The Effects of Age-Related Cognitive Change on Social Engagement: An Exploration of Cohort and Electrophysiological Data

A thesis submitted to The University of Manchester for the degree of Doctor of Philosophy in the Faculty of Biology, Medicine, and Health

2023

Josephine F Kearney

School of Health Sciences

Contents

Abstract 6

Declaration 7

Copyright Statement 7

Acknowledgements 8

Introduction 10

- Cognitive Changes in Ageing 10
- Neurophysiological changes in ageing 11
- Overlap of Language and Executive Functions 13
- Social factors and cognitive changes in later life 13
- Research of this Thesis 15
- Methodologies 16
- Hypothesis 17
- Aims and Objectives 17
- References 18

Cognitive Mediation of Social Engagement and Socioeconomic Background: SEM Exploration in Cam-CAN, a Large Adult Lifespan Database 26

- Abstract 27
- Introduction 28
- Method 30
- Results 35
- Discussion 39
- References 45
- Supplementary Material 50

Age-Related Differences In Higher-Order Cognitive Mediation Of Socioeconomic Status And Social Engagement: A Structural Equation Modelling Study 57

- Abstract 58
- Introduction 59
- Methods 62
- Results 67
- Discussion 71
- References 77

Language, Executive Functions, and Social Inclusion in Ageing: An EEG Study 82

- Abstract 83
- Introduction 84
- Methods 87

Results 90
Discussion 99
References 105
Supplementary Materials 111
General Discussion 117
References 123

Word Count: 42958

List of Tables

Variables included in Cognitive Item EFA and CFA for both Under and Over 50 sub-groups. 33
Variables in Social Engagement Item EFA and CFA for Both Under and Over 50 sub-groups. 34
Direct paths in Under 50 sub-sample 36
Direct paths in Under 50 sub-sample. 38
Indirect paths in over 50 sub-sample. 38
Cognitive Variables included in the SEM model. 63
Questionnaire measures used in confirmatory factor analysis for both Under and Over 50 groups. 66
Significant direct pathways in Under 50 SEM 68
Significant indirect pathways in Under 50 model 69
Significant Direct Pathways of Over 50 SEM 71
Significant Indirect Pathways in Over 50 SEM 71
Three-way ANOVA of within and between subject effects on amplitude in Stop Signal task 93
Two-way ANOVA of within and between subject effects on amplitude in SLIP task 95

List of Figures

Participant inclusion cascade 30

Under 50 Confirmatory Factor Analysis Structures of cognitive measures 33

Over 50 Confirmatory Factor Analysis Structures of cognitive measures 33

Under 50 Confirmatory Factor Analysis Structures of social participation measures 34

Over 50 Confirmatory Factor Analysis Structures of social participation measures 35

Structural Equation Model of Under 50 sub-sample. 36

Structural Equation Model of Over 50 sub-sample 37

CFA factor loading of Social Engagement items for the Under 50 sub-group 66

CFA factor loading of Social Engagement items for the Over 50 sub-group. 66

Full SEM model of Under 50 sub-group 67

Full SEM model of Over 50 sub-group 70

SLIP stimuli presentation 88

WCST stimuli presentation 89

Stop Signal Response differences in Young and Older participants 91

Topographies of ERP amplitude for Young and Older participants in Stop Signal task 91

ERPs of Inhibit Response and Respond conditions for all participants in Stop Signal task 92

Incorrect-Correct response difference in Young and Older participants in SLIP task 94

Topographies of ERP amplitude for Young and Older participants in SLIP task 95

Topographies of amplitude for Young and Older participants in WCST task. 96

Topographies of time-frequency amplitude for Young and Older participants in WCST task. 97

Power spectra for the Correct and Incorrect responses of Young and Older participants in WCST task.. 98

Abstract

Ageing brings about a number of functional changes across many cognitive domains; slowed language production (Horton, Spieler, & Shriberg, 2010), reduced ability to effectively direct attentional behaviours and monitor conflict (Wascher, Schneider, Hoffmann, Beste, & Sänger, 2012; West & Schwarb, 2006), and most well-known are drastic declines in memory (Burke and MacKay, 1997). These cognitive abilities support our ability to create social bonds: communicating, effectively directing behaviour, and recalling past experiences (Diamond, 2013; Krueger et al., 2009; McHugh Power, Steptoe, Kee, & Lawlor, 2019). Preservation of cognitive health becomes increasingly important in later life to prevent social isolation and loneliness (Evans et al., 2019), which can have significant impacts on mental and physical health during old age (Cacioppo & Cacioppo, 2014; Cacioppo & Hawkley, 2003; Christiansen et al., 2021; Hawton et al., 2011).

This thesis investigated effects of age-related changes in cognition on the experience of social engagement and inclusion. Study 1 used factor analyses and Structural Equation Modelling (SEM) on data from the first wave of data collection for the Cam-CAN dataset (Shafto et al., 2014). The factor analysis uncovered differences in the underpinnings of cognition and social engagement in young and old adults. Structural Equation Modelling then revealed the interactions between these factors, as influenced by socioeconomic status (SES). This established a number of interactions between SES, cognition, and social engagement in both young and old adults, though only in the older group were cognitively mediated associations found. This study established the framework of differential representations in young and old adults, and highlighted facets of cognition that supported social engagement in later life. The second study investigated these associations further using the second wave of Cam-CAN data, where cognitive measures were more targeted. Structural Equation Modelling in this study showed more discreet relationships between cognition and social engagement that suggested older adults relied on mediation of specific cognitive abilities for social engagement. These findings highlight specific cognitive domains that can be targeted in interventions that address social isolation and loneliness among older adults, including supporting cognitive development in early adulthood or working to maintain cognitive skills throughout life. The third study of this thesis used electroencephalography (EEG), to investigate age differences in neural markers of language and executive function, as well as probing feelings of social inclusion in young and older adults. Several differences were found across the cognitive domains; older adults had a significantly reduced P300 amplitude in tests of inhibition, showed little correct/incorrect differences in mid-frontal theta (3-7Hz) in mental-shifting and showed a reduced left-frontal positivity in correct verbal responses. These findings demonstrate age-related differences in neurological measures across the three cognitive domains explored, suggesting that these cognitive processes are more effortful and recruit more global neural resources in older adults.

The research identified age-related differences in cognition, at behavioural and neuronal levels, and associated such differences with social engagement. By utilising both a large-scale, dataset and extremely targeted neurocognitive measures I have been able to establish a broad model of associations between social engagement and cognition at different life-stages, then elaborate on the underlying neurocognitive mechanisms of language and executive functions. This provides strong evidence for cognitive-social engagement associations that become more impactful in later-life and highlight neuro-cognitive differences in older people across multiple domains.

Declaration

No portion of the work referred to in the thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

Copyright Statement

Acknowledgements

I would like to thank Jason and Pam for all their support in my PhD, your guidance throughout has been invaluable.

Thank you to my parents for your at times aggressive support

Lastly, thank you to Aiden, without whom this would never have been possible.

Journal Format Rationale

This thesis has been submitted in Journal format, as agreed with my supervisory team, where all chapters are presented as an independent journal article. This format was chosen as, while the chapters are a complete and combined body of work, they are also stand-alone pieces of research to be submitted to journals for publication.

Introduction

Cognitive Changes in Ageing

Ageing brings about a number of functional changes across many cognitive domains. Cognition describes a number of processes within the brain that allow us to learn, interact and move through our daily lives. Linguistically, this can be seen in slower speech rates, longer pauses, and increased use of filler words in the language domain (Horton et al., 2010). In the executive function domain, this is characterised by reduced ability to shift one's attention, direct purposeful behaviour, and monitor conflict (Wascher et al., 2012; West & Schwarb, 2006). Perhaps most infamously, there are steep declines in memory that impact on the recall of imagery, words, and places (Burke & Mackay, 1997). An individual's cognitive ability supports their capacity to build and maintain social engagement: language is used to communicate, executive function to direct behaviour, and memory to recall names, faces, and previous experiences (Diamond, 2013; Krueger et al., 2009; McHugh Power et al., 2019). Being able to preserve cognitive health becomes increasingly important in preventing social isolation and loneliness in the later years of life (Evans et al., 2019), which can contribute to serious effects on mental and physical health problems during old age, including increasing the risk of depression, sleep disturbances, cardio-vascular disease, diabetes, and stroke (Cacioppo & Cacioppo, 2014; Cacioppo & Hawkley, 2003; Christiansen et al., 2021; Hawton et al., 2011).

The aim of this research is to investigate the relationships between cognition, quantified by behavioural and neurophysiological measures of cognitive ability, and social interaction in later life (while controlling for socioeconomic background). Establishing the interplay between people's social and cognitive lives, and the influence of ageing on these connections, is important if adequate support is to be made available in older age. Developing this understanding will have significant implications for the ways in which we consider maintaining social participation and cognitive health in later life. In this chapter, I review the current understanding of age-related changes across cognitive domains, the association between those changes with social engagement in later life, and the potential impacts of one's socioeconomic status on that relationship. Appropriate methodologies for investigating cognition and the relationships with social interaction will also be reviewed.

Behavioural evidence of cognitive change in ageing

Intuitively, there is a strong connection between language comprehension and language production in the brain, but historically age-related changes in language ability were not believed to be equal between the two systems. The understanding of language has been found to be relatively preserved in normal ageing, whereas language production becomes impaired to some degree (Shafto & Tyler, 2014). There are several ways in which older adults, when compared to younger adults, show reduced language production ability. Many studies have shown that older adults show a higher incidence of tip of the tongue (TOT) word finding difficulties (Evrard, 2002; Juncos-Rabadán et al., 2010). TOT increases particularly when words are uncommon or used infrequently, and older participants generated few persistent alternates, i.e., words that share some features with the target but are not correct (Burke et al., 1991). These word finding failures are commonly associated with limited ability to retrieve phonological information, caused by deterioration in the connection between linguistic components of a given word (Burke & Shafto, 2004b). Older adults also show reduced speed and accuracy in picture and object naming, possibly due to the increased cognitive demand of internal monitoring of planned speech (Belke & Meyer, 2007; Tsang & Lee, 2003). Finally, older adults demonstrate greater dysfluency of speech; that is, reduction in flow and rates of an utterance. This disturbance in fluency is marked by slower speech rates, taking longer pauses during conversational speech and higher dependence on filler words (Horton et al., 2010).

While language production shows significant declines, studies have shown that older adults are still able to identify semantically related words as effectively as their younger counterparts in semantic priming tasks (Burke & Yee, 1984). The semantic priming effect occurs when the target word is more rapidly and accurately identified preceding a semantically related 'prime' word (Davenport & Potter, 2005), which requires lexical comprehension of the priming and target word (Burke & Yee, 1984; Laver & Burke, 1993). While this suggests that older adults perform as well as their younger counterparts in language comprehension tasks, this appears to only be true when task conditions are optimal. Recent evidence that in older participants comprehension of spoken language decreased when the listening conditions became more challenging (Peelle et al., 2010), with similar findings having been observed in reading comprehension tasks with increased distractors (Gao et al., 2012). This suggests that while language comprehension is better preserved during normal ageing, allocation of attentional resources to support comprehension may become more challenging.

Such attentional resources stem from executive functions, which are a collection of cognitive processes that govern a person's actions to direct attention, plan an action, and adapt thoughts and behaviours to achieve goal-directed behaviour (Diamond, 2013a). These processes have also been found to deteriorate over the course of normal ageing; as in the above research in reading and listening comprehension, older adults have shown reduced attentional control when the number of distractors in a task increases (Wascher et al., 2012). Similar findings have been found in working memory tasks, where increased distraction load resulted in a reduction in appropriate attentional allocation in older participants (De Beni & Palladino, 2010). Executive function decline in internal monitoring and working memory manipulation has also been associated with poorer performance in n-back memory tasks (Clarys, Bugaiska, Tapia, & Alexia Baudouin, 2009). Research has also shown that older adults make more preservative errors than younger adults in sorting tasks, which suggests a reduction in self-monitoring for errors, as well as working memory deficits (Zelazo et al., 2004). Combined, this work demonstrates the multifaceted consequences of ageing on executive functions, which in turn can have considerable effects on other cognitive domains.

Neurophysiological changes in ageing

Effects of neurophysiological ageing on Language

The behavioural changes outlined above are underpinned by structural and functional changes in the brain throughout the life-course. Supporting behavioural research, neuroimaging studies have evidenced neurological changes in the brain that are associated with declines in language in later life. Language specific brain regions are typically localised to the left hemisphere, specifically the temporal cortex and surrounding structures (Plante et al., 2015). This includes functions such as sound processing for comprehension of speech in the auditory cortex (Forseth et al., 2020) and visual processing for word recognition in the visual cortex (Cohen et al., 2002). Deficits in speech production in ageing likely occur due to changes in cognitive domains required for the formation and output of speech, such as lexical decisions, and phonological selection (Buchsbaum et al., 2001b; Maril et al., 2001; Zatorre et al., 1996a). Indeed, age-related decline is seen in the hippocampus and lateral prefrontal cortex that impedes working memory and memory consolidation, which in turn make word retrieval and information manipulation increasingly difficult (Wingfield & Grossman, 2006). Research has demonstrated a shift from region specific, task-based neural activation in verbal encoding tasks in younger adults, to simultaneous under-recruitment of brain regions associated with semantic information and generalised activation of frontal brain regions in older adults (Logan et al., 2002). This more widespread, but less dynamic, activation is believed to impede task performance and has been suggested to indicate a decline in neural efficiency in language tasks (Cabeza et al., 2002). Even adults deemed "good" at sentence comprehension showed reduced activation (compared to younger adults) in regions typically associated with language comprehension, but increased activation in regions more associated with working memory load (Grossman et al., 2002). This is indicative of working memory recruitment as a compensatory function in the older brain when linguistic abilities begin to deteriorate in older age (Wingfield and Grossman, 2006).

Degradation of white matter integrity in the left anterior insula and left arcuate fasciculus, brain structures associated phonological processing and production, have been correlated with increased word finding difficulties in normally ageing participants (Shafto et al., 2007; Stamatakis et al., 2011). Older adults' brain activity in successful word finding is generally found to be comparable to that of younger adults, recruiting the anterior cingulate, inferior frontal and insular cortices, all associated with cognitive control and monitoring (Wierenga et al., 2008). When word finding is unsuccessful it appears that these regions are not recruited effectively, suggesting that word finding failures are, in part, due to deterioration of other supporting cognitive features like cognitive control (Shafto & Tyler, 2014).

Effects of neurophysiological ageing on Executive Functions

Due to the fact that executive functions are numerous and multifaceted they are not confined to a narrow brain area, but instead a network of functionally and structurally interlaced regions that rely on interaction to facilitate the processes (Yuan & Raz, 2014b).

Common regions of activation during executive function tasks are predominantly found in the frontal lobe; a meta-analysis investigating regions active during the Wisconsin Card Sorting Test (WCST), which relies on task-switching and response inhibition, showed consistent findings of increased activation in the prefrontal cortex, anterior cingulate cortex, and inferior parietal lobule, with additional recruitment of the ventral prefrontal cortex (Buchsbaum et al., 2005). Further meta-analysis showed that research repeatedly finds that the Stroop task, drawing on conflict monitoring and again on response suppression, elicits an increase in activation in the anterior cingulate and inferior frontal gyrus (Laird et al., 2005). Lesion studies have also demonstrated the importance of frontal regions in executive functions; patients with frontal lesions perform significantly worse on the WCST, tests of verbal fluency and the Stroop test than healthy controls (Alvarez & Emory, 2006). Research has also shown that older adults have different patterns of activation in tasks that put high demands on working memory compared to younger adults, suggesting that, with age comes functional changes that contribute to reduction of executive abilities (Rypma et al., 2001). However, studies of working memory find an extensive network of regions beyond the prefrontal cortex, such as the premotor cortex and posterior parietal cortex (Owen et al., 2005; Yendiki et al., 2010), this suggests that while executive functions draw mainly from frontal cortices, they are a multi-region, brain-wide network.

The changes in executive functions have also been demonstrated using electroencephalography (EEG), which has highlighted age-related electrophysiological changes in regulative control and conflict monitoring (West & Schwarb, 2006). This research showed that older adults had a stronger reliance on frontal processes during tasks that required on-going information processing (regulative control) that younger adults did not and that expected EEG correlates of conflict monitoring, while observed in young participants, were reversed in older adults. This suggests that in ageing as the structure of the brain changes, particularly frontal regions employed in these processes, so do the functional processes, perhaps to compensate for the structural shift. Studies have also shown that the older participants have a reduction of posterior P300 amplitude and delayed latency in auditory and visual odd-ball tasks, (Fjell & Walhovd, 2001; O'Connell et al., 2012). The P300 is implicated in response inhibition in the stop-signal and go-nogo tasks (Huster et al., 2013), successful inhibition of a response is associated with an early peak (Ramautar et al., 2004), as such the differences in older participants P300 may suggest a neurological slowing in inhibition. Odd-ball tasks have also shown ageing effects have also been seen in the N200 component, wherein latencies of the component increase linearly with age (Enoki et al., 1993). The N200 reflects a number of executive functions such as inhibition, conflict monitoring and attentional control (Botvinick et al., 2001; Folstein & Van Petten, 2007; Huster et al., 2013) and increased response pressure has shown increased N200 amplitudes in conditions where participants are required to respond rather than inhibit (Band et al., 2003), participants with high N200 amplitudes made fewer errors (Schmajuk et al., 2006). Similarly, to the ageing effects on the P300, the increased latency in the N200 may reflect a cognitive slowing in ageing.

