures with lifestyle factors interacting with biological processes to determine brain health outcomes.

To summarise, the present findings support the association between lifestyle modifiable factors and cognitive functioning with lower brain health potential being associated with lower cognitive functioning. By encapsulating modifiable lifestyle risk, the LIBRA index offers a practical and actionable tool for dementia prevention and highlights the importance of targeting lifestyle change to protect brain health across the lifespan as a way to preserve brain health and reduce the future burden of dementia.

Interaction Effects of SES, Sex, and LIBRA

The final research aim was to explore the interactions between independent variables of education, sex, and LIBRA, and cognitive functioning. This was a central aim of the present study and it was hypothesised that the associations between cognitive functioning and each independent variable would be conditional upon the other variables. Therefore, it was expected that all variables tested for interactions would be moderators. Moderation effects were tested using a hierarchical multiple regression model. Unexpectedly, no interaction effects between the independent variables were observed within the regression model. To be specific, none of the interaction terms including Education x LIBRA, Education x Sex, Sex x LIBRA, or Education x Sex x LIBRA were able to significantly predict cognitive functioning. Consequently, all interaction hypotheses were rejected.

The current results and model which included the main effects of both demographic and lifestyle factors contributed meaningfully to cognitive functioning performance such that they were able to explain 19% of the variance. This percentage of variance is higher than that observed in the study by Stephens et al. (2014) and may be reflective of the differing (i.e. present study did not include conditions such as stroke, cancer, or self-rated health) and the additional modifiable factor (Chronic Kidney Disease) that was included in the present study. However, the inclusion of interaction terms in Model 3 and 4 did not meaningfully improve model fit. These results suggest that the associations between cognitive functioning and the independent variables operated additively rather than interactively with each variable exerting its own unique but non-conditional influence.

Among SES indicators, education had previously emerged as the most robust predictor of cognitive functioning. Therefore, the lack of moderation effects were contrary to the expectations derived from Cognitive Reserve Theory which proposes that education can act as a buffer and attenuate the adverse cognitive impact (Bloomberg et al., 2021; Deary et al., 2009; Marioni et al., 2012; Stern, 2009). The literature review highlights that education is a consistent predictor of cognitive functioning (Bloomberg et al., 2021; Deary et al., 2009; Zhang, 2006) and there are suggestions that it may interact with sex, given the historical disparities in women's access to SES factors such as education as well as its potential impact on cognitive reserve (Okamoto et al., 2021; Mielke et al., 2014; Hasselgren et al., 2020). However, the present results indicated that while females scored higher in cognitive functioning and education was also a significant predictor of higher cognitive functioning rank, education was not able to buffer the cognitive outcomes by sex. This suggests that although males and females can differ (particularly in specific cognitive domains) (Bloomberg et al., 2021; Nooyens et al., 2022), the cognitive benefits of education appear to be broadly similar across sexes. In other words, education improves cognition (as evidenced earlier) regardless of sex, while sex itself influences cognition. While unexpected, these results may be shaped by the New Zealand context, where the sex gap is lower and thus educational opportunities are similar for both males and females (Jatrana, 2021).

Additionally, the Andersen Behavioural Model (Andersen & Newman, 1973) proposes that education can function as a predisposing factor which shapes health beliefs and behaviours (Andersen & Newman, 1973). According to this, higher levels of education can encourage proactive engagement with preventive health practices potentially through health literacy and healthier lifestyle (Park & Kang, 2008; Wang & Conwell, 2022; Zhang et al., 2022b). Considering this, moderation effects should have been observed between SES and lifestyle modifiable factors. Although this was not the case, the absence of moderation effects, aligned with Heger et al. (2024) who also found no moderation effects of SES on the relationship between LIBRA and cognitive functioning. Therefore, this indicates that, within this sample, education and lifestyle modifiable factors acted additively through parallel (rather than interactive) pathways whereby education acted on elevating cognitive reserve and health literacy, and LIBRA reflected the modifiable behavioural and biomedical risks. However, as stated, there was no evidence that one factor was able to buffer or amplify the influence of the other. Although moderation was not detected, it highlights the complexity of education which can act indirectly. This pattern of effect is consistent with the Social Determinants of Health framework which positions education as a structural condition simultaneously (along with other determinants) shaping both exposure to risk and the capacity to respond to it (Marmot et al., 2008; World Health Organization, 2008). The pattern also fits the biopsychosocial view in which social (SES) and behavioural (LIBRA) domains may each contribute to cognitive health, even if statistical interaction was not observed here. However, longitudinal designs are required to examine further converging influences on cognitive health.

The lack of the sex and LIBRA interaction was also present. This is notable given the evidence of sex based differences in cognitive profiles and dementia trajectories (Mielke et al., 2014; Levine et al., 2021) as well as differences in health behaviours (Mielke et al., 2014; Okamoto et al., 2021; Shang et al., 2023). In the context of the present study, the lack of sex differences in the LIBRA and cognitive functioning association suggests that the biological and social factors that underpin sex based cognitive differences may not significantly alter the impact of cumulative lifestyle risk. This could be due to the range of factors that are encompassed within the LIBRA index. The LIBRA index includes factors that are relevant to both sexes and that lifestyle risk operates through mechanisms (i.e. inflammatory, vascular etc) that are relevant and produce similar cognitive consequences, regardless of sex. Therefore, the present results suggest that the mechanisms by which lifestyle risk influences global cognition may be largely sex-neutral in the present study population.

Considering the lack of significant two-way interactions, it was unlikely that a three-way interaction would be significant. However, this was still tested and found to be non-significant. Several possible explanations exist for the absence of moderation. One such explanation includes the modified LIBRA index within the present study. Several components (hypercholesterolemia, cognitive activity, diet, and obesity) were unavailable in the dataset. The reduced availability of the overall index may have reduced its overall capacity to detect moderation effects and may have led to a decreased variance observed in the main effects model. Secondly, the use of a global cognitive measure could have obscured the domain specific pathways given that domain specific advantages are present across both males and females (Bloomberg et al., 2021; Nooyens et al., 2022) which may have produced differing moderation effects. Third, the cross-sectional nature of the data may have restricted the ability to observe the dynamic interactions that may emerge longitudinally (discussed at a later stage).

When taken together, the findings are suggestive of an additive effect of education, sex, and lifestyle modifiable behaviours on cognitive functioning rather than the interactive and multiplicative effects as suggested in the biopsychosocial model (Engel, 1977; Spector & Orrell, 2010). This is based on the findings that each independent variable (of education, sex, and LIBRA) was able to retain its significance on cognitive functioning within the multivariate model, independently. The multivariate model was able to reflect this finding whereby the model including the main effects was able to explain 19% of the variance in cognitive functioning. However, the full model, with the inclusion of interactive terms, did not change and was only able to explain 19% of the variance in cognitive functioning. This is not an increase and is suggestive of the interpretation that cognitive functioning is shaped through parallel pathways where education is able to contribute to reserve and knowledge based resources, sex captures the biological and socio-structural influences, and lifestyle risk is reflective of modifiable exposures. However, the absence of moderation does not diminish the importance of these factors or the importance of the biopsychosocial model but rather is indicative of the idea that the factors act in a complimentary rather than conditional manner. Therefore, while all factors are influential, their effects may sometimes be additive and distinct rather than dynamically interactive.

Importantly, the present study aimed to identify vulnerable and intersectional groups of individuals through these interactions. The lack of significant interaction effects prevented the identification of specific high risk combinations. While the lack of interactions is not fully consistent with the biopsychosocial model’s emphasis on interdependence (Engel, 1977), the persistence of independent effects of the variables aligns with its multi-layered perspective. Therefore, although the moderation hypotheses of the study were not satisfied, the main effects still highlight the independent risk and protective contribution of each factor. For instance, lower education, the male sex, and a higher lifestyle risk each independently conferred vulnerability to poorer cognitive functioning. This pattern is indicative of the need for multi-domain prevention strategies that address both social and behavioural determinants of cognitive health.

Covariates

The present study included three covariates which included age, ethnicity, and marital status. As expected, age emerged as a significant covariate and was negatively associated with cognitive functioning. This meant that cognitive functioning scores decreased with increasing age. The finding aligns with the cognitive ageing literature outlined earlier which states some reductions in cognitive functioning as normative neurobiological changes (Blazer et al., 2015; Deary et al., 2009; Murman, 2015).

Furthermore, ethnicity also remained as a significant covariate, with non-Māori participants having scores that were indicative of higher cognitive functioning than Māori participants. This pattern reflects known structural inequities and cumulative life-course disadvantages that can shape health and cognitive outcomes (Dyall, 2014). In the New Zealand context, this is not a trivial finding considering Māori are often disproportionately affected (Dyall, 2014). Even when considering current tools, Dudley et al. (2019) found that Māori understanding of dementia ('mate wareware') was as a holistic concept rather than standardised tests. Therefore, while ethnicity has been included as a covariate in the present study, for effective prevention and intervention, it should be considered as an independent variable with further stratified analysis. Doing so, will ensure the appreciation of nuanced risk factors and interactions for cognitive functioning and is in line with the work of Ma'u et al. (2021a) as well as Zawaly et al. (2021). Its inclusion as a stratified independent variable in further studies should be alongside the incorporation of culturally responsive interpretation that uphold Te Tiriti o Waitangi obligations for equity.

Within the present study, marital status did not emerge as a significant covariate of cognitive functioning and thus was not included in further analysis past the bivariate level. The non-significant findings contrast with previous research that show the positive influences of being partnered which is largely due to the higher levels of social engagement as well as financial support (Feng et al., 2014; Liu et al., 2019; Sundström et al., 2015). However, the absence of an association may be reflective of other pathways such as the quality of the relationship and social connection as opposed to marital status alone as suggested by Liu et al. (2019), which were not investigated in the present study.