Overlap of Language and Executive Functions

Cognitive functions rarely exist in isolation; as such, these processes often share overlapping structural and functional features within the brain. As discussed above, the prefrontal and anterior cingulate cortices are both associated with many aspects of language and executive processing, suggesting that these regions support cognitive sub-mechanisms common to both language and executive functions. Language and executive functions are often investigated using tasks that do not clearly differentiate between the two systems, for example verbal fluency tasks where the participant is asked to generate as many words as possible under time constraints, either in a category (often animals) or starting with a certain letter, respectively. Similarly, the Stroop task requires a participant to name the colour of the target stimuli when faced with semantically incongruent information, e.g., the participant should name the colours of the letters of a target word "RED" when the word itself says "GREEN" (Van der Elst et al., 2006). Both of these tests draw from language and executive function as linguistic ability is needed to generate the words and executive ability is needed to facilitate recall, produce the response, monitor past responses, and inhibit incorrect ones (Shao et al., 2014). Working memory is also a vital part of both language and executive functioning. Working memory is needed to facilitate attentional direction and updating in executive processing (Clarys, Bugaiska, Tapia, & Alexia Baudouin, 2009; De Beni & Palladino, 2010); in language, working memory is needed to process incoming information and select appropriate responses (Baddeley, 2003; Baddeley & Hitch, 1974). Overlap between the systems can be observed in the electrophysiological behaviours of the brain, which can be measured using electroencephalography (EEG). We have discussed how both language and executive functions require self-monitoring of behaviours and speech output for mistakes, or error-monitoring. Error monitoring is associated with a distinct negative deflection in EEG signals known as error-related negativity (ERN). The ERN is an event related potential (ERP) observed in brain activity 100ms post-error, it is rapid onset means that it can be observed before the motor response of an error (Gehring et al., 1993)., suggesting errors can be detected internally before awareness in the individual (O'Connell et al., 2007). As self-monitoring becomes more effortful in later life speech and behavioural errors more common (Belke & Meyer, 2007; Birdi et al., 1997; West & Schwarb, 2006); it may be that internal self-regulation represented by the ERN, becomes affected by ageing. A similar component, Correct Response Negativity (CRN), that occurs over a similar time course in correct responses (Imhof & Rüsseler, 2019), response confidence and attentional allocation have been found modulate the amplitude of this ERP (Files et al., 2021; Matsuhashi et al., 2021). However, there is little research characterising age-related changes in either ERN or CRN, if ageing is accompanied by increased errors, one might predict a change in this neurological feature.

Social factors and cognitive changes in later life

Cognition is not the only facet of one's life that changes in later life, social engagement can also be affected by advancing age. Social engagement refers to the amount an individual participates in social groups within their community and broader society. These interactions can be considered in two ways: (1) the structure, meaning the size of the network and (2) the frequency of interaction and the function, which contributes to the feeling of satisfaction and perceived levels of support received through the interaction (Keller-Cohen et al., 2006). There is evidence to support the relationship between both aspects of social interaction and preservation of cognitive ability: a lower risk of cognitive decline is associated with higher levels of social participation, engagement in leisure activities, diversity of social contacts, and greater frequency of contact with friends and family (Bassuk et al., 1999; Fabrigoule et al., 1995; Zunzunegui et al., 2003). Additionally, a study of Swedish adults over 75 years showed that there was an increased risk of dementia in people who were living alone and had no social contact. This risk increase was not observed in those who lived alone but experienced fulfilling social contact, even if it was infrequent (Fratiglioni et al., 2000). Such findings suggest that, while the structural aspect must be present for social interaction to exist, the quality of social interactions should not be overlooked.

It is of great importance to understand the impacts of cognitive health on social engagement in later life because social isolation and increased feelings of loneliness are associated with serious negative physical health outcomes and increased mortality rates similar to those of clinical risk factors (McHugh Power et al., 2019). Social support, having people that can help physically or emotionally during difficult periods of time, is vital for mental and physical health throughout life (Ozbay et al., 2007). Reduced social bonds have been associated with a substantial increased risk of chronic heart disease and stroke (Valtorta et al., 2016), and increased mortality rates in those suffering from heart disease (Murberg & Bru, 2001). Social isolation and lack of social support has also been linked to type two diabetes, with living alone being a particularly strong predictor of type two diabetes diagnosis in older women (Brinkhues et al., 2017). Lower levels of social engagement, particularly poor social support, has been associated with a significantly increased risk of developing dementia in later life, whereas good social engagement was found to somewhat protect against this risk (Fratiglioni et al., 2000). There is also evidence of adverse effects of social isolation on quality of sleep for adults over 60 years old, independent of one's own perception of loneliness (Yu et al., 2018). Research has shown that subjective perceptions of isolation from family and friends is associated with more depressive symptoms (Taylor et al., 2018). Conversely, research indicates that greater instances of social interaction promote and improve quality of life in elderly populations (Datta et al., 2016).

Social isolation, a reduction of contact with social support, can have a serious impact on the physical and mental health of a person, and it is of note that this is still true if the isolation is perceived and not objective (Cacioppo & Hawkley, 2009; Manemann et al., 2018). Longitudinal research has demonstrated that loneliness and social isolation are associated with general measures of cognition (verbal fluency, immediate and delayed recall), which is mediated somewhat by level of educational attainment (Shankar et al., 2013). More specifically, an individual's perception of their degree of isolation (loneliness) has been shown to impact on lifetime change in IQ and cognitive ability (Gow et al., 2007), and is a predictor of dementia in later-life (Wilson et al., 2007). This has been further exemplified using experimental manipulations, where even though there is no real change to the participant's actual level of isolation, the perception of decreased inclusion caused significant change in the participant's cognitive ability (Baumeister et al., 2002; Cacioppo et al., 2006). Additionally, loneliness interacts with executive functions: attentional and emotional regulation have both been found to be impacted by loneliness, as well as decreasing likelihood to engage in physical activity (Cacioppo et al., 2000; Hawkley et al., 2009). Baumeister and colleagues found that increased anticipation of loneliness was detrimental to self-regulatory behaviours and high-level cognition (Baumeister et al., 2005).

Investigation into how socioeconomic factors, such as educational background, occupation, or income, might differentially impact specific cognitive domains remains somewhat sparse. There is research showing a relationship between level of education and executive function ability (St Clair-Thompson & Gathercole, 2006), but much of the research into the interactions between executive function and socioeconomic status (SES) factors focuses largely on early developmental periods. Such research has shown that children from lower SES backgrounds have poorer performance in working memory, inhibition control and attention orienting tasks (Lipina & Posner, 2012; Mezzacappa, 2004). A study using EEG in children showed differences in ERP amplitude in a selective attention task based on maternal educational attainment (Stevens, Lauinger, & Neville, 2009). Behavioural performance was similar in both high- and low-SES groups: the low-SES group showed a greater neural response for the unattended channels, suggesting that high-SES children were better at directing attention to one stimulus over a distractor. Additionally, these executive function differences have also been shown to persist into mid-life (Singh-Manoux et al., 2005; Turrell et al., 2002), but it is not clear how this continues into old age. While this research can be informative for how SES might influence executive function in advancing age, further investigation into these interactions is needed so that we can more fully understand not only the nature of these interactions but the implications they may have for our wellbeing as we age.

Similar evidence for the impact of SES on language largely focuses on early developmental periods with little consideration for the effects of SES throughout the life course. It has been demonstrated that SES influences language ability during childhood and development in that children from more advantaged backgrounds have larger vocabularies (Hart & Risley, 1995). A study using functional magnetic resonance imaging (fMRI) showed positive correlations in activation between brain regions associated with phonological awareness and word recognition in children from low-SES backgrounds, but no such relationship in high-SES (Noble et al., 2006). As with research in SES and executive functions these studies provide evidence of interactions between SES and language, though how this may develop with age remains largely unexplored. This thesis will aim to characterise how this advantage at a younger age translates to ability in later-life and attempt to shed light on the potential protective elements of SES on specific cognitive abilities.

The implications of this research are that our social lives, and how we perceive ourselves in them, are deeply intertwined with our cognitive lives. However, the direction of the nature of the relationship between our two selves is yet to be clearly defined, particularly within the context of ageing. The goal of this research is to not only define the relationships and interactions between all three elements of interest. In particular this research will focus on the influence of age and background on self-monitoring of errors in the brain, an element of cognition that has the potential to link language and executive function. Further to this, this thesis will investigate how such changes in our ability to monitor and regulate our own errors affects perception of loneliness in ageing.

Research of this Thesis

The research presented here used a dual approach to investigate the relationship between cognition and social engagement in older people. Secondary data from a wide scale dataset was used to model interactions between SES, cognition, and social engagement across the adult lifespan, allowing for examination of a large population with several broad measures of cognition and social engagement. Primary data collection then explored such interactions using targeted measures of cognition and neural activity in a smaller sample, allowing for specific manipulation of the elements of interest to better develop understanding of the cognition-social engagement interactions.

The first study of this thesis used data from the first cohort of the Cambridge Centre of Ageing Neuroscience (Cam-CAN) dataset, large, cross-sectional, adult-lifespan, population-representative sample containing a wealth of SES, cognition, and social engagement measures (Shafto, Tyler, Dixon, Taylor, Rowe, et al., 2014). This study used exploratory and confirmatory factor analysis to examine the underlying relationships in the cognitive and social engagement variables, which allowed for accurate characterisation of how cognitive abilities and social connections were represented in the sample. SEM analysis was then used to investigate the relationships between these factors in two age groups. The methodology used in this study allowed for a data driven approach to understanding age-based interactions between the social and cognitive factors. The findings of this initial study stood as a framework for the cognition-social interactions that was probed in subsequent studies in this thesis. Building on the findings of Study 1, Study 2 used specific cognitive measures from the second wave of Cam-CAN dataset. The targeted measures of this study aimed to investigate the discrete facets of cognition that may influence social engagement, which has not been fully teased apart by previous research. SEM was also employed in Study 2 to establish more nuanced connections between the cognitive and social measures to deepen our understanding of these interactions.

Finally, with a theoretical basis established in the previous studies, Study 3 investigated the relationships observed in Study 1 and Study 2 by using specific experimental manipulations of language and executive functions while recording electroencephalography (EEG) and detailed questionnaires probing participants' experiences of social support and isolation. This research aimed to identify associations between these features and perception of social inclusion, not previously been evidenced in the literature.

Methodologies

Factor Analysis and Structural Equation Modelling

This thesis aims to explore complex and intricate interactions between multiple elements of human life, accomplished using a number of methodologies. Factor analysis allows data to be regrouped based on underlying relationships defined by shared variance (Yong & Pearce, 2013). There are two main techniques in factor analysis; exploratory (EFA) and confirmatory (CFA); EFA determines the underlying constructs within a dataset, whereas CFA confirms a priori hypotheses based on representations of variables within factors (Child, 2006). Factor analyses allows for numerous measured, observed variables to be condensed via dimension reduction into fewer latent, unobserved variables (Bartholomew et al., 2011) EFA is useful when the underlying relationships within the data are less clear, or an a priori assumption for the relationship has not been made, allowing for the discovery of influencing factors within the data (Child, 2006). Alternatively, when the structure of the factors linking measures together is known CFA is a more useful tool and can be applied to the dataset to determine whether the hypothesised factor structure is accurate (Streiner, 1994). This restructuring of the variables places measures with shared variance into descriptive categories representative of the underlying constructs within the data (Yong & Pearce, 2013). This is particularly useful when using large datasets, such as the one used in this thesis, as it allows for the assembly of various cognitive and social measures into descriptive factors for further analysis.

Once the constructs within the data have been established, Structural Equation Modelling (SEM) can then be used to ascertain the relationships between the latent variables themselves (Streiner, 2006). SEM combines CFA and path analysis to test multiple potential interrelationships simultaneously, indicating causality be the fit of the model to the data.

In studies 1 and 2 of this thesis, the data was explored using EFA to establish suitable social engagement and cognitive factors based on the measures and data with the Cambridge Centre for Ageing and Neuroscience (Cam-CAN) dataset. This exploration informs CFA to create latent social and cognitive variables used with SEM analysis of both the first and second wave of data collected to investigate the relationships between SES, cognition, and social engagement.

Electrophysiology

Cognitive processes often occur rapidly in the brain, making capture of the neural unpinning of these processes difficult – though possible – with behavioural or fMRI methods. However, using EEG allows for real-time capture of global brain activity that might otherwise be missed. It is a non-invasive method of neuroimaging, with electrodes being placed on the participant's scalp to record electrophysiological activity within the brain.

EEG can measure spontaneous fluctuations in the voltage of the brain's electrical activity (Markand, 2014) such changes in activity are directly related to the ion exchange of neurons which supports the change in potentials of a neuron which allows for between neuron communication (Kandel & Squire, 2000). The electrical exchanges between individual neurons are far too small to be captured by EEG, rather the data collected during EEG represents the summation of synchronous activity of millions of similarly aligned neurons, allowing for detection of a change in field potentials (Teplan, 2002). It is because of this the signal is believed to come from pyramidal cells found in the cortex, as their alignment is suitable to be captured by EEG and they fire synchronously (Teplan, 2002).

Analysis of EEG in the frequency domain can be used to investigate neural oscillations in frequencies from 0-100Hz, which have been identified as a set of coherent bands: delta (1-4Hz), theta (4-8Hz), alpha (8-12Hz), beta (13-30Hz),) and gamma (>30Hz) which are associated with a number of cognitive states and changes (Markand, 2014). Analysis of EEG signals in the time domain can also be used to characterise event related potentials (ERPs): distinct positive and negative voltage changes in electrophysiological behaviour in response to an event or presentation of stimuli (Luck, 2005). These EEG analysis techniques can be used to determine age-related functional changes within the brain, and as such the third study of this thesis will use these techniques to investigate language and executive function processing in the brain, and the relationship of the brain activity to social engagement in participants.

Hypothesis

The overarching hypothesis of this thesis is that older people will be significantly different in their cognitive performance compared to the younger participants, with cognition mediating the relationship between social background and social engagement. I predict that in all studies older people will show a greater reliance on cognitive abilities to support and facilitate social engagement and interaction than their younger counterparts. In Study 1 and Study 2 this will be exemplified by a greater number of mediating relationships between measures of cognition and social engagement, and in Study 3 the neurological responses of the older participants will have greater correlations with social inclusion measures.

Finally, specific to the Study 3, I predict that older adults will show differences in the amplitude and latency of the electrophysiological measurements of cognition, compared to the young adult group, with these differences being associated with performance in the cognitive tasks and feelings of social inclusion.

Aims and Objectives

The aim of my thesis was to investigate the relationships between socioeconomic background, language and executive function, and social interaction in later life using the range of analytic methodologies and data types discussed above.

Study 1 aimed to characterise the age-related differences in connections between cognitive and social measures, using broad definitions of cognition to establish the structure of these relationships and create a framework that subsequent studies could advance upon. The relationships established in this study were the framework for the subsequent studies of this thesis.

The aim of Study 2 was to use more targeted measures of cognition to replicate and extend the findings of the first study. This research demonstrated how specific measures of cognition were able to reveal more nuanced relationships between cognition and social measures, identifying intricate pathways between specific domains of cognition and social engagement in older participants.

Finally, Study 3 aimed to build further on the findings of Study 1 and Study 2 by using electrophysiological markers of cognition and questionnaires targeting social isolation and inclusion. In this study I demonstrated a neural underpinning of age-related differences in cognition, particularly in executive functions, which would be undetectable from behavioural measures alone.

The combined findings from these studies have significant implications for the ways in which we consider maintaining social participation and cognitive health in later life. Based on the findings of this thesis, future work should focus on the relationship between executive functions and social engagement in older adults to develop interventions that target these domains, which can then support continuous social connections in our later years.

References

Alvarez, J. A., & Emory, E. (2006). Executive function and the frontal lobes: A meta-analytic review. In *Neuropsychology Review* (Vol. 16, Issue 1, pp. 17–42). https://doi.org/10.1007/s11065-006-9002-x

Baddeley, A. (2003). Working memory and language: an overview. *Journal of Communication Disorders*, *36*(3), 189–208. https://doi.org/10.1016/S0021-9924(03)00019-4

Baddeley, A. D., & Hitch, G. (1974). Working Memory. *Psychology of Learning and Motivation - Advances in Research and Theory*, *8*(C), 47–89. https://doi.org/10.1016/S0079-7421(08)60452-1

Band, G. P. H., Ridderinkhof, K. R., & van der Molen, M. W. (2003). Speed-accuracy modulation in case of conflict: the roles of activation and inhibition. *Psychological Research*, *67*(4), 266–279. https://doi.org/10.1007/s00426-002-0127-0

Bartholomew, D., Knott, M., & Moustaki, I. (2011). *Latent Variable Models and Factor Analysis*. Wiley. https://doi.org/10.1002/9781119970583

Bassuk, S. S., Glass, T. A., & Berkman, L. F. (1999). Social Disengagement and Incident Cognitive Decline in Community-Dwelling Elderly Persons. *Annals of Internal Medicine*, *131*(3), 165. https://doi.org/10.7326/0003-4819-131-3-199908030-00002

Baumeister, R. F., Nathan Dewall, C., Ciarocco, N. J., & Twenge, J. M. (2005). Social exclusion impairs self-regulation. *Journal of Personality and Social Psychology*, *88*(4), 589–604. https://doi.org/10.1037/0022-3514.88.4.589

Baumeister, R. F., Twenge, J. M., & Nuss, C. K. (2002). Effects of social exclusion on cognitive processes: Anticipated aloneness reduces intelligent thought. *Journal of Personality and Social Psychology*, *83*(4), 817–827. https://doi.org/10.1037/0022-3514.83.4.817

Belke, E., & Meyer, A. S. (2007). Single and multiple object naming in healthy ageing. *Language and Cognitive Processes*, *22*(8), 1178–1211. https://doi.org/10.1080/01690960701461541

Birdi, K., Pennington, J., & Zapf, D. (1997). Ageing and errors in computer-based work: An observational field study. *Journal of Occupational and Organizational Psychology*, *70*(1), 35–47. https://doi.org/10.1111/j.2044-8325.1997.tb00629.x

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review*, *108*(3), 624–652. http://www.ncbi.nlm.nih.gov/pubmed/11488380

Brinkhues, S., Dukers-Muijrers, N. H. T. M., Hoebe, C. J. P. A., Van Der Kallen, C. J. H., Dagnelie, P. C., Koster, A., Henry, R. M. A., Sep, S. J. S., Schaper, N. C., Stehouwer, C. D. A., Bosma, H., Savelkoul, P. H. M., & Schram, M. T. (2017). Socially isolated individuals are more prone to have newly diagnosed and prevalent type 2 diabetes mellitus - the Maastricht study. *BMC Public Health*, *17*(1). https://doi.org/10.1186/S12889-017-4948-6

Buchsbaum, B. R., Greer, S., Chang, W. L., & Berman, K. F. (2005). Meta-analysis of neuroimaging studies of the Wisconsin Card-Sorting Task and component processes. *Human Brain Mapping*, *25*(1), 35–45. https://doi.org/10.1002/hbm.20128