Implications

Considering the consequences of cognitive impairment, that can extend past the individual (Blazer et al., 2015), there was a considerable need to assess those that are most vulnerable. Although the present study was unable to determine an intersectional group that was most at risk it was able to identify that education, male sex as well as lifestyle risk (and covariates of older age and being Māori) are important contributors to cognitive functioning.

Therefore, from a public health perspective, programmes that target high risk groups such as those with lower education or an emphasis on those that are males, or those with higher lifestyle modifiable risk, individually, are likely to benefit from health promotion efforts and therefore yield the most benefits. Although sex and education as well as age and ethnicity are more difficult to intervene on directly, they help with the identification of higher risk groups (e.g. males or those with lower educational attainment) who may benefit disproportionately from health promotion efforts. This method allows not only earlier and targeted prevention of dementia but also has implications for health equity such that those in the highest risk groups are able to receive the attention that they require. Furthermore, there appears to be significant opportunities for health promotion which could include promotion across levels of targeting and reducing individual factors within the LIBRA. For instance, strategies that include tailored educational campaigns, smoking cessation support, along with mental health services can help increase brain health and help reduce risk in vulnerable populations (i.e. individuals with high modifiable risk). This is in line with international studies that have advocated for targeted interventions that focus on risk reduction particularly among the individuals that have lower brain health potential (i.e. higher LIBRA scores), regardless of demographic background (Deckers et al., 2019b). Through multi-level prevention strategies, it can be acknowledged that cognitive impairment and dementia risk is shaped by both individual behaviours as well as social determinants and thus requires a systemic action rather than just individual responsibility.

Although there is room for effective implementation, from a clinical standpoint, there is potential for the LIBRA index to serve as a structured preventive tool in routine clinical care across primary care, mental health, and geriatric care. Although clinicians often ask about behaviours such as smoking, diet, physical activity, the LIBRA index can provide a standardised and evidence-based way to combine these into a cumulative risk score of modifiable factors. This could support the identification of those with a lower potential of brain health and those with higher risks of future cognitive impairment and thus guide person-centred interventions. These interventions can include helping with setting realistic and achievable goals to increase physical activity, managing vascular risk factors, or providing psychological support. This is derived from the finding that LIBRA was independently associated with cognitive functioning which supports its potential use as a screening tool to identify patients that have lower brain health potential to reduce dementia. In situations where individuals are identified to require additional support, opportunities for change could include receiving support with behaviour change, motivational interviewing, and even potential avenues for cognitive behavioural therapy all of which could ultimately contribute to dementia prevention. However, in order to ensure equitable clinical application, it is critical to ensure that access to resources that enable lifestyle changes are uniform across populations. Thus, in the case of clinical use of the LIBRA index, there is need for it to be accompanied by assessments for further support and direction to appropriate support networks or referrals to community services. It is critical to note that this can only take place once further studies have been conducted using the full form LIBRA index as well as the LIBRA2 index that incorporates additional factors. Clinicians would then need to be provided education on the LIBRA index along with its measurement of lifestyle modifiable factors and representation of a brain health potential which is critical to both cognitive functioning and overall supports the concept of dementia prevention.

One of the most consistent findings across the literature review as well as the present analyses is the critical role of education as a protective factor for cognitive functioning. Even after adjusting for income and occupation, education remained a strong predictor. This underscores its contribution to cognitive reserve (Koster et al., 2005; Larnyo et al., 2022; Zhang et al., 2022b) and suggests a direct relevance to policy implications. However, unlike many lifestyle changes (i.e. quitting smoking or increasing exercise), education is a broader social determinant of health. Therefore, when considering policy implications, there is reason to extend beyond individual interventions and implement systemic level changes to support equitable access to reserve building resources. The prioritisation of compulsory schooling, lifelong learning opportunities through promotions of adult education, vocational training, and community-based learning initiative could help enhance cognitive reserve across the population, particularly in those that are from disadvantaged groups.

Although the present study alone is unable to dictate health policy, its findings can contribute to the guidance of future policy decisions. This would be particularly true when integrated with multiple data waves (i.e. a longitudinal design) from large scale longitudinal research such as the NZSLA. Evidence from international intervention research, such as the FINGER study by Deckers et al. (2021) show that interventions aimed at modifying lifestyle modifiable factors (i.e. reducing LIBRA scores) have been advantageous. The results of interventions targeting diet, exercise, vascular health, and cognitive training have all led to cognitive improvement across all participants regardless of their baseline lifestyle modifiable risk. Such findings reinforce that interventions grounded in improving modifiable risk factors of cognitive functioning can enhance cognitive outcomes. Suggestive of the need for both preventive strategies and interventions that are capable of supporting positive cognitive health across the lifespan, this aligns with the broader protective factors for cognitive health. The adoption of lifestyle modifiable principles as well as the prioritisation of increasing education within national dementia prevention strategies could encourage system wide changes. These changes could include campaigns for targeted brain health promotion as well as the development of equity focused health policies such as ensuring access to nutritious foods for weight management and the expansion of community mental health and preventive care resources. For example, the government's Health Active Learning initiative, which integrates nutrition and physical activity programmes into schools (Sport New Zealand, n.d.), could be extended into adult community education settings to enhance a lifelong cognitive reserve. There is also potential of implementing these policy initiatives in midlife to reflect the preventive potential of these interventions given that lifestyle factors can start exerting their effects before the clinical onset of dementia. From an ageing perspective, as there appears to be inequality in cognitive functioning, focussing on these aspects can lead individuals to sustain their current functionality or enter older age in a better circumstance.

Strengths

Having addressed the implications, the present section draws attention to the strengths of the study which include its integrated approach. That is, the examination of not only individual effects of SES, sex, and lifestyle modifiable factors on cognitive functioning but also examining the interactions between them. This also aligns with real world complexity where risk factors rarely occur in isolation, but rather influence each other (Wu et al., 2017). While no moderation effects were identifiable within the present study, by integrating and treating variables, in particular SES and sex as independent variables rather than covariates and by investigating the interactions between them, the study contributes to a deeper understanding of how diverse domains can potentially interact and influence each other. Overall, this enhances the study's credibility as null interactions are equally as important as significant interactions in order to clarify whether certain groups may be more disadvantaged. The present approach aligns with the need for dementia research to incorporate a multifactorial and holistic framework of risk rather than a reductive model of siloed risk factors (Wu et al., 2017). A multifactorial approach is crucial not only because it reflects real-world complexity, but also because it enhances the ecological validity of findings such that it is more likely to be transferable to population level prevention strategies.

Another, but equally important strength is the conceptual integration of LIBRA which is a validated index of lifestyle dementia risk (Pons et al., 2018; Schiepers et al., 2018; Vos et al., 2017). The use of the LIBRA index shows a commitment to embedding individual level modifiable factors into analyses. This is consistent with the literature's emphasis on various opportunities for prevention with Livingston et al. (2020) and Ma'u et al. (2021a) estimating nearly two fifths to close to half of dementia cases having preventable opportunities by addressing modifiable risk factors. Through the inclusion of the LIBRA index alongside SES indicators and sex, the study shows its positioning as viewing dementia not solely as an inevitable outcome associated with ageing but also as a condition where risk can be altered by individuals and structural interventions. Thus, along with contributing to literature, it is also a part of a contemporary paradigm shift as well as a contributor for informing public health practices.

Furthermore, another methodological strength is the use of nationally representative (albeit somewhat demographically skewed) data from the NZLSA. While participants included within the present analysis were participants who volunteered for a face-to-face interview, the pool of participants from which the present dataset volunteered from include those that were randomly sampled from the national population. This extends beyond convenience samples and thus enhances the generalisability and the external validity of the findings, especially given the inclusion of middle-aged adults. In the present analysis, ages of participants ranged from 48 to 75 which are critical periods in cognitive functioning, particularly for the Māori and Pacific populations (Ma'u et al., 2021b). By incorporating a wider age range of participants than its predecessor study, HWR, the NZLSA avoids the limitation of focusing solely on older adults.

Lastly, a crucial strength of the study lies in its contextual relevance of the New Zealand setting. As portrayed in the literature review, New Zealand ranks highly in global measures of gender equality which may reduce many of the disparities observed in other countries. This unique social context means that it becomes possible to study sex differences in cognition in a setting where structural barriers are relatively minimised. However, at the same time, New Zealand's diverse population and significant health inequities across particular ethnicities (Ma'u et al., 2021a) suggest that there is importance in the integration of equity considerations within dementia research. By completing the analysis in this unique context, the study contributes findings that are more nationally relevant and meaningful.

Limitations and Future Directions

While several strengths of the study have been identified, five critical limitations are also present. A considerable limitation of this study is its cross-sectional design as opposed to a longitudinal design. This is considered to be a significant limitation, particularly when investigating cognitive outcomes due to the nature of cognitive functioning as a dynamic process that is influenced by ageing as well as cumulative exposures across the life course (Harada et al., 2013; Murman, 2015). Although associations between factors such as education, sex, lifestyle modifiable factors, and cognition were established, it is unclear whether these variables influence cognitive functioning prospectively or whether there may be reverse causation at play. For example, it is difficult to determine whether lifestyle modifiable factors cause changes in cognitive functioning or if decline in cognitive functioning affects lifestyle modifiable factors, which may be particularly relevant for middle-aged adults in the participant pool. Thus, in the present study, the lack of longitudinal data limits causal inferences to be drawn. Furthermore, the absence of a longitudinal design results in the inability to assess for lifetime influences. A single point in time is unable to account for historical exposures or trajectories that may shape cognitive outcomes in later life. For example, while current income, employment status and present LIBRA scores were all examined, their influences cannot be disentangled from earlier socioeconomic conditions and cumulative lifestyle behaviours that may have exerted lasting effects. While a contemporaneous association is examined, the pathways that affect cognitive functioning across the lifespan cannot be fully reflected within the present study.