Buchsbaum, B. R., Hickok, G., & Humphries, C. (2001). Role of left posterior superior temporal gyrus in phonological processing for speech perception and production. *Cognitive Science*, *25*(5), 663–678. https://doi.org/10.1207/S15516709COG2505_2

Burke, D. M., & Mackay, D. G. (1997). Memory, language, and ageing. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences*, *352*(1363), 1845–1856. https://doi.org/10.1098/rstb.1997.0170

Burke, D. M., MacKay, D. G., Worthley, J. S., & Wade, E. (1991). On the tip of the tongue: What causes word finding failures in young and older adults? *Journal of Memory and Language*, *30*(5), 542–579. https://doi.org/10.1016/0749-596X(91)90026-G

Burke, D. M., & Shafto, M. A. (2004). Aging and Language Production. *Current Directions in Psychological Science*, *13*(1), 21–24. https://doi.org/10.1111/j.0963-7214.2004.01301006.x

Burke, D. M., & Yee, P. L. (1984). Semantic priming during sentence processing by young and older adults. *Developmental Psychology*, *20*(5), 903–910. https://doi.org/10.1037/0012-1649.20.5.903

Cabeza, R., Anderson, N. D., Locantore, J. K., & McIntosh, A. R. (2002). Aging gracefully: Compensatory brain activity in high-performing older adults. *NeuroImage*, *17*(3), 1394–1402. https://doi.org/10.1006/NIMG.2002.1280

Cacioppo, J. T., & Cacioppo, S. (2014). Social Relationships and Health: The Toxic Effects of Perceived Social Isolation. *Social and Personality Psychology Compass*, *8*(2), 58–72. https://doi.org/10.1111/spc3.12087

Cacioppo, J. T., Ernst, J. M., Burleson, M. H., McClintock, M. K., Malarkey, W. B., Hawkley, L. C., Kowalewski, R. B., Paulsen, A., Hobson, J. A., Hugdahl, K., Spiegel, D., & Berntson, G. G. (2000). Lonely traits and concomitant physiological processes: The MacArthur social neuroscience studies. *International Journal of Psychophysiology*, *35*(2–3), 143–154. https://doi.org/10.1016/S0167-8760(99)00049-5

Cacioppo, J. T., & Hawkley, L. C. (2003). Social isolation and health, with an emphasis on underlying mechanisms. *Perspectives in Biology and Medicine*, *46*(3 SUPPL.), 39–52. https://doi.org/10.1353/pbm.2003.0063

Cacioppo, J. T., & Hawkley, L. C. (2009). Perceived social isolation and cognition. *Trends in Cognitive Sciences*, *13*(10), 447–454. https://doi.org/10.1016/J.TICS.2009.06.005

Cacioppo, J. T., Hawkley, L. C., Ernst, J. M., Burleson, M., Berntson, G. G., Nouriani, B., & Spiegel, D. (2006). Loneliness within a nomological net: An evolutionary perspective. *Journal of Research in Personality*, *40*(6), 1054–1085. https://doi.org/10.1016/j.jrp.2005.11.007

Child, D. T. (2006). *The Essentials of Factor Analysis* (Third).

Christiansen, J., Lund, R., Qualter, P., Andersen, C. M., Pedersen, S. S., & Lasgaard, M. (2021). Loneliness, Social Isolation, and Chronic Disease Outcomes. *Annals of Behavioral Medicine*, *55*(3), 203–215. https://doi.org/10.1093/abm/kaaa044

Clarys, D., Bugaiska, A., Tapia, G., & Alexia Baudouin, and. (2009). Ageing, remembering, and executive function. *Memory*, *17*(2), 158–168. https://doi.org/10.1080/09658210802188301

Cohen, L., Lehéricy, S., Chochon, F., Lemer, C., Rivaud, S., & Dehaene, S. (2002). Language-specific tuning of visual cortex? Functional properties of the Visual Word Form Area. *Brain*, *125*(5), 1054–1069. https://doi.org/10.1093/brain/awf094

Datta, D., Majumdar, K. K., & Pratim Datta, P. (2016). *ROLE OF SOCIAL INTERACTION ON QUALITY OF LIFE NATIONAL JOURNAL OF MEDICAL RESEARCH ROLE OF SOCIAL INTERACTION ON QUALITY OF LIFE*. https://www.researchgate.net/publication/317105953

Davenport, J. L., & Potter, M. C. (2005). The locus of semantic priming in RSVP target search. *Memory and Cognition*, *33*(2), 241–248. https://doi.org/10.3758/BF03195313/METRICS

De Beni, R., & Palladino, P. (2010). Decline in working memory updating through ageing: Intrusion error analyses. *Http://Dx.Doi.Org/10.1080/09658210244000568*, *12*(1), 75–89. https://doi.org/10.1080/09658210244000568

Diamond, A. (2013). Executive functions. *Annual Review of Psychology*, *64*, 135–168. https://doi.org/10.1146/annurev-psych-113011-143750

Enoki, H., Sanada, S., Yoshinaga, H., Oka, E., & Ohtahara, S. (1993). The effects of age on the N200 component of the auditory event-related potentials. *Cognitive Brain Research*, *1*(3), 161–167. https://doi.org/10.1016/0926-6410(93)90023-X

Evans, I. E. M., Llewellyn, D. J., Matthews, F. E., Woods, R. T., Brayne, C., Clare, L., Clarra, L., Windle, G., Burholt, V., Philips, J., McCracken, C., & Bennett, K. (2019). Social isolation, cognitive reserve, and cognition in healthy older people. *PLoS ONE*, *13*(8), e0201008. https://doi.org/10.1371/journal.pone.0201008

Evrard, M. (2002). Ageing and Lexical Access to Common and Proper Names in Picture Naming. *Brain and Language*, *81*(1–3), 174–179. https://doi.org/10.1006/BRLN.2001.2515

Fabrigoule, C., Letenneur, L., Dartigues, J. F., Zarrouk, M., Commenges, D., & Barberger-Gateau, P. (1995). Social and leisure activities and risk of dementia: a prospective longitudinal study. *Journal of the American Geriatrics Society*, *43*(5), 485–490. http://www.ncbi.nlm.nih.gov/pubmed/7730528

Files, B. T., Pollard, K. A., Oiknine, A. H., Khooshabeh, P., & Passaro, A. D. (2021). Correct response negativity may reflect subjective value of reaction time under regulatory fit in a speed-rewarded task. *Psychophysiology*, *58*(9). https://doi.org/10.1111/PSYP.13856

Fjell, A. M., & Walhovd, K. B. (2001). P300 and neuropsychological tests as measures of aging: Scalp topography and cognitive changes. *Brain Topography*, *14*(1), 25–40. https://doi.org/10.1023/A:1012563605837/METRICS

Folstein, J. R., & Van Petten, C. (2007). Influence of cognitive control and mismatch on the N2 component of the ERP: A review. *Psychophysiology*, *0*(0), 070915195953001-??? https://doi.org/10.1111/j.1469-8986.2007.00602.x

Forseth, K. J., Hickok, G., Rollo, P. S., & Tandon, N. (2020). Language prediction mechanisms in human auditory cortex. *Nature Communications*, *11*(1), 5240. https://doi.org/10.1038/s41467-020-19010-6

Fratiglioni, L., Wang, H.-X., Ericsson, K., Maytan, M., & Winblad, B. (2000). Influence of social network on occurrence of dementia: a community-based longitudinal study. *The Lancet*, *355*(9212), 1315–1319. https://doi.org/10.1016/S0140-6736(00)02113-9

Gao, X., Levinthal, B. R., & Stine-Morrow, E. A. L. (2012). The Effects of Ageing and Visual Noise on Conceptual Integration during Sentence Reading. *Quarterly Journal of Experimental Psychology*, *65*(9), 1833–1847. https://doi.org/10.1080/17470218.2012.674146

Gehring, W. J., Goss, B., Coles, M. G. H., Meyer, D. E., & Donchin, E. (1993). A Neural System for Error Detection and Compensation. *Psychological Science*, *4*(6), 385–390. https://doi.org/10.1111/j.1467-9280.1993.tb00586.x

Gow, A. J., Pattie, A., Whiteman, M. C., Whalley, L. J., & Deary, I. J. (2007). Social support and successful aging: Investigating the relationships between lifetime cognitive change and life satisfaction. *Journal of Individual Differences*, *28*(3), 103–115. https://doi.org/10.1027/1614-0001.28.3.103

Grossman, M., Cooke, A., DeVita, C., Alsop, D., Detre, J., Chen, W., & Gee, J. (2002). Age-related changes in working memory during sentence comprehension: An fMRI study. *NeuroImage*, *15*(2), 302–317. https://doi.org/10.1006/NIMG.2001.0971

Hart, B., & Risley, T. R. (1995). *Meaningful differences in the everyday experience of young American children. - PsycNET*.

Hawkley, L. C., Thisted, R. A., & Cacioppo, J. T. (2009). Loneliness Predicts Reduced Physical Activity: Cross-Sectional & Longitudinal Analyses. *Health Psychology*, *28*(3), 354–363. https://doi.org/10.1037/a0014400

Hawton, A., Green, C., Dickens, A. P., Richards, S. H., Taylor, R. S., Edwards, R., Greaves, C. J., & Campbell, J. L. (2011). The impact of social isolation on the health status and health-related quality of life of older people. *Quality of Life Research*, *20*(1), 57–67. https://doi.org/10.1007/s11136-010-9717-2

Horton, W. S., Spieler, D. H., & Shriberg, E. (2010). A Corpus Analysis of Patterns of Age-Related Change in Conversational Speech. *Psychology and Aging*, *25*(3), 708. https://doi.org/10.1037/A0019424

Huster, R. J., Enriquez-Geppert, S., Lavallee, C. F., Falkenstein, M., & Herrmann, C. S. (2013). Electroencephalography of response inhibition tasks: Functional networks and cognitive contributions. *International Journal of Psychophysiology*, *87*(3), 217–233. https://doi.org/10.1016/j.ijpsycho.2012.08.001

Imhof, M. F., & Rüsseler, J. (2019). Performance Monitoring and Correct Response Significance in Conscientious Individuals. *Frontiers in Human Neuroscience*, *13*. https://doi.org/10.3389/fnhum.2019.00239

Juncos-Rabadán, O., Facal, D., Rodríguez, M. S., & Pereiro, A. X. (2010). Lexical knowledge and lexical retrieval in ageing: Insights from a tip-of-the-tongue (TOT) study. *Language and Cognitive Processes*, *25*(10), 1301–1334. https://doi.org/10.1080/01690961003589484

Kandel, E. R., & Squire, L. R. (2000). Neuroscience: Breaking down scientific barriers to the study of brain and mind. In *Science* (Vol. 290, Issue 5494, pp. 1113–1120). https://doi.org/10.1126/science.290.5494.1113

Keller-Cohen, D., Fiori, K., Toler, A., & Bybee, D. (2006). Social relations, language and cognition in the 'oldest old.' *Ageing and Society*, *26*(4), 585–605. https://doi.org/10.1017/S0144686X06004910

Krueger, K. R., Wilson, R. S., Kamenetsky, J. M., Barnes, L. L., Bienias, J. L., & Bennett, D. A. (2009). Social engagement and cognitive function in old age. *Experimental Aging Research*, *35*(1), 45–60. https://doi.org/10.1080/03610730802545028

Laird, A. R., McMillan, K. M., Lancaster, J. L., Kochunov, P., Turkeltaub, P. E., Pardo, J. V., & Fox, P. T. (2005). A comparison of label-based review and ALE meta-analysis in the stroop task. *Human Brain Mapping*, *25*(1), 6–21. https://doi.org/10.1002/hbm.20129

Laver, G. D., & Burke, D. M. (1993). Why do semantic priming effects increase in old age? A meta-analysis. *Psychology and Aging*, *8*(1), 34–43. http://www.ncbi.nlm.nih.gov/pubmed/8461113

Lipina, S. J., & Posner, M. I. (2012). The impact of poverty on the development of brain networks. *Frontiers in Human Neuroscience*, *6*, 238. https://doi.org/10.3389/fnhum.2012.00238

Logan, J. M., Sanders, A. L., Snyder, A. Z., Morris, J. C., & Buckner, R. L. (2002). Under-Recruitment and Nonselective Recruitment: Dissociable Neural Mechanisms Associated with Aging. *Neuron*, *33*(5), 827–840. https://doi.org/10.1016/S0896-6273(02)00612-8

Luck, S. J. (2005). *An Introduction to the Event-Related Potential Technique, Second Edition | The MIT Press*. The MIT Press. https://mitpress.mit.edu/books/introduction-event-related-potential-technique-second-edition

Manemann, S. M., Chamberlain, A. M., Roger, V. L., Griffin, J. M., Boyd, C. M., Cudjoe, T. K. M., Jensen, D., Weston, S. A., Fabbri, M., Jiang, R., & Finney Rutten, L. J. (2018). Perceived Social Isolation and Outcomes in Patients With Heart Failure. *Journal of the American Heart Association*, *7*(11). https://doi.org/10.1161/JAHA.117.008069

Maril, A., Wagner, A. D., & Schacter, D. L. (2001). On the tip of the tongue: An event-related fMRI study of semantic retrieval failure and cognitive conflict. *Neuron*, *31*(4), 653–660. https://doi.org/10.1016/S0896-6273(01)00396-8

Markand, O. N. (2014). Electroencephalogram (EEG). In *Encyclopedia of the Neurological Sciences* (pp. 1084–1091). Elsevier Inc. https://doi.org/10.1016/B978-0-12-385157-4.00523-6

Matsuhashi, T., Segalowitz, S. J., Murphy, T. I., Nagano, Y., Hirao, T., & Masaki, H. (2021). Medial frontal negativities predict performance improvements during motor sequence but not motor adaptation learning. *Psychophysiology*, *58*(1), e13708. https://doi.org/10.1111/PSYP.13708

McHugh Power, J. E., Steptoe, A., Kee, F., & Lawlor, B. A. (2019). Loneliness and social engagement in older adults: A bivariate dual change score Analysis. *Psychology and Aging*, *34*(1), 152–162. https://doi.org/10.1037/pag0000287

Mezzacappa, E. (2004). Alerting, Orienting, and Executive Attention: Developmental Properties and Sociodemographic Correlates in an Epidemiological Sample of Young, Urban Children. *Child Development*, *75*(5), 1373–1386. https://doi.org/10.1111/j.1467-8624.2004.00746.x

Murberg, T. A., & Bru, E. (2001). Social relationships and mortality in patients with congestive heart failure. *Journal of Psychosomatic Research*, *51*(3), 521–527. https://doi.org/10.1016/S0022-3999(01)00226-4

Noble, K. G., Wolmetz, M. E., Ochs, L. G., Farah, M. J., & McCandliss, B. D. (2006). Brain behavior relationships in reading acquisition are modulated by socioeconomic factors. *Developmental Science*, *9*(6), 642–654. https://doi.org/10.1111/j.1467-7687.2006.00542.x

O'Connell, R. G., Balsters, J. H., Kilcullen, S. M., Campbell, W., Bokde, A. W., Lai, R., Upton, N., & Robertson, I. H. (2012). A simultaneous ERP/fMRI investigation of the P300 aging effect. *Neurobiology of Aging*, *33*(10), 2448–2461. https://doi.org/10.1016/J.NEUROBIOLAGING.2011.12.021

O'Connell, R. G., Dockree, P. M., Bellgrove, M. A., Kelly, S. P., Hester, R., Garavan, H., Robertson, I. H., & Foxe, J. J. (2007). The role of cingulate cortex in the detection of errors with and without awareness: a high-density electrical mapping study. *European Journal of Neuroscience*, *25*(8), 2571–2579. https://doi.org/10.1111/j.1460-9568.2007.05477.x

Owen, A. M., McMillan, K. M., Laird, A. R., & Bullmore, E. (2005). N-back working memory paradigm: A meta-analysis of normative functional neuroimaging studies. *Human Brain Mapping*, *25*(1), 46–59. https://doi.org/10.1002/hbm.20131

Peelle, J. E., Troiani, V., Wingfield, A., & Grossman, M. (2010). Neural Processing during Older Adults' Comprehension of Spoken Sentences: Age Differences in Resource Allocation and Connectivity. *Cerebral Cortex*, *20*(4), 773–782. https://doi.org/10.1093/cercor/bhp142

Plante, E., Almryde, K., Patterson, D. K., Vance, C. J., & Asbjørnsen, A. E. (2015). Language lateralization shifts with learning by adults. *Laterality: Asymmetries of Body, Brain and Cognition*, *20*(3), 306–325. https://doi.org/10.1080/1357650X.2014.963597

Ramautar, J. R., Kok, A., & Ridderinkhof, K. R. (2004). Effects of stop-signal probability in the stop-signal paradigm: The N2/P3 complex further validated. *Brain and Cognition*, *56*(2), 234–252. https://doi.org/10.1016/j.bandc.2004.07.002

Rypma, B., Prabhakaran, V., Desmond, J. E., & Gabrieli, J. D. (2001). Age differences in prefrontal cortical activity in working memory. *Psychology and Aging*, *16*(3), 371–384.