Expansion of the present study could involve a replication in addition to the inclusion of a longitudinal study design. A longitudinal design may be able to examine a causal pathway and the progression of changes in cognitive functioning in relation to lifestyle modifiable factors and SES over time as well as the inclusion of incident dementia. Studies that can track changes in LIBRA scores and its impact on cognitive trajectories will provide greater clarity on the temporal dynamics of risk accumulation and resilience. There is an opportunity to track changes over time with the present ongoing 2024 wave of the New Zealand Body, Mind and Ageing (NZ-BMA) study which is an expansion of the current study as well as part of a larger programme (Modifiable Pathways To Sustainable Ageing In Aotearoa) (Health & Ageing Research Team - HART, n.d.). Tracking participants' results across multiple waves would also allow researchers to model within-individual changes, examine cohort effects, and test for critical periods of change which could suggest when interventions may be the most effective. This would be particularly beneficial for midlife adults where risk factor modification could yield significant benefits in later life. Thus, the use of longitudinal designs can aid the exploration of critical periods of changes in cognitive functioning and can lead to more effective interventions.

Yet longitudinal designs also appear to present with limitations. By using the same test battery (e.g. ACE-R) on participants of a longitudinal study, there is a higher likelihood of a potential improvement in the tests through practice effects (Harada et al., 2013; Murman, 2015). This may have been more evident in the present study had a longitudinal study been conducted due to the shorter duration between re-tests (i.e. current availability of cognition data only available for 2010 and 2012 data waves). However the learning bias is likely to be eliminated in longitudinal studies with a longer duration between re-tests (Salthouse & Tucker-Drob, 2008). Furthermore, there may be some more strengths of using a cross-sectional study design rather than longitudinal. This includes the potential for survival bias which is particularly relevant when the study cohort also consists of older adults. This may occur in a longitudinal study due to its time consuming nature which may mean that those that remain in the study may be those that are healthier than their cohorts (Harada et al., 2013). Thus, generalisability could be compromised. Even though the present study is part of a longitudinal study which has been in place since 2006, the datasets available on cognition were limited. While cognitive assessments were not routinely collected, as mentioned, a new study on cognitive functioning is underway. Therefore, to assess this trajectory, there is a need to observe longitudinal data.

Another observed methodological limitation includes the use of a volunteer sample to complete the face-to-face interviews which included the cognitive assessment as a component. Although the aim of the NZLSA sample was to remain as representative of the New Zealand population, the 2010 subsample utilised in the present study, is a volunteer sample derived from the NZLSA 2010 participant pool which may have introduced potential biases that could reduce generalisability to the wider population. It is likely that the recruitment of participants for the voluntary face-to-face interview may have introduced biases where those most healthy or more advantaged were more likely to have consented to take part in the interview which was a requirement to have been included within the present study. For instance, those that have lower cognitive functioning or are significantly socioeconomically disadvantaged may have less support (e.g. social, financial etc) and find it harder to partake in the study to complete face-to-face interviews (Harada et al., 2013; (Murman, 2015). This means, the study is likely to include only those that are healthier, more advantaged, or those that have higher levels of cognitive functioning. Thus, the inclusion of potentially advantaged participants may lead to the inflation of scores across cognitive functioning as well as a potential risk of underestimating the impact of SES and lifestyle modifiable factors as those in disadvantaged groups with higher risk may be underrepresented. Overall, while the study provides informative findings, the use of a volunteer sample could mask the true magnitude of disadvantage and modifiable risk on cognitive functioning in the broader population. Therefore, although there is an absence of significant moderation effects in this study, the interpretation should not be that there is definitive evidence of its absence in the population i.e. it should be interpreted with caution.

It is also worth noting that within the data used in the present study, the only two options for sex included 'male' or 'female'. While this binary categorisation is reflective of the data available, it does not fully capture the diversity of gender identities in contemporary society. As a result, subsequent data waves of the present longitudinal study have incorporated more inclusive measures of gender which can aid understandings of cognitive trajectories across a broader spectrum of gender identities. By incorporating these additions in future analyses, there is space to examine how both biological and social dimensions of sex and gender can interact to influence cognitive outcomes. However, in order to effectively understand sex related differences in cognition, it is important to assess cognitive functioning across domain specific regions. This is necessary due to the sex specific advantages observed in cognitive functioning (Bloomberg et al., 2021; Nooyens et al., 2022).

Furthermore, the measurement of SES relied on individual indicators of education, income, and employment status. While this approach allows for detailed examination of each dimension, it may not fully capture the multidimensional and cumulative nature of SES particularly across both midlife and older adults. This is an important distinction as variables such as socioeconomic and modifiable lifestyle factors may exert different influences across the life course, particularly around retirement, when income and employment status may become less reliable indicators of material or social resources. Considering analyses were not stratified by these age subgroups, this may have attenuated some associations observed in the multivariate model. Future research should therefore strengthen measurement of SES by incorporating broader SES indices such as the Economic Living Standards Index (ELSI) which may be able to reflect the material living conditions in a more accurate manner (Noone et al., 2014). Along with more robust SES measures, stratifying analyses by age (i.e. midlife and older cohorts separately) to better clarify age specific pathways to cognitive functioning will also be beneficial.

The final limitation of the study concerns a measurement issue which includes the availability of only 8 out of 12 factors included in the original LIBRA index. Key LIBRA factors including hypercholesterolemia, cognitive activity, diet, and obesity were unavailable which restricted the comprehensiveness of the LIBRA score used in this analysis. As discussed, the modified LIBRA index may underestimate or overestimate an individual's overall dementia risk and affect both reliability and construct validity of the LIBRA score in this context. By extension, this would likely have limited the strength of the conclusions drawn about the relationship between modifiable risk factors and cognitive functioning as well as its interactions with the other independent variables within this study. To confirm the reliability of the 8 point LIBRA scale (used in the present study), there is a need for psychometric assessments to ensure that it is an equally reliable measure as the 12 point validated LIBRA scale. Doing so would help confirm the associations drawn in the present study. However, the acknowledgement of these limitations highlights the transparency of the study and sets important future directions. In future research, it would be beneficial to include data on all LIBRA factors in order to provide a more comprehensive measure of modifiable risk. In doing so, there would likely be an increase in the construct validity of analyses. Furthermore, beyond the restoration of the original LIBRA factors, there is also scope to utilise the LIBRA2 index which has been validated to be a better tool for dementia risk prediction due to the inclusion of further factors such as hearing impairment, social contact, and sleep within the framework as well as performing at the same level as the original LIBRA index (Rosenau et al., 2024). The addition of a LIBRA2 index may be able to account for a larger amount of variance than what was observed in the first model of the hierarchical multiple regression analysis in the present study. This is because the model in the present study suggested that a large proportion of variance (81%) remained unexplained by the included variables. Therefore, additional variance due to factors outside of those included, and the additional factors in the LIBRA2 index may account for some of this remaining variance. However, although the validation of the LIBRA2 sheds light on further established factors that play a role in cognitive functioning, it does not take into consideration any interactions between the variables within the index (Rosenau et al., 2024) which is an important consideration given the often co-occuring risk factors (Peters et al., 2019). Therefore, future research could replicate the present study by engaging additional and more comprehensive measures of lifestyle modifiable factors.

Conclusion

The basis of the present study was to identify individuals that are most at risk of lower cognitive functioning. This was achieved by examining how socioeconomic status, sex, and lifestyle-based modifiable risk factors can impact cognitive functioning in the New Zealand population. Guided by a biopsychosocial perspective that factors do not work in isolation, the study investigated not only the independent associations between the above independent predictors, but also aimed to examine whether there were any interactions between the factors which may be able to explain the disparities in brain health.

Through analyses, important findings emerged. These findings included education emerging as the most robust SES predictors of cognitive functioning. This reinforces its role as a critical factor for cognitive reserve whereby lifetime of intellectual stimulation could buffer cognitive decline. Secondly, females outperformed males in overall cognitive functioning however, the difference between medians was modest. The third finding included lifestyle modifiable factors being independently associated with cognitive functioning which highlights the importance of addressing lifestyle related behaviours to maintain brain health. However, the most important finding included the observance of no moderation effects between the factors which was contrary to expected outcomes.

The present study's findings carry theoretical, empirical, and practical significance. Theoretically, the study supports the biopsychosocial model, Cognitive Reserve Theory, and Social Determinants of Health as frameworks to understand cognitive functioning and shows that cognition is a reflection of various impacts of social resources, sex-linked influences, and lifestyle exposures. Empirically, the study provides novel evidence of these factors within the New Zealand cohort. The lack of an observed moderation may also reflect the New Zealand setting whereby gender equity and access to education is comparatively higher than other OECD countries which may have led to the reduction in disparities that might have otherwise emerged in contexts with greater inequality. From a practical standpoint, the findings emphasise priorities for prevention of cognitive decline and, ultimately, dementia. Firstly, policies that support educational opportunities and lifelong learning should remain in order to enhance cognitive reserve across the life course. Furthermore, interventions need to be targeted to support increasing brain health by lowering LIBRA scores and thus improving cognitive outcomes.