Schmajuk, M., Liotti, M., Busse, L., & Woldorff, M. G. (2006). Electrophysiological activity underlying inhibitory control processes in normal adults. *Neuropsychologia*, *44*(3), 384–395. https://doi.org/10.1016/J.NEUROPSYCHOLOGIA.2005.06.005

Shafto, M. A., Burke, D. M., Stamatakis, E. A., Tam, P. P., & Tyler, L. K. (2007). On the tip-of-the-tongue: Neural correlates of increased word-finding failures in normal aging. *Journal of Cognitive Neuroscience*, *19*(12), 2060–2070. https://doi.org/10.1162/jocn.2007.19.12.2060

Shafto, M. A., & Tyler, L. K. (2014). Language in the aging brain: The network dynamics of cognitive decline and preservation. *Science*, *346*(6209), 583–587. https://doi.org/10.1126/SCIENCE.1254404/ASSET/42E30CF7-110E-4D95-AFAC-DBB4B0C29E6B/ASSETS/GRAPHIC/346_583_F1.JPEG

Shafto, M. A., Tyler, L. K., Dixon, M., Taylor, J. R., Rowe, J. B., Cusack, R., Calder, A. J., Marslen-Wilson, W. D., Duncan, J., Dalgleish, T., Henson, R. N., Brayne, C., & Matthews, F. E. (2014). The Cambridge Centre for Ageing and Neuroscience (Cam-CAN) study protocol: a cross-sectional, lifespan, multidisciplinary examination of healthy cognitive ageing. *BMC Neurology*, *14*(1), 204. https://doi.org/10.1186/s12883-014-0204-1

Shankar, Aparna .;, Hamer, Mark. ;, McMunn, Anne. ;, And, & Steptoe, Andrew. (2013). Social Isolation and Loneliness: Relationships With Cognitive Function. *Encyclopedia of Mental Health*, *75*, 161–170. https://doi.org/10.1016/B978-0-12-397045-9.00118-X

Shao, Z., Janse, E., Visser, K., & Meyer, A. S. (2014). What do verbal fluency tasks measure? Predictors of verbal fluency performance in older adults. *Frontiers in Psychology*, *5*, 772. https://doi.org/10.3389/fpsyg.2014.00772

Singh-Manoux, A., Marmot, M. G., & Adler, N. E. (2005). Does Subjective Social Status Predict Health and Change in Health Status Better Than Objective Status? *Psychosomatic Medicine*, *67*(6), 855–861. https://doi.org/10.1097/01.psy.0000188434.52941.a0

St Clair-Thompson, H. L., & Gathercole, S. E. (2006). Executive functions and achievements in school: Shifting, updating, inhibition, and working memory. *Quarterly Journal of Experimental Psychology*, *59*(4), 745–759. https://doi.org/10.1080/17470210500162854

Stamatakis, E. A., Shafto, M. A., Williams, G., Tam, P., & Tyler, L. K. (2011). White Matter Changes and Word Finding Failures with Increasing Age. *PLOS ONE*, *6*(1), e14496. https://doi.org/10.1371/JOURNAL.PONE.0014496

Stevens, C., Lauinger, B., & Neville, H. (2009). Differences in the neural mechanisms of selective attention in children from different socioeconomic backgrounds: an event-related brain potential study. *Developmental Science*, *12*(4), 634–646. https://doi.org/10.1111/j.1467-7687.2009.00807.x

Streiner, D. L. (1994). Figuring Out Factors: The Use and Misuse of Factor Analysis. *The Canadian Journal of Psychiatry*, *39*(3), 135–140. https://doi.org/10.1177/070674379403900303

Streiner, D. L. (2006). Building a Better Model: An Introduction to Structural Equation Modelling. *The Canadian Journal of Psychiatry*, *51*(5), 317–324. https://doi.org/10.1177/070674370605100507

Taylor, H. O., Taylor, R. J., Nguyen, A. W., & Chatters, L. (2018). Social Isolation, Depression, and Psychological Distress Among Older Adults. *Journal of Aging and Health*, *30*(2), 229–246. https://doi.org/10.1177/0898264316673511

Teplan, M. (2002). Fundamentals of EEG Measurement. In *MEASUREMENT SCIENCE REVIEW* (Vol. 2, Issue 2).

Tsang, H.-L., & Lee, T. M. C. (2003). The effect of ageing on confrontational naming ability. *Archives of Clinical Neuropsychology*, *18*(1), 81–89. https://doi.org/10.1093/arclin/18.1.81

Turrell, G., Lynch, J. W., Kaplan, G. A., Everson, S. A., Helkala, E.-L., Kauhanen, J., & Salonen, J. T. (2002). Socioeconomic Position Across the Lifecourse and Cognitive Function in Late Middle Age. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *57*(1), S43–S51. https://doi.org/10.1093/geronb/57.1.S43

Valtorta, N. K., Kanaan, M., Gilbody, S., Ronzi, S., & Hanratty, B. (2016). Loneliness and social isolation as risk factors for coronary heart disease and stroke: systematic review and meta-analysis of longitudinal observational studies. *Heart*, *102*(13), 1009–1016. https://doi.org/10.1136/HEARTJNL-2015-308790

Van der Elst, W., Van Boxtel, M. P. J., Van Breukelen, G. J. P., & Jolles, J. (2006). The Stroop Color-Word Test. *Assessment*, *13*(1), 62–79. https://doi.org/10.1177/1073191105283427

Wascher, E., Schneider, D., Hoffmann, S., Beste, C., & Sänger, J. (2012). When compensation fails: Attentional deficits in healthy ageing caused by visual distraction. *Neuropsychologia*, *50*(14), 3185–3192. https://doi.org/10.1016/J.NEUROPSYCHOLOGIA.2012.09.033

West, R., & Schwarb, H. (2006). The influence of aging and frontal function on the neural correlates of regulative and evaluative aspects of cognitive control. *Neuropsychology*, *20*(4), 468–481. https://doi.org/10.1037/0894-4105.20.4.468

Wierenga, C. E., Benjamin, M., Gopinath, K., Perlstein, W. M., Leonard, C. M., Rothi, L. J. G., Conway, T., Cato, M. A., Briggs, R., & Crosson, B. (2008). Age-related changes in word retrieval: Role of bilateral frontal and subcortical networks. *Neurobiology of Aging*, *29*(3), 436–451. https://doi.org/10.1016/J.NEUROBIOLAGING.2006.10.024

Wilson, R. S., Krueger, K. R., Arnold, S. E., Schneider, J. A., Kelly, J. F., Barnes, L. L., Tang, Y., & Bennett, D. A. (2007). Loneliness and risk of Alzheimer disease. *Archives of General Psychiatry*, *64*(2), 234–240. https://doi.org/10.1001/archpsyc.64.2.234

Wingfield, A., & Grossman, M. (2006). Language and the Aging Brain: Patterns of Neural Compensation Revealed by Functional Brain Imaging. *Journal of Neurophysiology*, *96*(6), 2830–2839. https://doi.org/10.1152/jn.00628.2006

Yendiki, A., Greve, D. N., Wallace, S., Vangel, M., Bockholt, J., Mueller, B. A., Magnotta, V., Andreasen, N., Manoach, D. S., & Gollub, R. L. (2010). Multi-site characterization of an fMRI working memory paradigm: Reliability of activation indices. *NeuroImage*, *53*(1), 119–131. https://doi.org/10.1016/j.neuroimage.2010.02.084

Yong, A. G., & Pearce, S. (2013). A Beginner's Guide to Factor Analysis: Focusing on Exploratory Factor Analysis. *Tutorials in Quantitative Methods for Psychology*, *9*(2), 79–94. https://doi.org/10.20982/tqmp.09.2.p079

Yu, B., Steptoe, A., Niu, K., Ku, P.-W., & Chen, L.-J. (2018). Prospective associations of social isolation and loneliness with poor sleep quality in older adults. *Quality of Life Research*, *27*(3), 683–691. https://doi.org/10.1007/s11136-017-1752-9

Yuan, P., & Raz, N. (2014). Prefrontal cortex and executive functions in healthy adults: A meta-analysis of structural neuroimaging studies. *Neuroscience & Biobehavioral Reviews*, *42*, 180–192. https://doi.org/10.1016/J.NEUBIOREV.2014.02.005

Zatorre, R. J., Meyer, E., Gjedde, A., & Evans, A. C. (1996). PET Studies of Phonetic Processing of Speech: Review, Replication, and Reanalysis. *Cerebral Cortex*, *6*(1), 21–30. https://doi.org/10.1093/CERCOR/6.1.21

Zelazo, P. D., Craik, F. I. M., & Booth, L. (2004). Executive function across the life span. *Acta Psychologica*, *115*(2–3), 167–183. https://doi.org/10.1016/j.actpsy.2003.12.005

Zunzunegui, M.-V., Alvarado, B. E., Del Ser, T., & Otero, A. (2003). Social networks, social integration, and social engagement determine cognitive decline in community-dwelling Spanish older adults. *The Journals of Gerontology. Series B, Psychological Sciences and Social Sciences*, *58*(2), S93–S100. https://doi.org/10.1093/geronb/58.2.s93

Cognitive Mediation of Social Engagement and Socioeconomic Background: SEM Exploration in Cam-CAN, a Large Adult Lifespan Database

Josephine Kearney (University of Manchester), Pamela Qualter (University of Manchester), Cam-CAN (University of Cambridge), Jason R Taylor (University of Manchester).

Abstract

Ageing is associated with declines in cognition, which presents challenges for maintaining social connections. In the current study, we explored the associations between domains of cognition, social engagement, and socioeconomic status (SES), separately for younger and older adults. Data from the Cambridge Centre for Ageing and Neuroscience (Cam-CAN) were analysed using exploratory and confirmatory factor analysis, and structural equation modelling (SEM). Factor analyses showed that the older participant group (aged 50 years or older) had differential separation of the cognitive domains and greater complexity in associations between SES and cognition. Additionally, social engagement was reflected differently between the two groups: the factors in the Under 50 group related to *who* was being communicated with (family vs. friends); factors in the Over 50 group reflected *how* communication took place (synchronously vs asynchronously). The SEM analyses indicated that language and memory were important mediators between SES and social engagement in older adults. Younger participants (aged under 50 years) showed separate direct associations between SES and cognition and between SES and social engagement, suggesting that higher SES separately accounts for the variability in cognitive ability and social involvement. These findings demonstrate that with greater age comes increased complexity between cognition and social interactions, and a reliance on specific cognitive faculties to support and maintain social engagement. It also demonstrates the need for age-based interventions when combating issues surrounding loneliness and social isolation, including support of cognitive development throughout early adulthood and maintenance of cognitive ability in later life.

Introduction

An individual's cognitive ability supports their capacity to build and maintain social engagement: language is used to communicate, executive function to direct behaviour, and memory to recall names, faces, and previous experiences (Diamond, 2013; Krueger et al., 2009; McHugh Power, Steptoe, Kee, and Lawlor, 2019). Being able to preserve cognitive health becomes increasingly important in preventing social isolation and loneliness in the later years of life (Evans et al., 2019). However, extant empirical evidence offers little specificity regarding the cognitive domains, as such we currently do not know which aspects of cognitive function are important for maintaining social interaction and connection throughout life. Research looking at the interaction between cognitive ability and social participation commonly focuses on a general conceptualisation of cognition (e.g., Borgeest, Henson, Shafto, Samu, and Kievit, 2020; Holtzman et al., 2004). The current research, instead, focuses on two cognitive components likely to be the most important for formation and preservation of social bonds. Specifically, we explore the ability to produce and understand language, which is intuitively part of social connection, and facets of memory function that are intrinsic to daily living. Thus, the current research examines the relationships between distinct aspects of cognition and social engagement among adults of different ages, and the influences of these cognitive domains on the relationship between socioeconomic status and social interaction.

Humans enjoy interacting and communicating with other humans, and when opportunities for social interaction are taken away from us, we often feel uncomfortable and experience negative emotional responses (Qualter et al., 2015). Language and the ability to communicate are fundamental in supporting those social communications. However, ageing is known to cause language-based cognitive difficulties that make social interaction more difficult for individuals as they move into old age. For example, older adults show a greater incidence of tip-of-tongue (ToT) word finding problems, where the desired word may feel just out of memory's reach, particularly for uncommon or infrequent words (Burke, MacKay, Worthley, and Wade, 1991; Evrard, 2002; Juncos-Rabadán, Facal, Rodríguez, and Pereiro, 2010); significant decreases in picture and object naming speed and accuracy (Belke and Meyer, 2007; Tsang and Lee, 2003); and slowing of speech such that they take longer conversational pauses and show a greater dependence on filler words (Horton, Spieler, and Shriberg, 2010). There is significant atrophy of brain structures throughout the ageing process, including pre-frontal, temporal, and cingulate cortices (Fjell et al., 2009), which support error detection in language production and phonological processing for comprehension (Buchsbaum, Hickok, and Humphries, 2001; Maril, Wagner, and Schacter, 2001; Zatorre, Meyer, Gjedde, and Evans, 1996). This ultimately means social communication is likely to become more difficult over the course of healthy ageing.

Social communication relies strongly on one's working memory for both language comprehension and production. Working memory is needed to retrieve and appropriately manipulate stored linguistic information, then plan the correct spoken output (Goldrick, Ferreira, Miozzo, Martin and Slevc, 2014). The phonological loop, a central component of working memory, facilitates the processing of incoming auditory (or visual in the case of written language) information for language comprehension (Baddeley and Hitch, 1974; Baddeley, 2003). The phonological loop also plays a role in language production, either appraising out-going information for speech or for internal rehearsal for later recall (Baddeley, 2003). However, another component of working memory, the central executive, changes during the ageing process (Salthouse and Babcock, 1992). For example, older people demonstrate difficulty in discarding irrelevant information in memory updating tasks, when compared to younger people (De Beni and Palladino, 2010); slowing in working memory updating ability has been associated with decreased reaction times in picture naming tasks (Piai and Roelofs, 2013), suggesting that a reduction working memory capacity can contribute to slowed word generation. Similarly, neuroimaging studies have shown that increased working memory demands elicit different patterns of activation in the prefrontal cortex in older adults compared to younger (Rypma, Prabhakaran, Desmond, and Gabrieli, 2001), suggesting that ageing brings about both a biological and cognitive shifts in working memory processes. Such changes in the neural underpinnings of working memory mean that it is likely to be harder for older adults to engage in successful social interaction because they find it increasingly difficult to follow and shift focus in conversations due to greater demands on deteriorating executive faculties.

The preservation of these cognitive skills is vital in later life to support social interaction and reduce the potential for feelings of loneliness. Ageing presents a number of challenges in maintaining such social connections, including reduced mobility, reduced physical ability, and loss of close relations (Jylha, 2004; van den Berg, Kemperman, de Kleijn, and Borgers, 2016). Additionally, as reviewed above, old age is often accompanied by changes in cognitive functions, making the evaluation of anti-social behaviour more challenging and reconnection with social groups more difficult. Supporting that thesis, recent research has found that preservation of cognitive skills into later life predicts lower reports of perceived loneliness in older people (Sin, Shao, and Lee, 2020), suggesting that greater preservation of cognitive skills affects how connected older people feel to others. Because social isolation and loneliness can have serious effects on mental and physical health problems during old age, including increasing the risk of depression, sleep disturbances, cardio-vascular disease, diabetes, and stroke (Cacioppo and Cacioppo, 2014; Cacioppo and Hawkley, 2003; Christiansen et al., 2021; Hawton et al., 2011), there is a need to explore factors that can reduce such negative social consequences. In the current study, we explore the role of cognitive ability in social engagement across adulthood, exploring how those aspects of cognitive skill influence different types of social interactions.

When modelling the connections between social and cognitive domains, it is also important to consider how the complex interactions between cognitive ability and social engagement are influenced by socioeconomic background. Lower educational attainment has been linked prospectively to cognitive performance at different life stages, with lower education individuals showing more variability in neuropsychological test results across the lifespan, with patterns of performance being domain specific (Ardila, Ostrosky-Solis, Rosselli, and Gomez, 2000). Further research has shown that educational attainment can mediate the negative effects of social isolation on cognitive ability in elderly populations (Shankar, Hamer, McMunn, And, and Steptoe, 2013). Key elements of socioeconomic status (SES), such as educational attainment and household income, have also been associated with increased connectivity in resting-state brain networks and increased cognitive performance (Shen et al., 2018). There are also strong indications that higher levels of socioeconomic status are associated with preservation of cognitive abilities and feelings of greater social connection (Borgeest et al., 2020; Cacioppo et al., 2000; Hawkley, Thisted, and Cacioppo, 2009; Shankar et al., 2013). However, there remain questions about how changes in *specific* cognitive domains may be influenced by socioeconomic status, and, in turn, the consequences for social interaction. In the current study we aim to fill that gap in our knowledge.

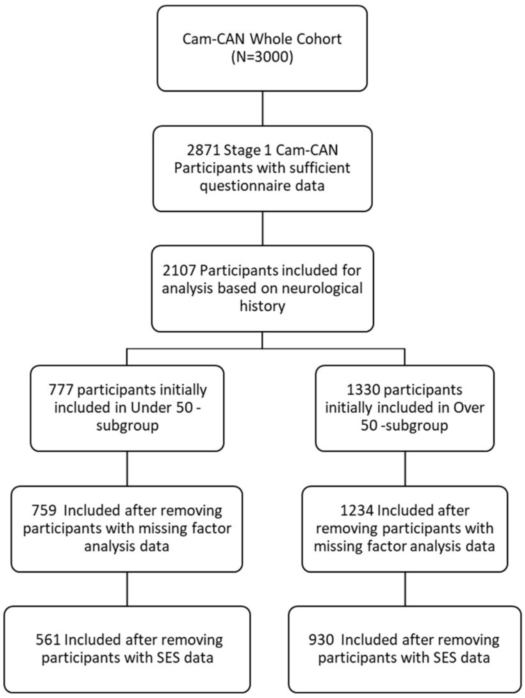
Extant research has indicated some connections between social engagement, cognitive domains, and socioeconomic background, but it offers no suggestion of how these elements may interact in a fully integrative model, or of the effects of ageing on such relationships. The current study extends this previous work to explore how these aspects interact and influence each other at different stages of adulthood. To investigate these relationships, we apply Exploratory and Confirmatory Factor Analysis (EFA/CFA) and Structural Equation Modelling (SEM) to data from the large, cross-sectional, adult-lifespan, population-representative sample from the Cambridge Centre of Ageing and Neuroscience (Cam-CAN) cohort, drawing from the stage one dataset (N = 3000; Shafto et al., 2014). This dataset contains many measures of ability in specific cognitive domains appropriate for this research and has measures of social involvement and socioeconomic status. SEM has previously been used in this context to model “successful” ageing, showing that engagement in both physical and social activity decreases the likelihood of physical and mental decline in later life (Doyle, Mc Kee, and Sherriff, 2012), and that social structure in ageing, in combination with physical and cognitive support, are important (Hess, 2001). We use data from the full sample of Cam-CAN so that we can explore the relationships of SES, social engagement, and targeted language and executive function abilities across the lifespan.

The key hypothesis of this study is that cognitive ability factors will interact differentially with SES and social interaction factors for young and older adults, indicative of the cognitive ageing process. Additionally, maintained ability in cognitive functions, including language and memory, will have a greater influence on social participation for those in the older adult group, likely due to cognitive changes associated with ageing. Regardless of age, we expect that socioeconomic background will be influential to both cognitive and social factors across age groups.

Method

Participants

A total of 1491 participants were sampled from the Stage One cohort of Cambridge Centre for Ageing and Neuroscience (Cam-CAN; for full details on recruitment protocol see the Cam-CAN protocol; Shafto et al., 2014). The data was collected in 2011, whereby eligible individuals aged 18 and over were randomly drawn from GP registers, to ensure adequate representation of the population and reduce bias that could be introduced through recruitment via advertisement. Potential participants were then sampled from iteratively to secure sufficient numbers per age decile, accounting for a 30% response rate. Invitation letters included an option to decline study participation (further reducing selection bias), those that did not decline to take part received a home visit with the researchers. Data was collected from 3000 participants in the first stage (86%



of which were British natives), from this initial sample, participants were excluded from the current analyses based on completeness of questionnaires, history of neurological conditions, and pronounced language production and comprehension difficulties (N = 893 excluded). We created two age-based sub-samples: under 50 years old (18-49) and 50 years old or older (50-98; henceforth called 'Over 50'). Participants were excluded due to missing data at various stages (see Figure 1), leaving the Under 50 sub-sample N = 546 (mean age = 35.90, SD = 8.10, 324 female), and the Over 50 sub-sample N = 930 (mean age = 71.84, SD = 11.32, 525 female).

Figure 1: participant inclusion cascade (for full exclusion criteria see supplementary).

Participant group cut-offs (<50/≥50 years old) were chosen due to evidence of significant brain structural differences after 50 years of age (Ge et al., 2002). Additionally, median division of large groups has been argued to be a robust method of dichotomizing data, allowing for a clearer comparison between groups, without significant loss of power or data integrity (Iacobucci et al., 2015).

Socioeconomic Measures

For both participant groups, Educational Attainment and Average Household Income were used as measures of socioeconomic status (SES), collected as part of a home interview. Country of Birth, Shift Work, Employment, and Retirement Status were considered for use as SES measures, but due to insufficient variance within these variables it was not possible to use them in this analysis (See supplementary material for full details). Participants' Educational Attainment was derived using a culmination score of qualifications achieved based on the Life Experience Questionnaire score (Valenzuela and Sachdev, 2007).

Average Household Income was scored 1-5 based on total household income before tax; 1: Less than £18,000, 2: £18,000 to £30,999, 3: £31,000 to £51,999, 4: £52,000 to £100,000 5: Greater than £100,000. Average Household Income in those that reported to be retired was found to have a similar distribution to the general sample

Cognitive Measures

A number of cognitive measures collected as part of Cam-CAN's Stage One cognitive assessment were identified as appropriate variables for use in this study as they probed the cognitive domains of interest (see Table 1). These measures were included in an exploratory factor analysis (EFA) prior to the present study (the full exploration is not reported here, see supplementary materials); parallel analysis was conducted to establish the appropriate number of factors to be extracted and avoid over-extraction in EFA (Patil et al., 2008). Confirmatory factor analysis was then conducted in Mplus Version 8.4 (Muthén and Muthén, 2019) to ensure the goodness of fit of these factors to the data. Note that while the parallel analysis and subsequent EFA of the Over 50 sample suggested that four factors would be appropriate, the CFA of four factors was not found to be a good fit and so the factors in this group were reduced to three.

CFA Variable Name	**Composite score variable name**	**Cam-CAN Variable**
C1	Generate "S" Words	Number of S Words
C2	Simple repetition	Repeat Apple
		Repeat Table
		Repeat Penny
C3	Subtracting 7 backwards	Serial 7 answers
C4	Spell "World" Forwards	Spell WORLD
C5	Spell "World" Backwards	Spell WORLD backwards
C6	Recall Simple Word	Recall Apple
		Recall Table
		Recall Penny
C7	Generate "P" Words	Number of P words
C8	Generate Animal Names	Number of animals
C9	Complete Verbal Instructions	Close your eyes
		Look at ceiling
		Tap shoulders
		Touch right ear
		Nod your head
C10	Complete Written Sentence	Complete a written sentence

CFA Variable Name	Composite score variable name	Cam-CAN Variable
C11	Complex Repetition	Repeat Hippopotamus
		Repeat Eccentricity
		Repeat Unintelligible
		Repeat Statistician
		Repeat Above beyond and below
		Repeat No ifs ands or buts
C12	Picture Identification (naming)	Name Pencil
		Name Watch
		Name Kangaroo
		Name Penguin
		Name Anchor
		Name Camel
		Name Harp
		Name Rhinoceros
		Name Barrel
		Name Crown
		Name Crocodile/Alligator
		Name Accordion
C13	Picture Identification (pointing)	Point Monarchy
		Point Marsupial
		Point Antarctic
		Point Nautical
C14	Single Word Reading	Read Sew
		Read Pint
		Read Soot
		Read Dough
		Read Height
C15	Visuospatial score	Copy overlapping pentagons
		Copy wire cube
		Draw clock face
		All numbers
		Set hands to 11:10
C16	Abstract Thinking Score	How are apple and banana alike?
		How are shirt and dress alike?
		How are table and chair alike?
		How are plant and animal alike?
C17	Self-Reported memory score	Do you feel you have problems with your memory?
		What day of the week it is
		Repeating same story/message
		Forget family/friends have died
		Forget month/year
		Can do something again before realising have done it before

CFA Variable Name	Composite score variable name	Cam-CAN Variable
		Great difficulty finding way around known places
		Problem knowing where things are
		Difficulty remembering what have read
		Difficulty following a TV programme
		My memory difficulties have a major impact on my ability for everyday things
C18	Spot the Word Score	Spot the word real test completed

Table 1: Variables included in Cognitive Item EFA and CFA for both Under and Over 50 sub-groups.

Three factors were derived for the under 50 sample: Language Development (labelled as such due to this factor loading onto abilities thought to develop in childhood, including vocabulary, picture naming and irregular word reading), Verbal Fluency (this factor loads on three spontaneous naming tasks, thought to represent verbal fluency ability), and Working Memory (so called as tasks thought to tap working memory load onto this factor, spelling “World” forward and backward) (Figure 2). The initial EFA of the Over 50 data suggested four factors would be appropriate, however CFA analysis revealed that it was necessary to constrain the data further to three factors for the over 50 sample: Verbal Fluency (as above, three naming tasks loaded together in this factor), Language and Working Memory (named as such due to this factor loading onto memory based tasks such as word repetition, following experimenter instructions, and forward and backward spelling, and linguistic ability tasks such as written a sentence and identifying images), and Long Term Memory (here participant’s self-reported memory abilities and delayed word recall load onto the factor) (Figure 3).

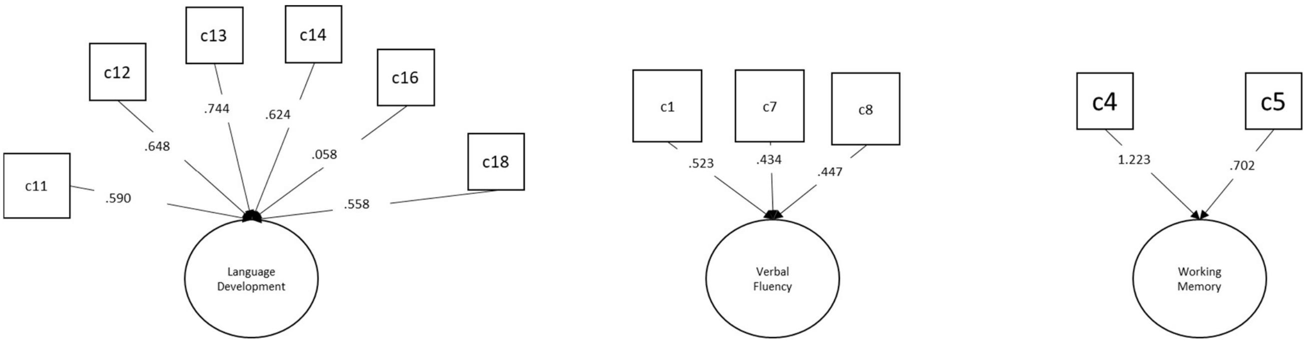


Figure 2: Under 50 Confirmatory Factor Analysis Structures of cognitive measures (variable key in Table 1)

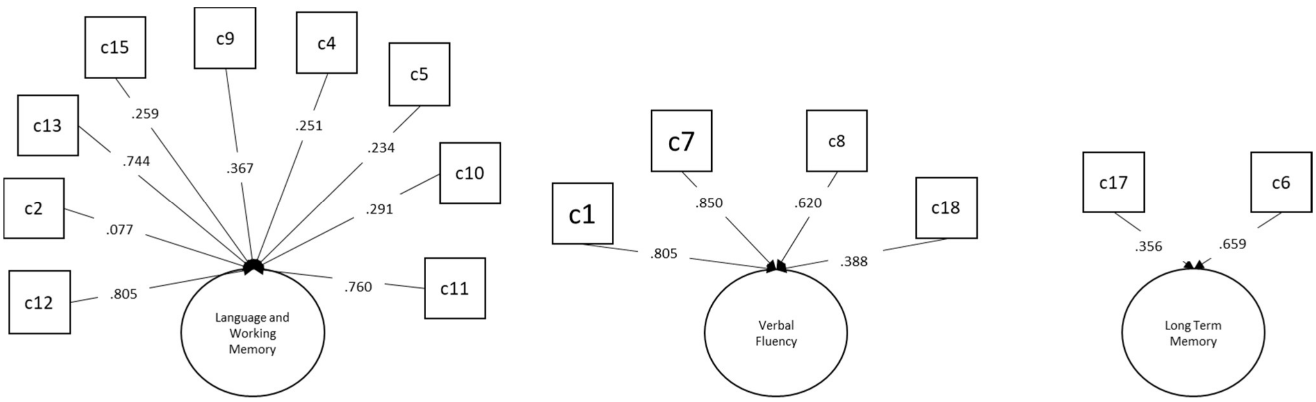


Figure 3: Over 50 Confirmatory Factor Analysis Structures of cognitive measures (variable key in Table 1)

There are distinctions in all factors between the two age groups: the language factor in the older group also included elements of memory, the verbal fluency factor had the addition of the spot the word task (which also draws on memory, Wall et al., 1994), and the memory factor in this group reflects long term memory, rather than working memory.

Social Interaction Measures

Similarly, to the cognitive measures, social participation variables were derived from an exploratory factor analysis (EFA) of Cam-CAN's social participation questionnaire data (see Table 2) conducted prior to the present study (see supplementary materials). Again, these factors were established using parallel analysis, then tested using CFA in Mplus.

CFA Variable Name	Variable Name
S1	**Total Number of Social Activities***
S2	**Total Time Spent at Social Activities***
S3	**How often see relatives to speak to?†**
S4	**How often speak to relatives over phone? †**
S5	**How often text/email relatives? †**
S6	**How often to friends/family visit you? †**
S7	**How often speak to friends over phone? †**
S8	**How often text/email friends? †**

*Table 2: Variables in Social Engagement Item EFA and CFA for Both Under and Over 50 sub-groups. * S1 and S2 are both derived from a single item in the Cam-CAN dataset "Attend any meetings/groups/classes? How Often?" † Participants chose from the following responses: 1. Never 2. Daily 3. 2-3 times a week 4. At least weekly 5. At least monthly 6. Less often 7. Don't know 8. No answer 9. Not asked.*

The Under 50 sample had 3 factors of social interaction: Social Participation, Communication with Relatives, and Communication with Friends (Figure 4). The Over 50 sample also had 3 factors of social engagement, though these were different from those seen in the under 50 sub-group: Asynchronous Communication, Social Participation, and Synchronous Communication (Figure 5). The factor labels reflect the finding that the loadings appeared to reflect the communication *method* in this group, rather than the *target group* being communicated with (e.g. "How often text/email relatives?" and "How often text/email friends?" load onto the same factor, Asynchronous Communication), as seen in the Under 50 group, where (for example) "How often speak to friends over phone" and "How often text/email friends?" load together to create the factor Communication with Friends. These factors were then used as the social engagement variables in the analysis reported here.

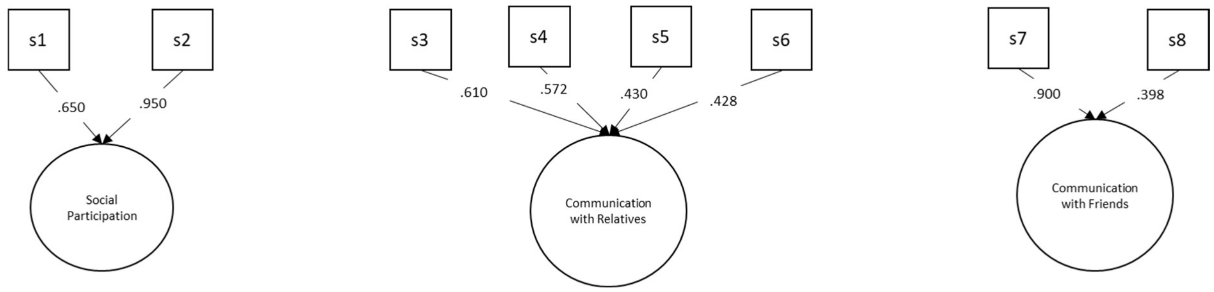


Figure 4: Under 50 Confirmatory Factor Analysis Structures of social participation measures (variable key in Table 2)

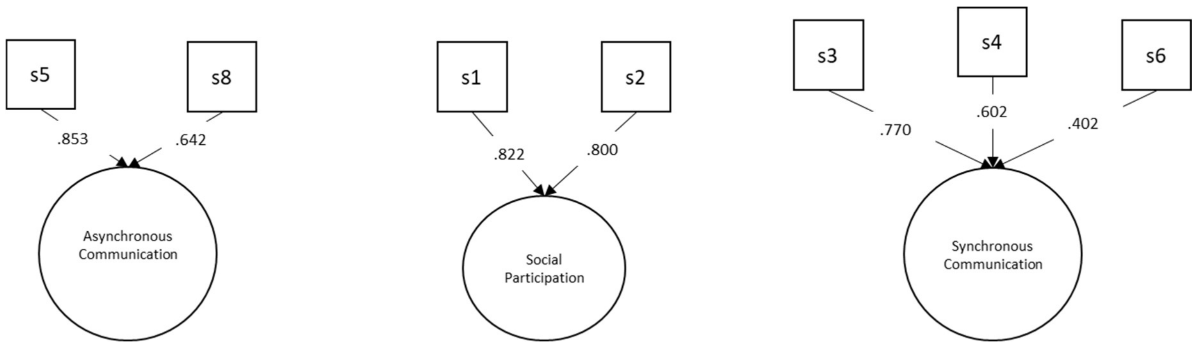


Figure 5: Over 50 Confirmatory Factor Analysis Structures of social participation measures (variable key in Table 2)

Structural Equation Modelling

The models of interaction between SES, cognition, and social engagement in both age groups were tested using structural equation modelling (SEM) in Mplus version 8.4 (Muthén and Muthén, 2019), using maximum likelihood estimation with robust standard error (Hu and Bentler, 2009). The differences in the factor loadings shown above was taken as confirmation of appropriateness of splitting the sample by age[1]. Model fit was evaluated using comparative fit index (CFI), Tucker-Lewis Index (TLI), and root mean square error of approximation (RMSEA) (Schreiber, Stage, King, Nora, and Barlow, 2006).

Results

Under 50 group

The model fit for the Under 50 group was considered adequate (Marsh and Hau, 1999), x2 (167) = 903.821, p <.005; RMSEA = 0.090, 90% CI [0.084, 0.096], p <.001; CFI = 0.784, TLI = 0.782. The two SES measures, Educational Attainment and Average Household Income, were significantly correlated (*r* = 0.229, *p*<.005). Two of the cognitive factors, Language Development and Verbal Fluency, were significantly correlated (*r* = 0.523, *p*<.005), as were two of the social factors, Communication with Relatives and Communication with Friends (r = 0.378, p<.005). The direct relationships between SES measures, cognition, and social participation measures in the under 50 sub-sample are shown in Table 3; the full SEM model is shown in Figure 6. Language Development showed direct associations with both SES measures, Educational Attainment and Average Household Income, as did Verbal Fluency. Working Memory only showed a direct relationship with Average Household Income, no association with Educational Attainment was observed.

Social Participation, and Communication with Relatives were directly associated with Educational Attainment only; there were no paths between social engagement factors and Average Household Income. The model showed no independent or mediating paths from cognitive variables to social engagement variables. Communication with friends was found to be independent of all other factors within the model, apart from its correlation with Communication with Relatives.

[1] an initial EFA with three participant groups (18 – 29, 30 – 50, 50+) showed no distinction between the younger and middle age groups.