In conclusion, the present study is able to demonstrate that education, sex, and modifiable risk factors all independently contribute to cognitive functioning but their effects are not conditionally reliant on one another. By situating these results within a biopsychosocial framework, the study underscores the importance of integrating several factors in dementia prevention strategies. To build on the present findings, future research should consider longitudinal designs, domain-specific cognitive analyses, as well implement culturally tailored interventions which are all needed and necessary within the New Zealand context. Collectively, the results highlight that there is a need for further exploration of factors impacting brain health in order to reduce the burden of dementia that comes along with the ageing population to ensure healthy ageing.

References

Aajami, Z., Toroski, M., Bahrami, M., & Borhaninejad, V. (2020). Relationship between depression and cognitive impairment among elderly: A cross-sectional study. *Journal of caring sciences*, *9*(3), 148.

Akoglu, H. (2018). User's guide to correlation coefficients. *Turkish journal of emergency medicine*, *18*(3), 91-93.

Allin, S., Masseria, C., & Mossialos, E. (2009). Measuring socioeconomic differences in use of health care services by wealth versus by income. *American journal of public health*, *99*(10), 1849-1855.

Andresen, E. M., Malmgren, J. A., Carter, W. B., & Patrick, D. L. (1994). Screening for depression in well older adults: evaluation of a short form of the CES-D (Center for Epidemiologic Studies Depression Scale). *American journal of preventive medicine*, *10*(2), 77–84.

Andersen, R., & Newman, J. F. (1973). Societal and individual determinants of medical care utilization in the United States. *The Milbank Memorial Fund Quarterly. Health and Society*, *51*(1), 95-124.

Artero, S., Ancelin, M. L., Portet, F., Dupuy, A., Berr, C., Dartigues, J. F., Tzourio, C., Rouaud, O., Poncet, M., Pasquier, F., Auriacombe, S., Touchon, J., & Ritchie, K. (2008). Risk profiles for mild cognitive impairment and progression to dementia are gender specific. *Journal of Neurology, Neurosurgery & Psychiatry*, *79*(9), 979-984.

Bales, K. R., Dodart, J. C., DeMattos, R. B., Holtzman, D. M., & Paul, S. M. (2002). Apolipoprotein E, amyloid, and Alzheimer disease. *Molecular interventions*, *2*(6), 363.

Beard, J. R., Officer, A., De Carvalho, I. A., Sadana, R., Pot, A. M., Michel, J. P., Lloyd-Sherlock, P., Epping-Jordan, J. E., Peeters, G. M. E. E., Mahanani, W. R., Thiyagarajan, J. A., & Chatterji, S. (2016). The World report on ageing and health: a policy framework for healthy ageing. *The Lancet*, *387*(10033), 2145-2154.

Bertrand, M. (2020). Gender in the twenty-first century. *AEA Papers and proceedings*, *110*, 1-24.

Blakely, T., Tobias, M., Robson, B., Ajwani, S., Bonné, M., & Woodward, A. (2005). Widening ethnic mortality disparities in New Zealand 1981–99. *Social science & medicine*, *61*(10), 2233-2251.

Blazer, D. G., Yaffe, K., & Karlawish, J. (2015). Cognitive aging: a report from the Institute of Medicine. *Jama*, *313*(21), 2121-2122.

Blondell, S. J., Hammersley-Mather, R., & Veerman, J. L. (2014). Does physical activity prevent cognitive decline and dementia?: A systematic review and meta-analysis of longitudinal studies. *BMC public health*, *14*, 1-12.

Bloomberg, M., Dugravot, A., Dumurgier, J., Kivimaki, M., Fayosse, A., Steptoe, A., Britton, A., Singh-Manoux, A., & Sabia, S. (2021). Sex differences and the role of education in cognitive ageing: analysis of two UK-based prospective cohort studies. *Lancet Public Health*, *6*(2), e106–115.

Bonilla-Santos, J., González-Hernández, A., Sierra-Barón, W., Gómez-Acosta, A., & Cala-Martínez, D. Y. (2024). Evidence of validity and reliability of the Colombian version of Addenbroke's Cognitive Examination Revised (ACE-R). *Aging & Mental Health*, *28*(5), 812-818.

Bonsang, E., Adam, S., & Perelman, S. (2012). Does retirement affect cognitive functioning?. *Journal of health economics*, *31*(3), 490-501.

Brown, R. T., & Covinsky, K. E. (2020). Moving prevention of functional impairment upstream: is middle age an ideal time for intervention? *Women's midlife health*, *6*(1).

Bush, K., Kivlahan, D. R., McDonell, M. B., Fihn, S. D., Bradley, K. A., & Ambulatory Care Quality Improvement Project (ACQUIP. (1998). The AUDIT alcohol consumption questions (AUDIT-C): an effective brief screening test for problem drinking. *Archives of internal medicine*, *158*(16), 1789-1795.

Callow, L., Alpass, F., Leathem, J., & Stephens, C. (2015). Normative data for older new Zealanders on the Addenbrooke's cognitive examination-revised. *New Zealand Journal of Psychology*, *44*(3), 29-41.

Canavan, M., & O'Donnell, M. J. (2022). Hypertension and cognitive impairment: a review of mechanisms and key concepts. *Frontiers in Neurology*, *13*, 821135.

Chatterji, S., Byles, J., Cutler, D., Seeman, T., & Verdes, E. (2015). Health, functioning, and disability in older adults—present status and future implications. *The lancet*, *385*(9967), 563-575.

Cherubini, A., Lowenthal, D. T., Paran, E., Mecocci, P., Williams, L. S., & Senin, U. (2010). Hypertension and cognitive function in the elderly. *Disease-a-month*, *56*(3), 106-147.

Cody, K. A., Koscik, R. L., Erickson, C. M., Berman, S. E., Jonaitis, E. M., Williams, V. J., Mueller, K. D., Christian, B. T., Chin, N. A., Clark, L. R., Betthauser, T. J., & Johnson, S. C. (2022). Associations of the Lifestyle for Brain Health index with longitudinal cognition and brain amyloid beta in clinically unimpaired older adults: findings from the Wisconsin Registry for Alzheimer's Prevention. *Alzheimer's & Dementia: Diagnosis, Assessment & Disease Monitoring*, *14*(1), e12351.

Deary, I. J., Corley, J., Gow, A. J., Harris, S. E., Houlihan, L. M., Marioni, R. E., Penke, L., Rafnsson, S. B., & Starr, J. M. (2009). Age-associated cognitive decline. *British medical bulletin*, *92*(1), 135-152.

Deckers, K., Barbera, M., Köhler, S., Ngandu, T., van Boxtel, M., Rusanen, M., Laatikainen, T., Verhey, F., Soininen, H., & Kivipelto, M. (2019a). Long‐term dementia risk prediction by the LIBRA score: a 30‐year follow‐up of the CAIDE study. *International Journal of Geriatric Psychiatry*, *35*(2), 195-203.

Deckers, K., Cadar, D., van Boxtel, M. P., Verhey, F. R., Steptoe, A., & Köhler, S. (2019b). Modifiable risk factors explain socioeconomic inequalities in dementia risk: evidence from a population-based prospective cohort study. *Journal of Alzheimer's Disease*, *71*(2), 549-557.

Deckers, K., Köhler, S., Ngandu, T., Antikainen, R., Laatikainen, T., Soininen, H., Strandberg, T., Verhey, F., Kivipelto, M., & Solomon, A. (2021). Quantifying dementia prevention potential in the FINGER randomized controlled trial using the LIBRA prevention index. *Alzheimer's & Dementia*, *17*(7), 1205-1212.

Deckers, K., Nooyens, A., van Boxtel, M., Verhey, F., Verschuren, M., & Köhler, S. (2019c). Gender and educational differences in the association between lifestyle and cognitive decline over 10 years: The Doetinchem Cohort Study. *Journal of Alzheimer's Disease*, *70*(s1), S31-S41.

Deckers, K., Van Boxtel, M. P., Schiepers, O. J., De Vugt, M., Munoz Sanchez, J. L., Anstey, K. J., Brayne, C., Dartigues, J. F., Engedal, K., Kivipelto, M., Ritchie, K., Starr, J. M., Yaffe, K., Irving, K., Verhey, F. R. J., & Köhler, S. (2015). Target risk factors for dementia prevention: a systematic review and Delphi consensus study on the evidence from observational studies. *International journal of geriatric psychiatry*, *30*(3), 234-246.

Díaz‐Venegas, C., Downer, B., Langa, K. M., & Wong, R. (2016). Racial and ethnic differences in cognitive function among older adults in the USA. *International journal of geriatric psychiatry*, *31*(9), 1004-1012.

Dong, Y., & Peng, C. Y. J. (2013). Principled missing data methods for researchers. *SpringerPlus*, *2*(1), 222.

Dudley, M., Menzies, O., Elder, H., Nathan, L., Garrett, N., & Wilson, D. (2019). Mate wareware: Understanding'dementia'from a Māori perspective. *The New Zealand Medical Journal (Online)*, *132*(1503), 66-74.

Duncan, G. J., & Magnuson, K. (2012). Socioeconomic status and cognitive functioning: moving from correlation to causation. *Wiley Interdisciplinary Reviews: Cognitive Science*, *3*(3), 377-386.

Dyall, L. (2014). Dementia: continuation of health and ethnic inequalities in New Zealand. *The New Zealand Medical Journal (Online)*, *127*(1389).

Dye, L., Boyle, N. B., Champ, C., & Lawton, C. (2017). The relationship between obesity and cognitive health and decline. *Proceedings of the nutrition society*, *76*(4), 443-454.

Engel, G. L. (1977). The need for a new medical model: a challenge for biomedicine. *Science*, *196*(4286), 129-136.

Emrani, S., & Sundermann, E. E. (2025). Sex/gender differences in the clinical trajectory of Alzheimer's disease: Insights into diagnosis and cognitive reserve. *Frontiers in Neuroendocrinology*, *77*, 101184.

Feng, L., Ng, X. T., Yap, P., Li, J., Lee, T. S., Håkansson, K., Kua, E. H., & Ng, T. P. (2014). Marital status and cognitive impairment among community-dwelling Chinese older adults: the role of gender and social engagement. *Dementia and geriatric cognitive disorders extra*, *4*(3), 375-384.

Fillit, H. M., Butler, R. N., O'Connell, A. W., Albert, M. S., Birren, J. E., Cotman, C. W., Greenough, W. T., Gold, P. E., Kramer, A. F., & Kuller, L. H. (2002). Achieving and maintaining cognitive vitality with aging. In *Mayo Clinic Proceedings* (Vol. 77, No. 7, pp. 681-696). Elsevier.

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.

Gong, Y. S., Hou, F. L., Guo, J., Lin, L., & Zhu, F. Y. (2021). Effects of alcohol intake on cognitive function and β-amyloid protein in APP/PS1 transgenic mice. *Food and Chemical Toxicology*, *151*, 112105.

Gorman, E., Scobie, G. M., & Towers, A. (2012). *Health and retirement of older New Zealanders.* No. 12/02. New Zealand Treasury Working Paper.

Griva, K., & Newman, S. P. (2021). Cognitive functioning in patients with CKD and ESRD. *Psychosocial Aspects of Chronic Kidney Disease*, 229-256.

Gu, D., Andreev, K., & Dupre, M. E. (2021). Major trends in population growth around the world. *China CDC weekly*, *3*(28), 604-613.

Harada, C. N., Love, M. C. N., & Triebel, K. (2013). Normal cognitive aging. *Clinics in geriatric medicine*, *29*(4), 737.

Harrison, S. L., Ding, J., Tang, E. Y., Siervo, M., Robinson, L., Jagger, C., & Stephan, B. C. (2014). Cardiovascular disease risk models and longitudinal changes in cognition: a systematic review. *Plos one*, *9*(12), e114431.

Health & Ageing Research Team - HART. (n.d.). *Health & Ageing Research Team - HART - Massey University.* Massey University. https://www.massey.ac.nz/about/colleges-schools-and-institutes/college-of-humanities-and-social-sciences/research-in-the-college-of-humanities-and-social-sciences/psychology-research/health-and-ageing-research-team-hart/.

Hasselgren, C., Ekbrand, H., Halleröd, B., Mellqvist Fässberg, M., Zettergren, A., Johansson, L., Skoog, I., & Dellve, L. (2020). Sex differences in dementia: on the potentially mediating effects of educational attainment and experiences of psychological distress. *BMC psychiatry*, *20*, 1-13.

Heger, I., van Boxtel, M., Deckers, K., Bosma, H., Verhey, F., & Köhler, S. (2024). Socioeconomic position, modifiable dementia risk and cognitive decline: results of 12-year Maastricht Aging Study. *International Psychogeriatrics*, *36*(7), 574-586.

Hugo, J., & Ganguli, M. (2014). Dementia and cognitive impairment: epidemiology, diagnosis, and treatment. *Clinics in geriatric medicine*, *30*(3), 421.

Irwin, M., Artin, K. H., & Oxman, M. N. (1999). Screening for depression in the older adult: criterion validity of the 10-item Center for Epidemiological Studies Depression Scale (CES-D). *Archives of internal medicine*, *159*(15), 1701-1704.

Jatrana, S. (2021). Gender differences in self-reported health and psychological distress among New Zealand adults. *Demographic Research*, *45*, 693-726.

Katayama, O., Lee, S., Bae, S., Makino, K., Shinkai, Y., Chiba, I., Harada, K., & Shimada, H. (2021). Lifestyle changes and outcomes of older adults with mild cognitive impairment: A 4-year longitudinal study. *Archives of Gerontology and Geriatrics*, *94*, 104376.

Kautzky-Willer, A., Harreiter, J., & Pacini, G. (2016). Sex and gender differences in risk, pathophysiology and complications of type 2 diabetes mellitus. *Endocrine reviews*, *37*(3), 278-316.

Knight, M. M. (2000). Cognitive ability and functional status. *Journal of advanced nursing*, *31*(6), 1459-1468.

Koster, A., Penninx, B. W., Bosma, H., Kempen, G. I., Newman, A. B., Rubin, S. M., Satterfield, S., Atkinson, H. H., Ayonayon, H. N., Rosano, C., Yaffe, K., Harris, T. B., Rooks, R. N., Thm Van Eijk, J., & Kritchevsky, S. B. (2005). Socioeconomic differences in cognitive decline and the role of biomedical factors. *Annals of epidemiology*, *15*(8), 564-571.

Kutner, M. H., Nachtsheim, C. J., & Neter, J. (2004). *Applied linear regression models* (4th ed.). McGraw-Hill/Irwin.

Larnyo, E., Dai, B., Nutakor, J. A., Ampon-Wireko, S., Larnyo, A., & Appiah, R. (2022). Examining the impact of socioeconomic status, demographic characteristics, lifestyle and other risk factors on adults' cognitive functioning in developing countries: an analysis of five selected WHO SAGE Wave 1 Countries. International Journal for Equity in Health. *21*(1).

Lee, S., Kawachi, I., Berkman, L. F., & Grodstein, F. (2003). Education, other socioeconomic indicators, and cognitive function. *American journal of epidemiology*, *157*(8), 712-720.

Levine, D. A., Gross, A. L., Briceño, E. M., Tilton, N., Giordani, B. J., Sussman, J. B., Hayward, R. A., Burke, J. F., Hingtgen, S., Elkind, M. S. V., Manly, J. J., Gottesman, R. F., Gaskin, D. J., Sidney, S., Sacco, R. L., Tom, S. E., Wright, C. B., Yaffe, K., & Galecki, A. T. (2021). Sex differences in cognitive decline among US adults. *JAMA network open*, *4*(2), Article e210169-e210169.

Liang, X., Huang, Y., & Han, X. (2021). Associations between coronary heart disease and risk of cognitive impairment: a meta‐analysis. *Brain and behavior*, *11*(5), e02108.

Lin, K. A., Choudhury, K. R., Rathakrishnan, B. G., Marks, D. M., Petrella, J. R., Doraiswamy, P. M., & Initiative., A. s. D. N. (2015). Marked gender differences in progression of mild cognitive impairment over 8 years. *Alzheimer's & dementia: translational research & clinical interventions*, *1*(2), 103-110.

Liu, H., Zhang, Y., Burgard, S. A., & Needham, B. L. (2019). Marital status and cognitive impairment in the United States: evidence from the National Health and Aging Trends Study. *Annals of Epidemiology*, *38*, 28-34.

Livingston, G., Huntley, J., Sommerlad, A., Ames, D., Ballard, C., Banerjee, S., Brayne, C., Burns, A., Cohen-Mansfield, J., Cooper, C., Costafreda, S. G., Dias, A., Fox, N., Gitlin, L. N., Howard, R., Kales, H. C., Kivimäki, M., Larson, E. B., Ogunniyi, A., Orgeta, V., Ritchie, K., Rockwood, K., Sampson, E. L., Samus, Q., Schneider, L. S., Selbæk, G., Teri, L., & Mukadam, N. (2020). Dementia prevention, intervention, and care: 2020 report of the Lancet Commission. *The lancet*, *396*(10248), 413-446.

Ma'u, E., Cullum, S., Cheung, G., Livingston, G. & Mukadam, N. Differences in the potential for dementia prevention between major ethnic groups within one country: a cross sectional analysis of population attributable fraction of potentially modifiable risk factors in New Zealand. *Lancet Reg. Health - Western Pac.*13, 100191. https://doi-org.ezproxy.massey.ac.nz/10.1016/j.lanwpc.2021.100191 (2021a).

Ma'u, E., Cullum, S., Yates, S., Te Ao, B., Cheung, G., Burholt, V., Dudley, M., Krishnamurthi, R., & Kerse, N. (2021b). *Dementia economic impact report 2020/prepared for Alzheimers New Zealand: authors: Ma'u E, Cullum S, Yates S, Te Ao B, Cheung G, Burholt V, Dudley M, Krishnamurthi R, Kerse N*. Wellington: Alzheimers New Zealand, 2021.

Marioni, R. E., van den Hout, A., Valenzuela, M. J., Brayne, C., Matthews, F. E., Function, M. C., & Study, A. (2012). Active cognitive lifestyle associates with cognitive recovery and a reduced risk of cognitive decline. *Journal of Alzheimer's Disease*, *28*(1), 223-230.

Marden, J. R., Tchetgen Tchetgen, E. J., Kawachi, I., & Glymour, M. M. (2017). Contribution of socioeconomic status at 3 life-course periods to late-life memory function and decline: early and late predictors of dementia risk. *American journal of epidemiology*, *186*(7), 805-814.

Marmot, M., Friel, S., Bell, R., Houweling, T. A., & Taylor, S. (2008). Closing the gap in a generation: health equity through action on the social determinants of health. *The lancet*, *372*(9650), 1661-1669.

Maylor, E. A., Reimers, S., Choi, J., Collaer, M. L., Peters, M., & Silverman, I. (2007). Gender and sexual orientation differences in cognition across adulthood: Age is kinder to women than to men regardless of sexual orientation. *Archives of sexual behavior*, *36*(2), 235-249.

McMaughan, D. J., Oloruntoba, O., & Smith, M. L. (2020). Socioeconomic status and access to healthcare: interrelated drivers for healthy aging. *Frontiers in public health*, *8*.

Mian, M., Tahiri, J., Eldin, R., Altabaa, M., Sehar, U., & Reddy, P. H. (2024). Overlooked cases of mild cognitive impairment: Implications to early Alzheimer's disease. *Ageing Research Reviews*, *98*, Article 102335.