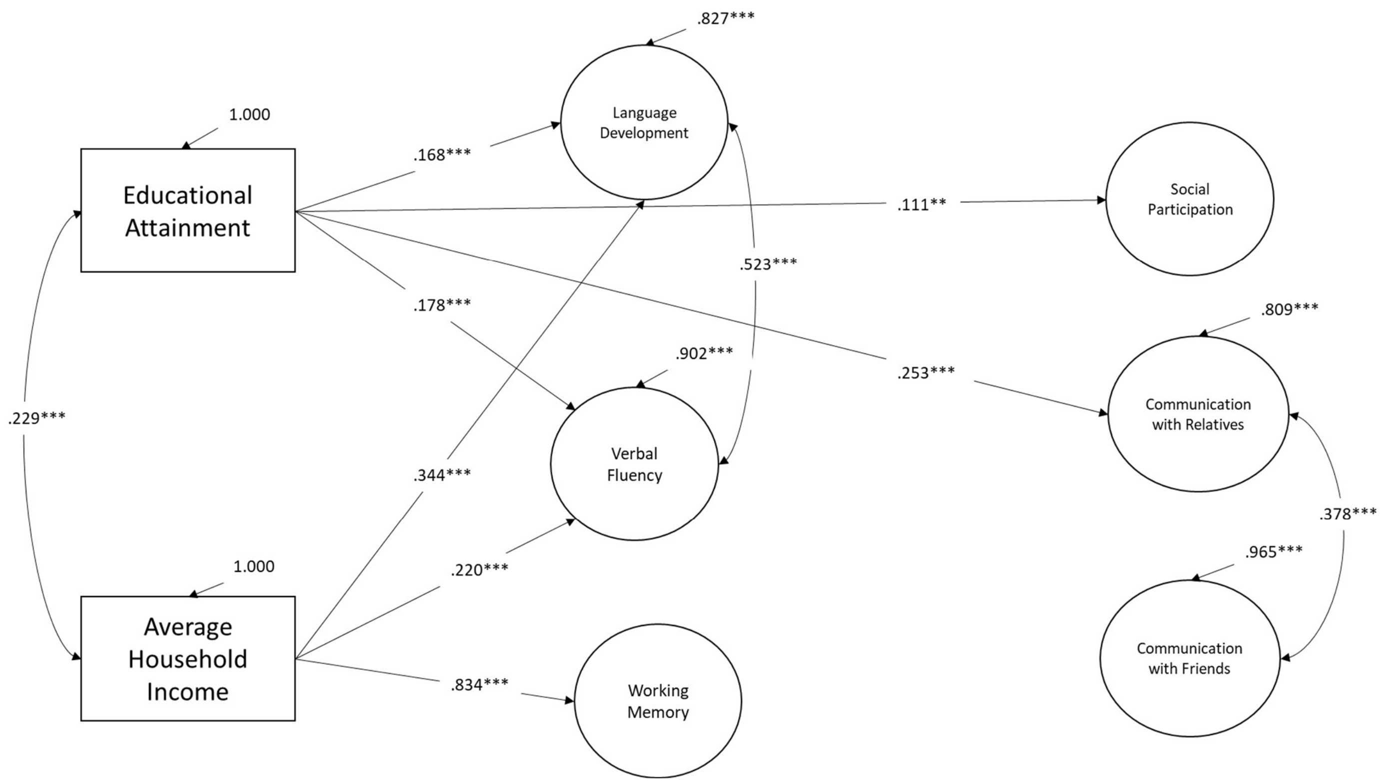


*Figure 6: Structural Equation Model of Under 50 sub-sample, *p<.05, **p<.01, ***p<.001.*

Direct Paths		**Coefficients**		**95% CI**	
		Beta	*SE*	*Lower Limit*	*Upper Limit*
Educational Attainment	**Language Development**	0.168	0.038	0.070	0.266
	Verbal Fluency	0.178	0.051	0.046	0.310
	Social Participation	0.111	0.041	0.006	0.216
	Communication with Relatives	0.253	0.053	0.117	0.389
Average Household Income	**Language Development**	0.344	0.037	0.248	0.440
	Verbal Fluency	0.220	0.054	0.082	0.358
	Working Memory	0.843	0.190	0.355	1.332

Table 3: Direct paths in Under 50 sub-sample

Over 50 group

Similarly, to the Under 50 group, the model fit was for the Over 50 group data was adequate, x2 (232) = 3958.925, p <.005; RMSEA = 0.138, 90% CI [0.134, 0.142], p <.001; CFI = 0.637, TLI = 0.570.

In this group, Asynchronous Communication and Synchronous Communication showed a small but significant correlation (r = 0.184, p<.001), as did Asynchronous Communication and Social Participation (r = 0.170, p<.001). No correlations were found between cognitive factors or between SES measures in this group.

The direct relationships between SES measures, cognition, and social participation measures in the over 50 sub-sample are shown in Table 4; indirect relationships are shown in Table 5; the full SEM model is shown in Figure 7. All three cognitive factors – Verbal Fluency, Language and Working Memory, and Long Term Memory – were found to have direct relationships with both SES measures, Educational Attainment and Average Household Income.

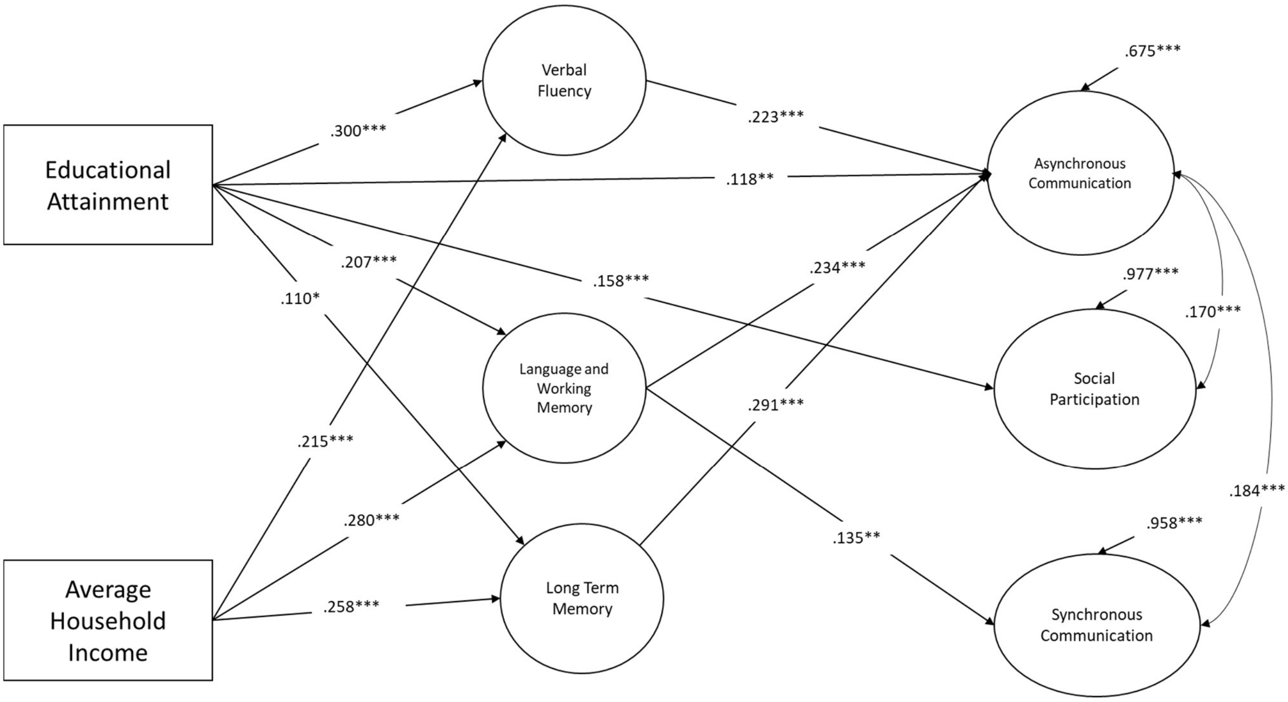


*Figure 7: Structural Equation Model of Over 50 sub-sample, *p<.05, **p<.01, ***p<.001.*

Asynchronous Communication had direct associations with all three cognitive factors, and with Educational Attainment, and additional analysis showed that both Verbal Fluency and Language and Working Memory mediated this latter SES-social relationship. No direct association was found between Asynchronous Communication and Average Household Income; however, indirect paths via each of the three cognitive factors significantly mediated this SES-social relationship. Social Participation had a direct relationship with Educational Attainment, but no direct associations with cognitive factors. Synchronous Communication was found to be directly influenced by Language and Working Memory, independent of SES measures, and had no other associations with cognitive factors or SES measures.

Direct Paths		Coefficients		95% CI	
		Beta	*SE*	*Lower Limit*	*Upper Limit*
Educational Attainment	**Verbal Fluency**	0.300	0.037	0.205	0.396
	Language and Working Memory	0.207	0.047	0.086	0.328
	Long Term Memory	0.110	0.051	-0.020	0.240
	Asynchronous Communication	0.118	0.047	-0.004	0.240
	Social Participation	0.158	0.044	0.045	0.272
Average Household Income	**Verbal Fluency**	0.215	0.037	0.121	0.309
	Language and Working Memory	0.280	0.049	0.153	0.408
	Long Term Memory	0.258	0.058	0.107	0.409
Language and Working Memory	**Synchronous Communication**	0.135	0.045	0.019	0.250

Table 4: Direct paths in Under 50 sub-sample.

Indirect Paths			Coefficients		95% CI	
SES Measure (A)	**Mediating Cognitive Factor (B)**	**Social Factor (C)**	*Beta*	*SE*	*Lower Limit*	*Upper Limit*
Educational Attainment	**Verbal Fluency**	Asynchronous Communication	0.067	0.016	0.026	0.108
	Language and Working Memory		0.048	0.014	0.011	0.086
Average Household Income	**Verbal Fluency**	Asynchronous Communication	0.048	0.013	0.015	0.081
	Language and Working Memory		0.066	0.017	0.022	0.110
	Long Term Memory		0.075	0.027	0.007	0.143

Table 5: Indirect paths in over 50 sub-sample.

Discussion

We investigated the relationships between cognitive domains and social engagement, as influenced by socioeconomic background, in two different age groups, and both the factor structures and SEMs differed qualitatively in interesting ways. Data for the older population showed different factor structures of cognitive domains at the factor level, which notably included a long-term memory factor that was absent in younger adults, and social factors that were distinguished by communication *types* – asynchronous vs. synchronous – rather than *groups* – family vs. friends – as found for the younger adults. The SEM for the older adult group revealed a number of direct and indirect relationships between SES, cognition, and social participation, whereas in the younger population, direct associations were found between SES measures and both cognitive and social participation measures, and none of the three measures of cognitive ability mediated relationships between SES and social participation. These findings highlight the importance of maintaining language and other cognitive functions in later life because they support successful social engagement, partially mediating the effects of SES.

Confirmatory factor analysis of the Under 50 sub-group supported three cognitive factors: Verbal Fluency; Working Memory; and Language *Development*, as indicated by factor loadings on simple and complex language tasks and categorical reasoning. In the Over 50 sub-group, Verbal Fluency and Language and Working Memory factors also emerged, however Language and Working Memory was captured within one factor for this sub-group. In the Over 50 sub-group both Verbal Fluency and Language and Working Memory were underpinned by different tasks from those found to support these factors in the Under 50s group, where language and working memory faculties are separated into independent factors.

The older group factor structure included a Long Term Memory factor, which may capture increased variance induced by age-related decline in medial temporal lobe-mediated episodic memory (St-Laurent et al., 2011; Vandermorris et al., 2013). We suggest Long Term Memory is represented in this factor the factor consisted of questions relating to one's semantic and episodic memory (simple word recall; memory self-report, which includes items such as: 'repeating same story/message', 'forget family/friends have died', 'can do something again before realising have done it before') and spatial memory (Uttl and Graff, 1993; Leon et al., 2013) (memory self-report items: 'great difficulty finding way around known places', 'problem knowing where things are'). Alternatively, this factor may reflect a greater need for cognitive compensation due to these age-related decrements in cognitive abilities (Juncos-Rabadn et al., 2012; Macpherson, Pipingas, and Silberstein, 2009).

The social factors within the Under 50 group represent *with whom* the individual may be communicating (relatives vs. friends), but do not distinguish between *communication types* (synchronous, asynchronous) as seen in the Over 50 social engagement factor loadings. The difference in factors between the two age groups could be due to the greater extent of technology's integration into communications for the Under 50 sub-group, whereas novel and rapidly changing technology may be more cognitively taxing for the Over 50 sub-group. Communicative technology, such as smartphones and personal computers, is likely to be less integrated into daily life for older adults (Frid, García, Laskibar, Etxaniz, and Gonzalez, 2013).

Somewhat surprisingly, we found a relative lack of relationships and mediating pathways in the Under 50 group. As healthy adults in their cognitive prime, perhaps this sub-group does not require significant cognitive support to maintain social relationships. While previous research has suggested moderate social participation can support cognition by age 50 (Bowling et al., 2016), our research investigated cognition's role in supporting socialising. An unexpected finding is the apparent independence of Communication with Friends from other factors in the model, which may reflect a tendency for friendships to be established and secure, regardless of socioeconomic background, at this point in one's life (Qualter et al., 2015). It may also be a result of variation in factors not measured in this study, such as personality type (introversion-extroversion). Research has shown varying results in the relationships between personality type, cognition, and differences in SES that may be of influence here (Lynn and Gordon, 1961), though without data regarding personality it is difficult to speculate the nature of those relationships here.

Interactions were more complex in the older age group (50+ years) model; this could perhaps reflect the increased variability due to age-related cognitive decline in multiple domains, in turn resulting in more pronounced associations between cognition and social engagement. Asynchronous Communication showed relationships with the Long Term Memory, Verbal Fluency, and Language and Working Memory factors in the older group model. The Verbal Fluency association suggests that ability to access vocabulary is required to support and maintain asynchronous communications, which becomes more cognitively strenuous during later life (Burke and Shafto, 2004; Meiran and Gotler, 2010). Reduced ability in vocabulary access could make generating asynchronous messages more effortful for older adults, so greater ability in this domain is required for the maintenance of asynchronous communication, such as emailing a friend or family member. Long Term Memory provides support for continuous, prolonged asynchronous conversation, allowing the individual to remember to return to the correspondence, recall shared experiences with their conversation partner, and encode the conversation itself into memory (Holtgraves, 2008). Similarly, the Asynchronous Communication and Language and Working Memory association provides evidence that maintained ability these in domains are supportive of ongoing asynchronous communication in later life. In this study this factor consisted of a number of language production and comprehension tasks, necessary for composing and understanding correspondence, but also encompassed memory elements needed not only to access vocabulary, but also to hold the thread of ongoing conversation and motivate a response. This is further supported by the independent relationship between Language and Working Memory and Synchronous Communication. This communication modality requires constant monitoring of language input (comprehension) and output (production), as well as memory resources to accurately follow and mentally update the conversation.

Asynchronous Communication was also associated with Educational Attainment in this group; however, indirect pathway analysis showed that Verbal Fluency and Language and Working Memory mediate this relationship. These cognitive domains facilitate vocabulary, memory, self-monitoring, and following conversation over extended periods of time; their mediation of this relationship suggests that communication of this type is cognitively taxing for older populations (Wascher et al., 2012). Social Participation, on the other hand, was associated only with Educational Attainment, and this relationship was not mediated by any cognitive variables.

Educational Attainment's relationship Asynchronous Communication suggests that a greater level of education positively supports this type of communication in the Over 50 group. The relationship observed with Asynchronous Communication in particular may be because higher education is associated with moving away from one's immediate area, which in turn increases the likelihood of having contacts across a wider geographical range (Leopold, Geissler, and Pink, 2012). Further, professional email correspondence is more likely to occur in roles that require further education, which in turn may lead to adopting this method of communication in a social context. However, as noted above, this relationship is indirectly mediated by several cognitive factors.

Average Household Income was also associated with Asynchronous Communication in the Over 50 group, suggesting that higher household income may provide more access to technology to communicate, and provide greater experience of using technology, including the use of personal computers (Niehaves and Plattfaut, 2014). This relationship between Asynchronous Communication and Average Household Income was only observed via mediating cognitive pathways: Verbal Fluency, Language and Working Memory, and Long Term Memory factors all mediate the relationship between Average Household Income and Asynchronous Communication in the Over 50 group. It is likely that there are cognitive changes that affect domains relevant to Asynchronous Communication, such as vocabulary selection, language generation, and memory of the conversation, which become increasingly effortful to draw from with age (Burke et al., 1991;

Wascher et al., 2012). It may also be the case that those with less advantaged backgrounds may have greater barriers to access asynchronous communication technology, which, especially considering the Covid-19 pandemic and increasing reliance on communication technology, could contribute to social isolation and reduce access to care (Ali, Alam, Taylor, and Ashraf, 2021).

The association between Social Participation and Educational Attainment in both age groups suggests that this element of SES supports a wider social group and provides increased means to facilitate them; it has been found that men who are married, own a home or a car, and are of higher social status are more likely to engage socially (Harwood, Pound, and Ebrahim, 2010). The paths between Social Participation and Educational Attainment were not found to be mediated by any of the cognitive variables, nor was there an association with Average Household Income in either group.

Previous studies have found relationships between general cognitive function, social engagement, and feelings of isolation (Borgeest et al., 2020; Keller-Cohen, Fiori, Toler, and Bybee, 2006; Shankar et al., 2013), but in the current study we found some distinct relationships between social participation and specific aspects of cognition, particularly in the language domain. There are two implications of these findings: 1) It would be beneficial to use even more targeted measures of cognition, something that future research should aim to expand on; and 2) The specific relationships between aspects of cognition and social engagement only in the older population suggests that there is a shift in reliance on cognitive ability as part of the ageing process. Thus, given that key cognitive skills have a significant impact on social participation during ageing, it is important to maintain and practise these cognitive abilities to reduce loneliness, though we give the caveat that causal direction cannot strictly be determined given that the data are cross-sectional.

We had initially expected that the factor analysis would differentiate between language domains and executive functions, particularly in the older group. However, despite the reasonable number of cognitive measures used in the exploratory factor analysis, no distinct executive function factor was established in either group. Working Memory, which is present in both groups (though incorporated with language in the Over 50 factor structure), likely captures some variability associated with executive functions. The 'working' aspect of working memory refers to active, flexible processing and maintenance of information across multiple systems, coordinated by a central executive (Baddeley and Hitch, 1974), and the backwards-spelling task in particular likely places demands on this faculty. Verbal fluency task performance is frontally mediated (Robinson et al., 2012) and requires goal-directed generation and selection. The lack of an executive function factor could be due to the high cognitive-domain specificity and relative simplicity of the cognitive tasks and questionnaires used at this point of the Cam-CAN data collection. Executive functions are complex facets of cognition, and their measurement typically involves complicated and/or protracted tasks (e.g., dual or multiple task performance, task switching) that were beyond the scope of this in-home interview phase of the Cam-CAN project. Though, as discussed above, Working Memory does draw from executive facilities (Baddeley and Hitch, 1974) suggesting an element of executive function is still reflected in our findings for both Under and Over 50 groups.