Mielke, M. M., Vemuri, P., & Rocca, W. A. (2014). Clinical epidemiology of Alzheimer's disease: assessing sex and gender differences. *Clinical epidemiology*, 37-48.

Mioshi, E., Dawson, K., Mitchell, J., Arnold, R., & Hodges, J. R. (2006). The Addenbrooke's Cognitive Examination Revised (ACE‐R): a brief cognitive test battery for dementia screening. *International Journal of Geriatric Psychiatry: A journal of the psychiatry of late life and allied sciences*, *21*(11), 1078-1085.

Murman, D. L. (2015). The impact of age on cognition. *Seminars in hearing*, *36*(3), 111-121.

Nebel, R. A., Aggarwal, N. T., Barnes, L. L., Gallagher, A., Goldstein, J. M., Kantarci, K., Mallampalli, M. P., Mormino, E. C., Scott, L., Yu, W. H., Maki, P. M., & Mielke, M. M. (2018). Understanding the impact of sex and gender in Alzheimer's disease: a call to action. *Alzheimer's & Dementia*, *14*(9), 1171-1183.

Neuffer, J., Wagner, M., Moreno, E., Le Grand, Q., Mishra, A., Trégouët, D. A., Leffondre, K., Proust‐Lima, C., Foubert‐Samier, A., & Berr, C. (2024). Association of LIfestyle for BRAin health risk score (LIBRA) and genetic susceptibility with incident dementia and cognitive decline. *Alzheimer's & Dementia*, *20*(6), 4250-4259.

Noone, J., Stephens, C., & Alpass, F. (2014). *Socioeconomic Status. Summary Report for the New Zealand Longitudinal Study of Ageing.*

Nooyens, A. C., Wijnhoven, H. A., Schaap, L. S., Sialino, L. D., Kok, A. A., Visser, M., Verschurena, W. M. M., Picaveta, S. J., & Van Oostrom, S. H. (2022). Sex differences in cognitive functioning with aging in the Netherlands. *Gerontology*, *68*(9), 999-1009.

Okamoto, S., Kobayashi, E., Murayama, H., Liang, J., Fukaya, T., & Shinkai, S. (2021). Decomposition of gender differences in cognitive functioning: National Survey of the Japanese elderly. *BMC geriatrics*, *21*, 11-13.

Pais, R., Ruano, L., P. Carvalho, O., & Barros, H. (2020). Global cognitive impairment prevalence and incidence in community dwelling older adults—a systematic review. *Geriatrics*, *5*(4), 84.

Park, C., & Kang, C. (2008). Does education induce healthy lifestyle?. *Journal of health economics*, *27*(6), 1516-1531.

Parr-Brownlie, L. C., Waters, D. L., Neville, S., Neha, T., & Muramatsu, N. (2020). Aging in New Zealand: Ka haere ki te ao pakeketanga. *The Gerontologist*, *60*(5), 812-820.

Peters, R., Booth, A., Rockwood, K., Peters, J., D'Este, C., & Anstey, K. J. (2019). Combining modifiable risk factors and risk of dementia: a systematic review and meta-analysis. *BMJ open*, *9*(1), e022846.

Pons, A., LaMonica, H. M., Mowszowski, L., Köhler, S., Deckers, K., & Naismith, S. L. (2018). Utility of the LIBRA Index in Relation to Cognitive Functioning in a Clinical Health Seeking Sample. *Journal of Alzheimer's Disease, 62*(2), 373-384.

Poulton, R., Moffitt, T. E., & Silva, P. A. (2015). The Dunedin Multidisciplinary Health and Development Study: overview of the first 40 years, with an eye to the future. *Social psychiatry and psychiatric epidemiology*, *50*(5), 679-693.

Prakash, O., & Jha, S. (2016). Differential diagnosis for cognitive decline in elderly. *Journal of Geriatric Mental Health*, *3*(1), 21-28.

Pryzgoda, J., & Chrisler, J. C. (2000). Definitions of gender and sex: The subtleties of meaning. *Sex roles*, *43*, 553-569.

Roberts, R. O., Knopman, D. S., Geda, Y. E., Cha, R. H., Roger, V. L., & Petersen, R. C. (2010). Coronary heart disease is associated with non-amnestic mild cognitive impairment. *Neurobiology of aging*, *31*(11), 1894-1902.

Rodriguez, F. S., Hofbauer, L. M., & Röhr, S. (2021). The role of education and income for cognitive functioning in old age: A cross‐country comparison. *International journal of geriatric psychiatry*, *36*(12), 1908-1921.

Rodriguez, F. S., Röhr, S., Dragano, N., Schmidt, B., Becher, H., Schikowski, T., Gastell, S., Hart, V., Hoven, H., Linseisen, J., Greiser, K. H., Leitzmann, M., Bohmann, P., Castell, S., Heise, J. K., Krist, L., Keil, Thomas., Karch, A., Teismann, H., Velásquez, I. M., Pischon, T., Peter, A., Führer, A., Mikolajczyk, R., Günther, K., Brand, T., Meinke-Franze, C., Schipf, S., Grabe, H. J., Brenner, H., Koch-Gallenkamp, L., Berger, K., Wagner, M., Katzke, V., Lieb, W., Pabst, A., & Riedel-Heller, S. G. (2024). Low income, being without employment, and living alone: how they are associated with cognitive functioning—Results from the German national cohort (NAKO). *Aging, neuropsychology, and cognition*, *32*(4), 542-557.

Röhr, S., Gibson, R. H., & Alpass, F. M. (2024a). Higher socioeconomic deprivation in areas predicts cognitive decline in New Zealanders without cognitive impairment. *Scientific reports*, *14*(1), 28314.

Röhr, S., Stephens, C., & Alpass, F. (2024b). Lifestyle for brain health and cognitive functioning in midlife to early late‐life New Zealanders: Utility of the LIBRA index. *International Journal of Geriatric Psychiatry*, *39*(5), e6091.

Rosenau, C., Köhler, S., van Boxtel, M., Tange, H., & Deckers, K. (2024). Validation of the Updated "LIfestyle for BRAin health" (LIBRA) Index in the English Longitudinal Study of Ageing and Maastricht Aging Study. *Journal of Alzheimer's disease : JAD*, *101*(4), 1237–1248. https://doi.org/10.3233/JAD-240666.

Salthouse, T. A. (2009). When does age-related cognitive decline begin? *Neurobiology of aging*, *30*(4), 507-514.

Salthouse, T. A., & Tucker-Drob, E. M. (2008). Implications of short-term retest effects for the interpretation of longitudinal change. *Neuropsychology*, *22*(6), 800.

Schiepers OJG, Köhler S, Deckers K, et al. Lifestyle for brain health (LIBRA): a new model for dementia prevention. *Int J Geriatr Psychiatr*. 2018; 33(1): 167-175. https://doi.org/10.1002/gps.4700.

Schwartz, B. S., Glass, T. A., Bolla, K. I., Stewart, W. F., Glass, G., Rasmussen, M., Bressler, J., Shi, W., & Bandeen-Roche, K. (2004). Disparities in cognitive functioning by race/ethnicity in the Baltimore Memory Study. *Environmental health perspectives*, *112*(3), 314-320.

Shang, X., Roccati, E., Zhu, Z., Kiburg, K., Wang, W., Huang, Y., Zhang, X., Zhang, X., Liu, J., Tang, S., Hu, Y., Ge, Z., Yu, H., & He, M. (2023). Leading mediators of sex differences in the incidence of dementia in community-dwelling adults in the UK Biobank: a retrospective cohort study. *Alzheimer's Research & Therapy*, *15*(1), 7.

Sommerlad, A., Ruegger, J., Singh-Manoux, A., Lewis, G., & Livingston, G. (2018). Marriage and risk of dementia: systematic review and meta-analysis of observational studies. *Journal of Neurology, Neurosurgery & Psychiatry*, *89*(3), 231-238.

Spector, A., & Orrell, M. (2010). Using a biopsychosocial model of dementia as a tool to guide clinical practice. *International Psychogeriatrics*, *22*(6), 957-965.

Sport New Zealand. (n.d.). *Healthy active learning. https://sportnz.org.nz/healthy-active-learning/healthy-active-learning/*.

Springer, K. W., Stellman, J. M., & Jordan-Young, R. M. (2012). Beyond a catalogue of differences: a theoretical frame and good practice guidelines for researching sex/gender in human health. *Social science & medicine*, *74*(11), 1817-1824.

Statistics New Zealand. (2021). *Growth in life expectancy slows*. https://www.stats.govt.nz/news/growth-in-life-expectancy-slows/.

Statistics New Zealand. (2024). *Household income and housing-cost statistics: Year ended June 2023*. https://www.stats.govt.nz/information-releases/household-income-and-housing-cost-statistics-year-ended-june-2023/.

Stephens, C., Spicer, J., Budge, C., Stevenson, B., & Alpass, F. (2014). Accounting for differences in cognitive health between older adults in New Zealand and the USA. *International Psychogeriatrics*, *27*(4), 591-600.

Stephens, C., Szabó, Á., & Breheny, M. (2022). Social inequalities over the lifecourse and healthy ageing in Aotearoa/New Zealand: Differences by Māori ethnicity and gender. *Ageing & Society*, *42*(4), 745-764.

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

Stevenson, B. (2014). *NZLSA measures*. Technical report for the New Zealand Longitudinal Study of Ageing. Palmerston North: Massey University.

Subramaniapillai, S., Almey, A., Rajah, M. N., & Einstein, G. (2021). Sex and gender differences in cognitive and brain reserve: Implications for Alzheimer's disease in women. *Frontiers in Neuroendocrinology*, *60*, 100879.

Sundström, A., Westerlund, O., & Kotyrlo, E. (2015). Marital status and risk of dementia: a nationwide population-based prospective study from Sweden. *BMJ open*, *6*(1), e008565.

Tabachnick, B. G., & Fidell, L. S. (2019). *Using multivariate statistics / Barbara G. Tabachnick, California State University, Northridge, Linda S. Fidell, California State University, Northridge. (Seventh edition.)* (Seventh edition.). Pearson.

Takase, M., Sugiura, K., Nakamoto, I., Watanabe, S., & Murayama, H. (2024). The association between employment and cognitive function in older adults: A systematic review. *Geriatrics & gerontology international*, *24*(12), 1283-1291.

Takechi, H., & Yoshino, H. (2023). Health Care Resource Use and Social Costs in Mild Cognitive Impairment and Mild Alzheimer's Disease. *Journal of Alzheimer's Disease Reports*, *7*(1), 731-738.

Towers, A. J. (2007). *Methodology. In, Health, Work and Retirement Survey: Summary report for the 2006 data wave*.

Towers, A., & Stevenson, B. (2014). *NZLSA cohort profile. Technical report for the New Zealand Longitudinal Study of Ageing*.

Ungvari, Z., Toth, P., Tarantini, S., Prodan, C. I., Sorond, F., Merkely, B., & Csiszar, A. (2021). Hypertension-induced cognitive impairment: from pathophysiology to public health. *Nature Reviews Nephrology*, *17*(10), 639-654.

Van Exel, E., Gussekloo, J., De Craen, A. J. M., Bootsma-Van Der Wiel, A., Houx, P., Knook, D. L., & Westendorp, R. G. J. (2001). Cognitive function in the oldest old: women perform better than men. *Journal of Neurology, Neurosurgery & Psychiatry*, *71*(1), 29-32.

Vélez-Coto, M., Rute-Pérez, S., Pérez-García, M., & Caracuel, A. (2021). Unemployment and general cognitive ability: A review and meta-analysis. *Journal of Economic Psychology*, *87*, 102430.

Vos, S. J., Van Boxtel, M. P., Schiepers, O. J., Deckers, K., De Vugt, M., Carrière, I., Dartigues, J. F., Peres, K., Artero, S., Ritchie, K., Galluzzo, L., Scafato, E., Frisoni, G. B., Huisman, M., Comijs, H. C., Sacuiu, S. F., Skoog, I., Irving, K., O'Donnell, C. A., Verhey, F. R. J., Visser, P. J., & Köhler, S. (2017). Modifiable risk factors for prevention of dementia in midlife, late life and the oldest-old: validation of the LIBRA index. *Journal of Alzheimer's Disease*, *58*(2), 537-547.

Wang, J., & Conwell, J. (2022). Higher education and health at midlife: Evaluating the role of college quality. *SSM-Population Health*, *19*, 101228.

Wang, A. Y., Hu, H. Y., Ou, Y. N., Wang, Z. T., Ma, Y. H., Tan, L., & Yu, J. T. (2023). Socioeconomic status and risks of cognitive impairment and dementia: a systematic review and meta-analysis of 39 prospective studies. *The journal of prevention of Alzheimer's disease*, *10*(1), 83-94.

Whalley, L. J., Deary, I. J., Appleton, C. L., & Starr, J. M. (2004). Cognitive reserve and the neurobiology of cognitive aging. *Ageing Research Reviews*, *3*(4), 369-382.

World Health Organization, Commission on Social Determinants of Health. Closing the gap in a generation: health equity through action on the social determinants of health. CSDH final report. Geneva: WHO; 2008.

Wood, K. M., Edwards, J. D., Clay, O. J., Wadley, V. G., Roenker, D. L., & Ball, K. K. (2005). Sensory and cognitive factors influencing functional ability in older adults. *Gerontology*, *51*(2), 131-141.

World Health Organization. (2020). *Healthy ageing and functional ability.* https://www.who.int/news-room/questions-and-answers/item/healthy-ageing-and-functional-ability.

Wu, Y. T., Beiser, A. S., Breteler, M., Fratiglioni, L., Helmer, C., Hendrie, H. C., Honda, H., Ikram, M. A., Langa, K. M., Lobo, A., Matthews, F. E., Ohara, T., Pérès, K., Qiu, C., Seshadri, S., Sjölund, B., Skoog, I., & Brayne, C. (2017). The changing prevalence and incidence of dementia over time—current evidence. *Nature Reviews Neurology*, *13*(6), 327-339.

Yoshida, H., Terada, S., Honda, H., Kishimoto, Y., Takeda, N., Oshima, E., Hirayama, K., Yokota, O., & Uchitomi, Y. (2012). Validation of the revised Addenbrooke's Cognitive Examination (ACE-R) for detecting mild cognitive impairment and dementia in a Japanese population. *International Psychogeriatrics*, *24*(1), 28-37.

Zawaly, K., Moyes, S. A., Buetow, S., Tippett, L., & Kerse, N. (2021). Modifiable risk factors and change in cognition of Māori and non-Māori in advanced age: LiLACS NZ. *Journal of Applied Gerontology*, *41*(1), 262-273.

Zawaly, K., Moyes, S. A., Wood, P. C., Cheung, G., Rolleston, A., Buetow, S., Tippett, L., & Kerse, N. (2019). Diagnostic accuracy of a global cognitive screen for Māori and non-Māori octogenarians. *Alzheimer's & Dementia: Translational Research & Clinical Interventions*, *5*, 542-552.

Zhang, Z. (2006). Gender differentials in cognitive impairment and decline of the oldest old in China. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *61*(2), S107-S115.

Zhang, M., Gale, S. D., Erickson, L. D., Brown, B. L., Woody, P., & Hedges, D. W. (2015). Cognitive function in older adults according to current socioeconomic status. *Aging, Neuropsychology, and Cognition*, *22*(5), 534-543.

Zhang, Y. R., Xu, W., Zhang, W., Wang, H. F., Ou, Y. N., Qu, Y., Shen, X. N. , Chen, S. D., Wu, K. M., Zhao, Q. H., Zhang, H. N., Sun, L., Dong, Q., Tan, L., Feng, L., Zhang, C., Evangelou, E., Smith, A. D., Yu, J. T. (2022a). Modifiable risk factors for incident dementia and cognitive impairment: an umbrella review of evidence. *Journal of Affective Disorders*, *314*, 160-167.

Zhang, Z., Zhao, Y., & Bian, Y. (2022b). A role of socioeconomic status in cognitive impairment among older adults in Macau: a decomposition approach. *Frontiers in Aging Neuroscience*, *14*, Article 804307.

Appendix: 'Kiwi' Addenbrooke's Cognitive Examination - ACE-R

ADDENBROOKE'S COGNITIVE EXAMINATION – ACE-R

Revised Version C (2004) - NZ Adaptation 1f (December 2007)

(Score 1-2)

Handedness:_Enter 1 for Left / 2 for Right [ ] 11

ORIENTATION

➢ Ask: What is the	Day ________	Date ________	Month ________	Year ________	Season ________	[Score 0-5] [ ] 12
➢ Ask: Which	Building/ Address ________	Floor/Ward ________	Town/Suburb ________	City ________	Country ________	[Score 0-5] [ ] 13

REGISTRATION

➢ Tell: 'I'm going to give you the name of three objects and I'd like you to repeat after me: shoe, flag,tree'. After subject repeats, say ' Try to remember those because I'm going to ask you later'. Score *only* the first trial (repeat 3 times if necessary).

Register number of trials ____

[Score 0-3] [ ] 14

ATTENTION & CONCENTRATION

➢ Ask the subject: 'could you take seven away from a hundred?'. And then seven from each response (5 subtractions). If subject fails, ask: 'did you mean __ ?' If subject still makes a mistake, switch to spelling. If subject corrects himself or herself, continue.

Stop after five subtractions (93, 86, 79, 72, 65). ____ ____ ____ ____ ____

➢ Ask: 'could you please spell **WORLD** for me? Then ask him/her to spell it backwards:

____ ____ ____ ____ ____
D L R O W

[Score 0-5] [ ] 15
(for the best performed task)

MEMORY - Recall

➢ Ask: 'Which 3 objects I asked you to repeat and remember?'

________ ________ ________

[Score 0-3] [ ] 16

MEMORY – Anterograde Memory

➢ Tell: ' I'm going to give you a name and address and I'd like you to repeat after me. We'll be doing that 3 times, so you have a chance to learn it because I'll be asking you later'

Score only the third trial

[Score 0 –7] [ ] 17

	1st Trial	2nd Trial	**3rd Trial**
John Martin	_ _	_ _	_ _
24 Market Street	_ _ _	_ _ _	_ _ _
Masterton	_	_	_
Wairarapa	_	_	_

MEMORY – Retrograde Memory

➢ Name of current Prime Minister ________________
➢ Name of British Royal family member who died in a car crash in Paris ? ________________
➢ Name of the current USA president ________________
➢ Name of the USA president who was assassinated in the 1960s ________________

[Score 0 – 4] [ ] 18

V E R B A L   F L U E N C Y - Letter 'P' and animals

➢ **Letters**

Say: 'I'm going to give you a letter of the alphabet and I'd like you to generate as many words as you can beginning with that letter, but not names of people or places. Are you ready? You've got a minute for that and the letter is letter P'

[Score 0 – 7] 19

total	correct
>17	7
14-17	6
11-13	5
8-10	4
6-7	3
4-5	2
3-4	1
<3	0

➢ **Animals**

Say: 'Now let's change. I'd like you to generate as many animals as possible, any kind of animal, beginning with any letter, it doesn't matter'.