The statistical methods of the study are robust; by conducting EFA to then guide CFA structure to create latent variables, we are confident of the representations of cognition and social participation within the data. The use of SEM allows for the exploration of multiple potential interrelationships within one analysis by combining factor and multiple regression analysis, and it enables the control of key demographic information. However, there is room for improvement in the cognitive tests used in the factor creation, which are clearly reflected in the factors themselves; for example, as discussed above, we were unable to establish a distinct executive function factor from the available measures. Though there is some representation of executive functions in the verbal fluency factor, this task is often used as language or executive function task interchangeably as linguistic ability is needed to generate the words and executive ability is needed to facilitate recall and response (Shao, Janse, Visser, and Meyer, 2014). The current study found that verbal fluency was particularly influential in supporting social participation, and past research has shown that this ability deteriorates with age (Gonzalez-Burgos et al., 2019), but without domain specific measures it is difficult to be certain of the underlying mechanisms of decline. The aim of future work will be to better delineate the shared and distinct processes of linguistic and executive domains using more clearly defined measures and data capture techniques.

The current study is not without limitations; the model fit indices for both models are under the traditionally accepted thresholds of a CFI and TLI greater than 0.95 and RMSEA less than 0.05 are considered to be a good indication of model fit, however there are a number of reasons why this may be the case beyond without need to discard the findings. Often goodness of fit (GoF) standards applied to CFA are overly restrictive for factors with more than 2 or 3 items loading on them, more items loading on factors is desirable for good construct validity but makes unlikely that the model then reach the .95 GoF cut-off (Marsh et al., 2004). Therefore, we suggest that the concern of GoF indices being below the expected requirements is likely due to increased complexity of the language-based factors in both age groups, especially for a medium sample size. Additionally, it is possible that there are underlying factors that contribute to the relationships that we were unable to account for, perhaps unrepresented SES elements or deeper measures of social support. Additionally, the cross-sectional nature of the data imposes constraints on interpretations involving causal relations. Indeed, the results have been interpreted as cognition mediating social engagement in older adults, but it is possible that these associations work conversely, or even bi-directionally. Previous research has shown that increased feelings of loneliness can impact executive functions, and diverse social contact supports language skills (Adams and Blieszner, 1995; Keller-Cohen et al., 2006), so it is possible that the relationship is bi-directional, something that cannot be explored without prospective data. Thus, there is a need for longitudinal research in cognitive – social associations to clearly explore how cognitive ability and social participation work together over time.

Within this data there was the potential for collinearity of Educational Attainment and Average Household Income to skew our findings, as these measures might be representative of the same underlying factor. However, tests of collinearity found that in both Under 50 and Over 50 found that these measures were not collinear, which can be further exampled in the differences in the relationships between these SES measures and cognition and social engagement. These findings indicate that while they probably do relate to similar underlying constructs, Education Attainment and Average Household Income are independent from each other.

The qualitative differences between the age groups' models highlight the complex relationship between cognition and social participation in later life. Where previous research has demonstrated the relationships between ageing, cognition, and social engagement, our findings highlight the importance of maintaining specific language skills into old age, to support and strengthen social bonds. Our study showed, relative to the younger adult group, the older adult group (50 years old and older) showed differences in cognitive domain and social participation representation at the factor level, and greater complexity of relationships between SES, cognitive domains, and social participation. We attempted to demonstrate the importance of considering cognitive domains beyond the umbrella term of "cognition", instead focusing on the interactions of specific cognitive elements with social engagement; future work could expand this approach to include other aspects of cognition known to be affected by age, such as executive functions. These findings highlight areas that may be of importance when considering interventions in various life stages; in particular, educational and language development support during young adulthood, with a focus on more general cognitive support in middle to older adulthood. Employing such an age-specific approach to cognitive intervention may provide individuals with robust language and general cognitive ability to better support social participation and reduce loneliness in later life.

In conclusion, this study provides evidence that social interactions and cognition are represented differently in populations under and over 50; older population social interactions are characterised by modality of interaction and more associated with maintained cognitive ability. We demonstrated that socioeconomic background, particularly Educational Attainment, is influential on both cognitive ability and social interaction in both age groups; however, these relationships with SES were found to be more numerous in the older population.

Statement of Ethical Approval

Ethical approval for the original Cam-CAN study was obtained from the Cambridgeshire 2 (now East of England - Cambridge Central) Research Ethics Committee. Participants gave written informed consent.

Conflict of interest

The authors declare no conflicts of interest.

Contributions

Josephine Kearney: Conceptualization, Methodology, Formal analysis, Writing - Original Draft, Visualization.

*Pamela Qualte*r: Validation, Writing - Review & Editing, Supervision.

*Ca*m-CAN: Investigation, Resources.

Jason R Taylor: Validation, Writing - Review & Editing, Supervision

Acknowledgements

We thank our colleague Dr Anna Woollams for her early contributions to this work.

References

Acheson, D. J., Hamidi, M., Binder, J. R., and Postle, B. R. (2011). A common neural substrate for language production and verbal working memory. *Journal of Cognitive Neuroscience*, *23*(6), 1358–1367. https://doi.org/10.1162/JOCN.2010.21519

Adams, R. G., and Blieszner, R. (1995). Aging Well With Friends and Family. *American Behavioral Scientist*, *39*(2), 209–224. https://doi.org/10.1177/0002764295039002008

Ali, M. A., Alam, K., Taylor, B., and Ashraf, M. (2021). Examining the determinants of eHealth usage among elderly people with disability: The moderating role of behavioural aspects. *International Journal of Medical Informatics*, *149*, 104411. https://doi.org/10.1016/j.ijmedinf.2021.104411

Ardila, A., Ostrosky-Solis, F., Rosselli, M., and Gomez, C. (2000). Age-Related Cognitive Decline During Normal Aging: The Complex Effect of Education. *Archives of Clinical Neuropsychology*, *15*(6), 495–513. https://doi.org/10.1093/arclin/15.6.495.

Baddeley, A. D. (2003). Working memory and language: an overview. *Journal of Communication Disorders*, *36*(3), 189–208. https://doi.org/10.1016/S0021-9924(03)00019-4

Baddeley, A. D., and Hitch, G. (1974). Working Memory. *Psychology of Learning and Motivation - Advances in Research and Theory*, *8*(C), 47–89. https://doi.org/10.1016/S0079-7421(08)60452-1

Belke, E., and Meyer, A. S. (2007). Single and multiple object naming in healthy ageing. *Language and Cognitive Processes*, *22*(8), 1178–1211. https://doi.org/10.1080/01690960701461541

Borgeest, G. S., Henson, R. N., Shafto, M., Samu, D., and Kievit, R. A. (2020). Greater lifestyle engagement is associated with better age-adjusted cognitive abilities. *PLOS ONE*, *15*(5), e0230077. https://doi.org/10.1371/journal.pone.0230077

Buchsbaum, B. R., Hickok, G., and Humphries, C. (2001). Role of left posterior superior temporal gyrus in phonological processing for speech perception and production. *Cognitive Science*, *25*(5), 663–678. https://doi.org/10.1207/s15516709cog2505_2

Burke, D. M., MacKay, D. G., Worthley, J. S., and Wade, E. (1991). On the tip of the tongue: What causes word finding failures in young and older adults? *Journal of Memory and Language*, *30*(5), 542–579. https://doi.org/10.1016/0749-596X(91)90026-G

Burke, D. M., and Shafto, M. A. (2004). Aging and Language Production. *Current Directions in Psychological Science*, *13*(1), 21–24. https://doi.org/10.1111/j.0963-7214.2004.01301006.x

Cacioppo, J. T., and Cacioppo, S. (2014). Social Relationships and Health: The Toxic Effects of Perceived Social Isolation. *Social and Personality Psychology Compass*, *8*(2), 58–72. https://doi.org/10.1111/spc3.12087

Cacioppo, J. T., Ernst, J. M., Burleson, M. H., McClintock, M. K., Malarkey, W. B., Hawkley, L. C., … Berntson, G. G. (2000). Lonely traits and concomitant physiological processes: The MacArthur social neuroscience studies. *International Journal of Psychophysiology*, *35*(2–3), 143–154. https://doi.org/10.1016/S0167-8760(99)00049-5

Cacioppo, J. T., and Hawkley, L. C. (2003). Social isolation and health, with an emphasis on underlying mechanisms. *Perspectives in Biology and Medicine*, *46*(3 SUPPL.), 39–52. https://doi.org/10.1353/pbm.2003.0063

Carter, C. S., Macdonald, A. M., Botvinick, M., Ross, L. L., Stenger, V. A., Noll, D., and Cohen, J. D. (2000). Parsing executive processes: Strategic vs. evaluative functions of the anterior cingulate cortex. *Proceedings of the National Academy of Sciences of the United States of America*, *97*(4), 1944–1948. https://doi.org/10.1073/pnas.97.4.1944

Christiansen, J., Lund, R., Qualter, P., Andersen, C. M., Pedersen, S. S., and Lasgaard, M. (2021). Loneliness, Social Isolation, and Chronic Disease Outcomes. *Annals of Behavioral Medicine*, *55*(3), 203–215. https://doi.org/10.1093/abm/kaaa044

Cowan, N., Rouder, J. N., Blume, C. L., and Saults, J. S. (2012). Models of Verbal Working Memory Capacity: What Does It Take to Make Them Work? *Psychological Review*, *119*(3), 480. https://doi.org/10.1037/A0027791

De Beni, R., and Palladino, P. (2010). Decline in working memory updating through ageing: Intrusion error analyses. *Http://Dx.Doi.Org/10.1080/09658210244000568*, *12*(1), 75–89. https://doi.org/10.1080/09658210244000568

Diamond, A. (2013). Executive functions. *Annual Review of Psychology*, *64*, 135–168. https://doi.org/10.1146/annurev-psych-113011-143750

Doyle, Y. G., Mc Kee, M., and Sherriff, M. (2012). A model of successful ageing in British populations. *European Journal of Public Health*, *22*(1), 71–76. https://doi.org/10.1093/eurpub/ckq132

Dudarev, V., and Hassin, R. R. (2016). Social task switching: On the automatic social engagement of executive functions. *Cognition*, *146*, 223–228. https://doi.org/10.1016/j.cognition.2015.10.001

Dumitrache, C. G., Rubio, L., Calet, N., González, J. A., and Simpson, I. C. (2020). 403 - Verbal fluency and spontaneous conversation in institutionalized older adults with and without cognitive impairment. *International Psychogeriatrics*, *32*(S1), 119–119. https://doi.org/10.1017/S1041610220002562

Evans, I. E. M., Llewellyn, D. J., Matthews, F. E., Woods, R. T., Brayne, C., Clare, L., … Bennett, K. (2019). Social isolation, cognitive reserve, and cognition in healthy older people. *PLoS ONE*, *13*(8), e0201008. https://doi.org/10.1371/journal.pone.0201008

Evrard, M. (2002). Ageing and Lexical Access to Common and Proper Names in Picture Naming. *Brain and Language*, *81*(1–3), 174–179. https://doi.org/10.1006/BRLN.2001.2515

Fjell, A. M., Walhovd, K. B., Fennema-Notestine, C., McEvoy, L. K., Hagler, D. J., Holland, D., … Dale, A. M. (2009). One-Year Brain Atrophy Evident in Healthy Aging. *Journal of Neuroscience*, *29*(48), 15223–15231. https://doi.org/10.1523/JNEUROSCI.3252-09.2009

Frankel, T., Penn, C., and Ormond-Brown, D. (2010). Executive dysfunction as an explanatory basis for conversation symptoms of aphasia: A pilot study. *Http://Dx.Doi.Org/10.1080/02687030701192448*, *21*(6–8), 814–828. https://doi.org/10.1080/02687030701192448

Frid, L., García, A., Laskibar, I., Etxaniz, A., and Gonzalez, M. F. (2013). *What Technology Can and Cannot Offer an Ageing Population: Current Situation and Future Approach*. https://doi.org/10.1007/978-1-4471-5082-4_1

Garavan, H., Ross, T. J., Murphy, K., Roche, R. A. P., and Stein, E. A. (2002). Dissociable executive functions in the dynamic control of behavior: Inhibition, error detection, and correction. *NeuroImage*, *17*(4), 1820–1829. https://doi.org/10.1006/nimg.2002.1326

Ge, Y., Grossman, R. I., Babb, J. S., Rabin, M. L., Mannon, L. J., and Kolson, D. L. (n.d.). *Age-Related Total Gray Matter and White Matter Changes in Normal Adult Brain. Part II: Quantitative Magnetization Transfer Ratio Histogram Analysis*.

Goldrick, M., Ferreira, V. S., Miozzo, M., Martin, R. C., and Slevc, L. R. (2014). Language Production and Working Memory. *The Oxford Handbook of Language Production*. https://doi.org/10.1093/OXFORDHB/9780199735471.013.009

Gonzalez-Burgos, L., Hernández-Cabrera, J. A., Westman, E., Barroso, J., and Ferreira, D. (2019). Cognitive compensatory mechanisms in normal aging: A study on verbal fluency and the contribution of other cognitive functions. *Aging*, *11*(12), 4090–4106. https://doi.org/10.18632/aging.102040

Harwood, R. H., Pound, P., and Ebrahim, S. (2010). Determinants of social engagement in older men. *Http://Dx.Doi.Org/10.1080/135485000106025*, *5*(1), 75–85. https://doi.org/10.1080/135485000106025

Hawkley, L. C., Thisted, R. A., and Cacioppo, J. T. (2009). Loneliness Predicts Reduced Physical Activity: Cross-Sectional and Longitudinal Analyses. *Health Psychology*, *28*(3), 354–363. https://doi.org/10.1037/a0014400

Hawton, A., Green, C., Dickens, A. P., Richards, S. H., Taylor, R. S., Edwards, R., … Campbell, J. L. (2011). The impact of social isolation on the health status and health-related quality of life of older people. *Quality of Life Research*, *20*(1), 57–67. https://doi.org/10.1007/s11136-010-9717-2

Hess, T. M. (2001). Ageing-related influences on personal need for structure. *International Journal of Behavioral Development*, *25*(6), 482–490. https://doi.org/10.1080/01650250042000429

Holtzman, R. E., Rebok, G. W., Saczynski, J. S., Kouzis, A. C., Doyle, K. W., and Eaton, W. W. (2004). Social network characteristics and cognition in middle-aged and older adults. *Journals of Gerontology - Series B Psychological Sciences and Social Sciences*, *59*(6), P278–P284. https://doi.org/10.1093/geronb/59.6.P278

Horton, W. S. (2010). Conversational Common Ground and Memory Processes in Language Production. *Http://Dx.Doi.Org/10.1207/S15326950dp4001_1*, *40*(1), 1–35. https://doi.org/10.1207/S15326950DP4001_1

Horton, W. S., Spieler, D. H., and Shriberg, E. (2010). A Corpus Analysis of Patterns of Age-Related Change in Conversational Speech. *Psychology and Aging*, *25*(3), 708. https://doi.org/10.1037/A0019424

Hu, L., and Bentler, P. M. (2009). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Https://Doi.Org/10.1080/10705519909540118*, *6*(1), 1–55. https://doi.org/10.1080/10705519909540118

Juncos-Rabadán, O., Facal, D., Rodríguez, M. S., and Pereiro, A. X. (2010). Lexical knowledge and lexical retrieval in ageing: Insights from a tip-of-the-tongue (TOT) study. *Language and Cognitive Processes*, *25*(10), 1301–1334. https://doi.org/10.1080/01690961003589484

Juncos-Rabadn, O., Pereiro, A. X., Facal, D., Rodriguez, N., Lojo, C., Caamaño, J. A., … Eiroa, P. (2012). Prevalence and correlates of cognitive impairment in adults with subjective memory complaints in primary care centres. *Dementia and Geriatric Cognitive Disorders*, *33*(4), 226–232. https://doi.org/10.1159/000338607

Jylha, M. (2004). Old Age and Loneliness: Cross-sectional and Longitudinal Analyses in the Tampere Longitudinal Study on Aging. In *Canadian Journal on Aging / La Revue canadienne du vieillissement* (Vol. 23). Retrieved from Article website: https://muse.jhu.edu/article/170808

Keller-Cohen, D., Fiori, K., Toler, A., and Bybee, D. (2006). Social relations, language and cognition in the ‘oldest old.’ *Ageing and Society*, *26*(4), 585–605. https://doi.org/10.1017/S0144686X06004910

Krueger, K. R., Wilson, R. S., Kamenetsky, J. M., Barnes, L. L., Bienias, J. L., and Bennett, D. A. (2009). Social engagement and cognitive function in old age. *Experimental Aging Research*, *35*(1), 45–60. https://doi.org/10.1080/03610730802545028

Leopold, T., Geissler, F., and Pink, S. (2012). How far do children move? Spatial distances after leaving the parental home. *Social Science Research*, *41*(4), 991–1002. https://doi.org/10.1016/j.ssresearch.2012.03.004

Lynn, R., and Gordon, I. E. (1961). The Relation of Neuroticism and Extraversion to Intelligence and Educational Attainment. *British Journal of Educational Psychology*, *31*(P2), 194–203. https://doi.org/10.1111/J.2044-

8279.1961.TB02931.X

Macpherson, H., Pipingas, A., and Silberstein, R. (2009). A steady state visually evoked potential investigation of memory and ageing. *Brain and Cognition*, *69*(3), 571–579. https://doi.org/10.1016/j.bandc.2008.12.003

Maril, A., Wagner, A. D., and Schacter, D. L. (2001). On the tip of the tongue: An event-related fMRI study of semantic retrieval failure and cognitive conflict. *Neuron*, *31*(4), 653–660. https://doi.org/10.1016/S0896-6273(01)00396-8

McHugh Power, J. E., Steptoe, A., Kee, F., and Lawlor, B. A. (2019). Loneliness and social engagement in older adults: A bivariate dual change score Analysis. *Psychology and Aging*, *34*(1), 152–162. https://doi.org/10.1037/pag0000287

Meiran, N., and Gotler, A. (2010). Modelling cognitive control in task switching and ageing. *Https://Doi.Org/10.1080/09541440042000269*, *13*(1–2), 165–186. https://doi.org/10.1080/09541440042000269

Niehaves, B., and Plattfaut, R. (2014). Internet adoption by the elderly: Employing IS technology acceptance theories for understanding the age-related digital divide. *European Journal of Information Systems*, *23*(6), 708–726. https://doi.org/10.1057/ejis.2013.19

Nozari, N., Dell, G. S., and Schwartz, M. F. (2011). Is comprehension necessary for error detection? A conflict-based account of monitoring in speech production. *Cognitive Psychology*, *63*(1), 1–33. https://doi.org/10.1016/j.cogpsych.2011.05.001