[Score 0 – 7] 20

total	correct
>21	7
17-21	6
14-16	5
11-13	4
9-10	3
7-8	2
5-6	1
<5	0

L A N G U A G E - Comprehension

➢ Show written instruction:

[Score 0-1] 21

Close your eyes

➢ 3 stage command:

'Take the paper in your left hand. Fold the paper in half. Put the paper on the floor'

(use right hand if subject is left handed)

[Score 0-3] 22

L A N G U A G E - Writing

➢ Ask the subject to make up a sentence and write it in the space below:

Score 1 if sentence contains a subject and a verb (see guide for examples)

[Score 0-1] 23

L A N G U A G E - Repetition

- Ask the subject to repeat:' hippopotamus'; 'eccentricity; 'unintelligible'; 'statistician' Score 2 if all correct; 1 if 3 correct; 0 if 2 or less.

[Score 0-2] Language 24

- Ask the subject to repeat: **'Above, beyond and below'**

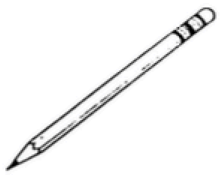
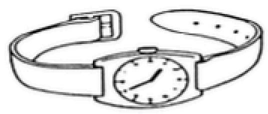
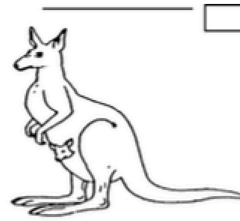
[Score 0-1] Language 25

- Ask the subject to repeat: **'No ifs, ands or buts'**

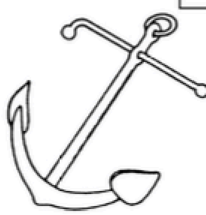
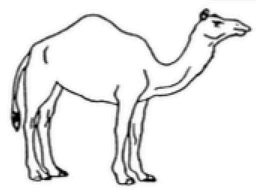
[Score 0-1] Language 26

L A N G U A G E - Naming

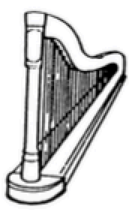
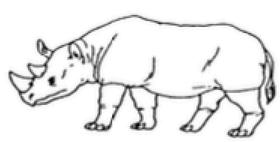
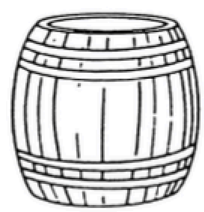
- Ask the subject to name the following pictures:

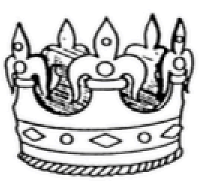
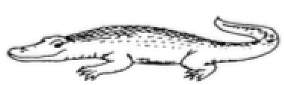
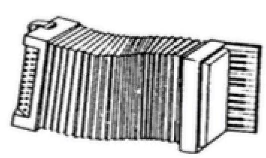




[Score 0-2] pencil + watch Language 27

[Score 0-10] Language 28

L A N G U A G E - Comprehension

- Using the pictures above, ask the subject to:
  - Point to the one which is associated with the monarchy ____________________
  - Point to the one which is a marsupial ____________________
  - Point to the one which is found in the Antarctic ____________________
  - Point to the one which has a nautical connection ____________________

[Score 0-4] Language 29

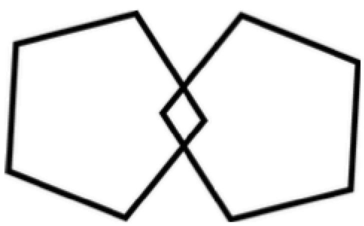
LANGUAGE - Reading

➢ **Ask the subject to read the following words:** [Score 0-1] 30

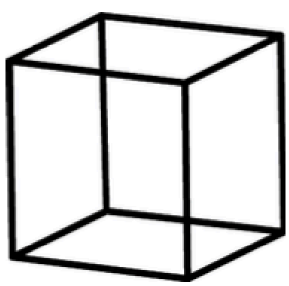
sew
pint
soot
dough
height

VISUOSPATIAL ABILITIES

➢ **Overlapping pentagons:** Ask the subject to copy this diagram: [Score 0-1] 31



➢ **Wire cube**: Ask the subject to copy this drawing (for scoring, see instructions guide) [Score 0-2] 32

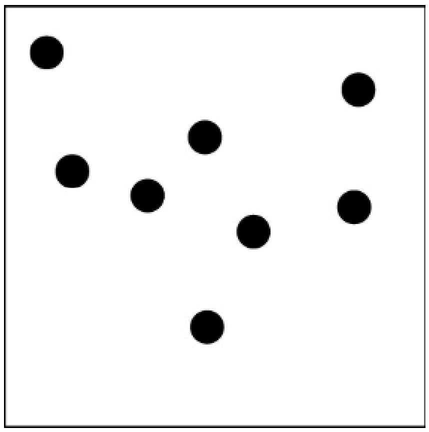


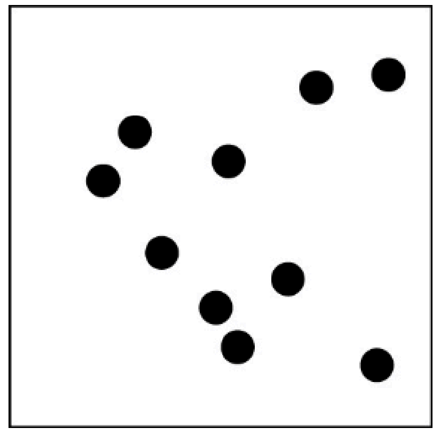
➢ **Clock:** Ask the subject to draw a clock face with numbers and the hands at ten past five. [Score 0-5] 33

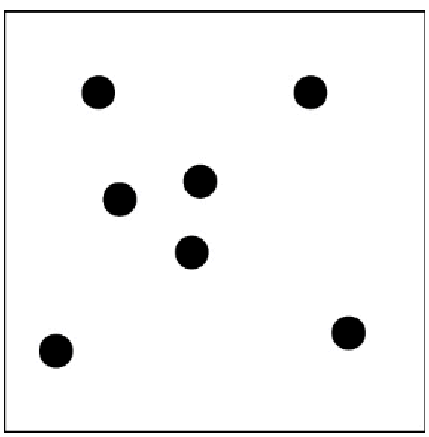
PERCEPTUAL ABILITIES

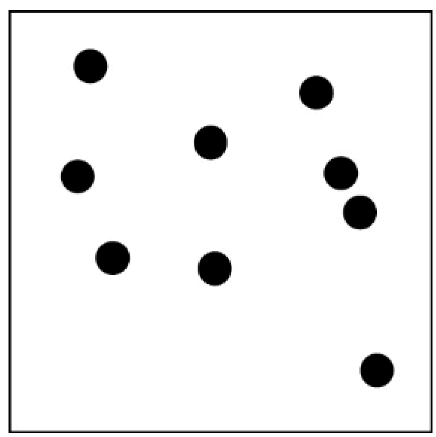
- Ask the subject to count the dots without pointing them

[Score 0-4] 34



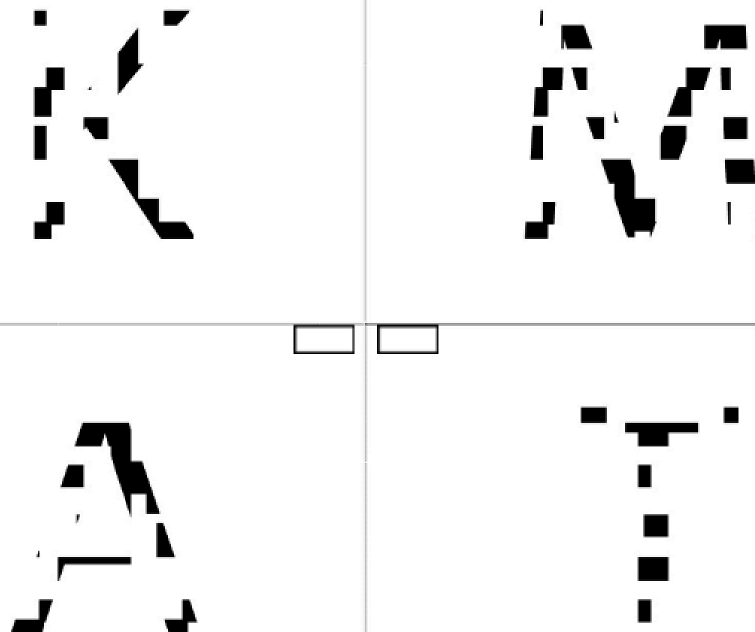






PERCEPTUAL ABILITIES

- Ask the subject to identify the letters [Score 0-4] 35



RECALL & RECOGNITION

- Ask ' Now tell me what you remember of the name address we were repeating at the beginning'

John Martin **24 Market Street** **Masterton** **Wairarapa**	__ __ __ __ __ __ __	[Score 0-7] 36

If subject fails to recall any of the 7 items, tick parts recalled and ask the question(s) that will help to recall only the missing one(s)

- Was it (score considering parts recalled and the recognised ones): [Score 0-5] 37

John Simmons		John Martin		Joseph Martin		recalled	
42		24		28		recalled	
Market Road		High Street		Market Street		recalled	
Carterton		Masterton		Martinborough		recalled	
Wairarapa		Waikanae		Wellington		recalled	

General Scores

MMSE	/30
ACE-R	/100

Fractionated scoring

Cut-off <88 gives 94% sensitivity and 89% specificity for dementia	**Attention and Orientation**	**/18**
	Memory	**/26**
Cut-off <82 gives 84% sensitivity and 1 00% specificity for dementia	**Fluency**	**/14**
	Language	**/26**
	Visuospatial	**/16**

V1f (30-12-07)