Piai, V., and Roelofs, A. (2013). Working memory capacity and dual-task interference in picture naming. *Acta Psychologica*, *142*(3), 332–342. https://doi.org/10.1016/J.ACTPSY.2013.01.006

Qualter, P., Vanhalst, J., Harris, R., Van Roekel, E., Lodder, G., Bangee, M., … Verhagen, M. (2015). Loneliness Across the Life Span. *Perspectives on Psychological Science*, *10*(2), 250–264. https://doi.org/10.1177/1745691615568999

Rypma, B., Prabhakaran, V., Desmond, J. E., and Gabrieli, J. D. (2001). Age differences in prefrontal cortical activity in working memory. *Psychology and Aging*, *16*(3), 371–384. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11554517

Salamé, P., and Baddeley, A. (1987). Noise, unattended speech and short-term memory. *Ergonomics*, *30*(8), 1185–1194. https://doi.org/10.1080/00140138708966007

Salthouse, T. A., and Babcock, R. L. (1992). Decomposing adult age differences in working memory. *Developmental Psychology*, *27*(5), 763. https://doi.org/10.1037/0012-1649.27.5.763

Schall, J. D. (2001). Neural basis of deciding, choosing and acting. *Nature Reviews Neuroscience*, *2*(1), 33–42. https://doi.org/10.1038/35049054

Schreiber, J. B., Stage, F. K., King, J., Nora, A., and Barlow, E. A. (2006). Reporting structural equation modeling and confirmatory factor analysis results: A review. *Journal of Educational Research*, Vol. 99, pp. 323–338. https://doi.org/10.3200/JOER.99.6.323-338

Schroll, M., Jónsson, P. V., Mor, V., Berg, K., and Sherwood, S. (1997). An international study of social engagement among nursing home residents. *Age and Ageing*, *26 Suppl 2*(SUPPL. 2), 55–59. https://doi.org/10.1093/AGEING/26.SUPPL_2.55

Shafto, M. A., Tyler, L. K., Dixon, M., Taylor, J. R., Rowe, J. B., Cusack, R., … Matthews, F. E. (2014). The Cambridge Centre for Ageing and Neuroscience (Cam-CAN) study protocol: A cross-sectional, lifespan, multidisciplinary examination of healthy cognitive ageing. *BMC Neurology*, *14*(1). https://doi.org/10.1186/s12883-014-0204-1

Shankar, A. ., Hamer, M. ., McMunn, A. ., And, and Steptoe, A. (2013). Social Isolation and Loneliness: Relationships With Cognitive Function. *Encyclopedia of Mental Health*, *75*, 161–170. https://doi.org/10.1016/B978-0-12-397045-9.00118-X

Shao, Z., Janse, E., Visser, K., and Meyer, A. S. (2014). What do verbal fluency tasks measure? Predictors of verbal fluency performance in older adults. *Frontiers in Psychology*, *5*, 772. https://doi.org/10.3389/fpsyg.2014.00772

Shen, X., Cox, S. R., Adams, M. J., Howard, D. M., Lawrie, S. M., Ritchie, S. J., … Whalley, H. C. (2018). Resting-State Connectivity and Its Association With Cognitive Performance, Educational Attainment, and Household Income in the UK Biobank. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging*, *3*(10), 878–886. https://doi.org/10.1016/J.BPSC.2018.06.007

Sin, E., Shao, R., and Lee, T. M. C. (2020). The executive control correlate of loneliness in healthy older people. *Aging and Mental Health*, 1–8. https://doi.org/10.1080/13607863.2020.1749832

Smith, E. E., Geva, A., Jonides, J., Miller, A., Reuter-Lorenz, P., and Koeppe, R. A. (2001). The neural basis of task-switching in working memory: Effects of performance and aging. *Proceedings of the National Academy of Sciences of the United States of America*, *98*(4), 2095–2100. https://doi.org/10.1073/pnas.98.4.2095

Tisserand, D. J., and Jolles, J. (2003). On the involvement of prefrontal networks in cognitive ageing. *Cortex; a Journal Devoted to the Study of the Nervous System and Behavior*, *39*(4–5), 1107–1128. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/14584569

Tsang, H.-L., and Lee, T. M. C. (2003). The effect of ageing on confrontational naming ability. *Archives of Clinical Neuropsychology*, *18*(1), 81–89. https://doi.org/10.1093/arclin/18.1.81

Valenzuela, M. J., and Sachdev, P. (2007). Assessment of complex mental activity across the lifespan: development of the Lifetime of Experiences Questionnaire (LEQ). *Psychological Medicine*, *37*(7), 1015–1025. https://doi.org/10.1017/S003329170600938X

van den Berg, P., Kemperman, A., de Kleijn, B., and Borgers, A. (2016). Ageing and loneliness: The role of mobility and the built environment. *Travel Behaviour and Society*, *5*, 48–55. https://doi.org/10.1016/j.tbs.2015.03.001

Wascher, E., Schneider, D., Hoffmann, S., Beste, C., and Sänger, J. (2012). When compensation fails: Attentional deficits in healthy ageing caused by visual distraction. *Neuropsychologia*, *50*(14), 3185–3192. https://doi.org/10.1016/J.NEUROPSYCHOLOGIA.2012.09.033

West, R., and Schwarb, H. (2006). The influence of aging and frontal function on the neural correlates of regulative and evaluative aspects of cognitive control. *Neuropsychology*, *20*(4), 468–481. https://doi.org/10.1037/0894-4105.20.4.468

Zatorre, R. J., Meyer, E., Gjedde, A., and Evans, A. C. (1996). PET Studies of Phonetic Processing of Speech: Review, Replication, and Reanalysis. *Cerebral Cortex*, *6*(1), 21–30. https://doi.org/10.1093/cercor/6.1.21

Supplementary Material

1. **Number of participants removed from analysis due to neurological conditions or language difficulties**

Reason for removal	Number of participants removed
Stroke	120
Meningitis/Encephalitis	33
Parkinson's Disease	8
Multiple Sclerosis	4
Serious Head Injury	286
Skull Fracture	13
Severe Stuttering	1
Poor Grasp Language	103
Brain Tumour	5
Alzheimer's Disease	1

2. **Social Background Cam-CAN variables collected at Stage 1 of Cam-CAN**

Cam-CAN Variable number	Cam-CAN Variable	Variable recoded?	Used in final analysis?
v73	**Which qualifications do you have?**	**Highest Qualification achieved**	**Yes**
v15	**Average total household income?**	**N/A**	**Yes**
v6	Type of accommodation?	N/A	Removed from analysis; lack of variance
v41	Number of years worked in this job?	N/A	Removed from analysis; lack of variance
v42	Number of weekly hours?	N/A	Removed from analysis; lack of variance
v24	Ethnic group?	Recoded to Minority status	Removed from analysis; lack of variance
v18	Year first come to live in UK?	recode to years lived in UK	Removed from analysis; lack of variance
v16	Where were you born?	Born in UK?	Removed from analysis; lack of variance
v43	Job involve shift work?	Shift work	Removed from analysis; lack of variance
v44	Job involve night shift work?	Night Shift work	Removed from analysis; lack of variance
v29	Ever had paid work?	N/A	Removed from analysis; lack of variance
v30	Current situation - not had paid work?	Working status	Removed from analysis; lack of variance
v31	Current situation - had paid work?	Working status	Removed from analysis; lack of variance
v34	Age retired?	Retired?	Removed from analysis; lack of variance
v74	Age completed full time education	N/A	Removed due to redundancy

3. **Social interaction Cam-CAN variables from wave 1, used to created EFA scores**

Cam-CAN Variable number	**Cam-CAN Variable**	**Variable recoded?**
v96	Attend any meetings/groups/classes?	Separated into Total number of social activities per week and total time spent at activities (hours per week)
v90	How often see relatives to speak to?	N/A
v91	How often speak to relatives over phone?	N/A
v92	How often text/email relatives?	N/A
v93	How often to friends/family visit you?	N/A
v94	How often speak to friends over phone?	N/A
v95	How often text/email friends?	N/A

4. **Table showing Under 50 standard deviation and range in Cognitive measures**

Under 50	Std. Deviation	Range
Verbal Fluency: Generate S words	5.44	37.00
Simple Repetition	0.26	3.00
Subtracting 7 from 100	1.48	5.00
Spell World Forward	0.09	1.00
Spell World Backward	0.21	1.00
Recall Simple Word	0.44	3.00
Verbal Fluency: Generate P words	5.13	34.00
Verbal Fluency (Animals)	6.20	35.00
Complete Instructions	0.35	2.00
Complete Written Sentence	0.10	1.00
Complex Repetition	0.56	3.00
Picture Identification (Naming)	1.55	18.00
Picture Identification (Pointing)	0.96	7.00
Single Word Reading	0.77	6.00
Visuospatial Score	0.63	4.00
Abstract Thinking Score	0.87	11.00
Self-Reported Memory	0.46	2.00

5. **Table showing Over 50 standard deviation and range in cognitive measures**

Over 50	Std. Deviation	Range
Verbal Fluency: Generate S words	6.04	44.00
Simple Repetition	0.48	3.00
Subtracting 7 from 100	1.57	5.00
Spell World Forward	0.17	1.00
Spell World Backward	0.30	1.00
Recall Simple Word	0.76	3.00
Verbal Fluency: Generate P words	5.94	38.00
Verbal Fluency (Animals)	6.33	39.00
Complete Instructions	0.55	3.00
Complete Written Sentence	0.14	1.00
Complex Repetition	0.74	5.00
Picture Identification (Naming)	1.30	22.00
Picture Identification (Pointing)	0.73	8.00
Single Word Reading	0.52	10.00
Visuospatial Score	1.29	12.00
Abstract Thinking Score	1.30	13.00
Self-Reported Memory	0.67	3.00

6. **Exploratory Factor Analysis**

Exploratory Factor Analysis (EFA) was conducted in the first instance using variables from the cognitive questionnaires (see Table 1.) and social engagement measures (see Table 2.) of the Cam-CAN database. EFA was used as this method allows for investigation of the underlying relationships between give data points and can be used in SEM analysis in a similar fashion to latent variables (unlike, for example, Principal Component Analysis which reduces data to explain the greatest variance and is not appropriate for use in SEM).

As part of the EFA we also employed Parallel Analysis (PA) using O'Connell syntax in SPSS., a method of factor extraction which compares the eigenvalues extracted from the dataset to the eigenvalues of a randomly generated correlation matrix of the same dimensions of the real dataset based on sample size and number of variables. This was deemed more appropriate than using Eigenvalue >1 as this method of factor extraction is prone to over-extracting factors from the data, which may create superfluous results. Conducting PA showed that for the cognitive measures EFA four factors were appropriate for the Over 50 sub-group, and three factors for the Under 50's group. Further PA showed that three social factors were appropriate for both age groups.

The cognitive and social variables in the Cam-CAN are highly correlated with each other, so it was appropriate to use an oblique rotation method, in the case of this analysis direct oblimin, rather than orthogonal (varimax), and maximum likelihood extraction (due to the assumption that data is normally distributed) for the EFA of cognitive and social factors in both age groups.

7. **Table of Cognitive Ability EFA factor loadings for Under 50 (shaded) and Over 50.**

Cognitive Test	Under 50	Over 50	Under 50	Over 50	Under 50	Over50
	Language Development	Language And Working Memory	Verbal Fluency	Verbal Fluency	Working Memory	Long Term Memory
Picture Identification (Naming)	0.648	0.805				
Picture Identification (Pointing)	0.744	0.744				
Single Word Reading	0.624	0.748				
Complex Repetition	0.590	0.760				
Spot the Word Score	0.558		0.388			
Abstract Thinking Score	0.058					0.356
Complete Instructions		0.367				
Recall Simple Word						0.659
Complete Written Sentence		0.291				
Verbal Fluency: Generate P Words			0.850	0.890		
Verbal Fluency: Generate S Words			0.805	0.909		
Verbal Fluency: Generate Animals			0.620	0.481		
Visuospatial Score		0.259				
Simple Repetition		0.077				
Subtracting 7 from 100						

Cognitive Test	Under 50	Over 50	Under 50	Over 50	Under 50	Over50
	Language Development	Language And Working Memory	Verbal Fluency	Verbal Fluency	Working Memory	Long Term Memory
Spell World Forward		0.251			1.223	
Spell World Backward		0.234			0.702	
Self-Reported Memory						

8. **Table of Social Interaction EFA factor loadings for Under 50 (shaded) and Over 50.**

Social Interaction Questions	Under 50	Over 50	Under 50	Over 50	Under 50	Over 50
	Social Participation	**Social Participation**	**Comm. with Friends**	Asynch. Comm.	**Comm. with Relatives**	Synch Comm.
How often text/email friends?			0.398	0.664		
How often text/email relatives?				0.853	0.430	
Total Number of Social Activities	0.650	0.822				
Total Time at Social Activities	0.950	0.800				
How often speak to friends over phone?			0.900			
How often see relatives to speak to?					0.610	0.770
How often speak to relatives over phone?					0.572	0.602
How often do friends/family visit you?					0.428	0.402

Age-Related Differences In Higher-Order Cognitive Mediation Of Socioeconomic Status And Social Engagement: A Structural Equation Modelling Study

Josephine Kearney (University of Manchester), Pamela Qualter (University of Manchester), Cam-CAN (University of Cambridge), Jason R Taylor (University of Manchester).

Abstract

Cognitive decline is one of the hallmarks of the ageing process, and it has been argued that these declines are likely detrimental to participation in social interactions. The current study investigates the relationships between various cognitive abilities, social engagement, and socioeconomic status (SES), in younger and older adults. Data from the Cambridge Centre for Ageing and Neuroscience (Cam-CAN) were analysed using confirmatory factor analysis (CFA) and structural equation modelling (SEM). Factor analysis supported the hypothesis that in adults over 50 years old social interaction was represented by *how* social engagement occurred (synchronously or asynchronously); in adults under 50 years old social interaction factors reflected *who* the social engagement was with (family or friends). The SEM analysis showed that Abstraction (the ability to find meaning in abstract proverbs) was a key mediator between social engagement and SES in younger adults. Fluid Intelligence (mental control and self-regulation) and Abstraction were important in mediating social engagement-SES associations in older adults. The relationships between cognition, social engagement and SES were evenly distributed between Educational Attainment and Average Household Income in the older adults, whereas the association between cognition and social engagement in younger adults was primarily associated with Educational Attainment. These findings indicate that among older adults, cognition relies on broader support from SES factors, and these higher-order cognitive domains support the maintenance of social connections. Among younger adults, cognition is relied on less to support social engagement, but Educational Attainment plays a larger role in underpinning cognitive abilities. These findings highlight specific cognitive domains that can be targeted in interventions that address social isolation and loneliness among older adults, including supporting cognitive development in early adulthood or working to maintain cognitive skills throughout life.

Introduction

The maintenance of social interactions in later life is vital in preventing isolation and loneliness, which can have significant effects on one's mental and physical health (Cacioppo et al., 2006). The ability to create and actively participate in social occurrences in older age relies on the preservation of one's cognitive faculties, in particular language (to use and understand speech) and executive functions (to direct attention and behaviours). However, there is limited research examining how those cognitive domains discretely and/or jointly support social engagement. Additionally, extant research makes little effort to use measures that differentiate between language and executive function, which limits our understanding of the cognitive support these abilities provide for social interactions, instead only informing on the effects of changes in general cognition (Borgeest et al., 2020; Holtzman et al., 2004). The current study strives for a greater degree of separation of language and executive function, using measures that allow for clearer distinctions between the domains. Specifically, we explore both language production and comprehension, and a number of distinct executive processes that are subject to changes as part of the ageing processes. Such an examination allows us to investigate the relationships between discrete cognitive abilities and social engagement in two adult populations.

Cognition in Later Life

Intuitively, language and communication skills are vital for social engagement, but another key element of social participation is executive functions, which is a broad collection of cognitive abilities that facilitate the direction of attention, action planning, flexibility of thought and self-monitoring of behaviours (Diamond, 2013). Because executive function can be considered as multifaceted network of abilities, the structural and functional underpinnings of the faculties are not confined to a narrow brain region; instead, ability in these domains relies on an interwoven system of brain areas (Yuan & Raz, 2014), These processes rely heavily on the frontal lobes the frontal lobe; lesion studies have shown that patients with frontal lesions perform significantly worse on tasks that require verbal fluency, response inhibition and task-switching (Alvarez & Emory, 2006). Similarly, studies using functional magnetic resonance imaging (fMRI) have demonstrated that tasks that drawn on executive functions, such as task-switching, self-monitoring and response inhibition, have repeatedly shown increased neural activity in the prefrontal cortex, anterior cingulate cortex and inferior frontal gyrus (Buchsbaum et al., 2005).

These frontal regions are particularly sensitive to functional and structural changes as part of the ageing process (Tisserand & Jolles, 2003) One study demonstrated that older participants performed worse than younger counterparts when distraction load is increased during a task, suggesting that effective attentional allocation can decrease with age (Washer et al, 2012). Similarly, fMRI research has shown differences in activation patterns between young and old population in tasks that put high demands on working memory, suggesting that functional changes occur over the life course that can alter executive ability (Rypma et al., 2001).

As mentioned above, language (spoken, written or gestural) is crucial for social engagement and requires the ability to produce a communicative output and comprehend the corresponding input from a social partner or group. While there are strong connections between production and comprehension, the two communicative systems are differently affected by ageing. Research has shown that language comprehension is preserved: older adults perform comparably to younger adults in tasks of sentence processing and semantic priming tasks, which necessitates understanding of a prime and target word (Burke & Yee, 1984; Laver & Burke, 1993) Conversely, both written and spoken language production appears to become more effortful with age. Word finding difficulties are a commonly reported issue in later-life, and studies have evidenced this in an increased number of tip of the tongue instances – where a word is seemingly just beyond reach (Juncos-Rabadán et al., 2010).

This phenomenon increases further with infrequent and uncommon words, whereby older people seem to be unable to generate substitutes to their target word (persistent alternatives), instead becoming "stuck" on a word (Burke et al., 1991). Such word finding difficulties, and trouble shifting to an alternative, suggest that older populations have increasingly limited access to or ability to retrieve mentally stored phonological information, perhaps due to deterioration in the connections between linguistic components of a chosen word (Burke & Shafto, 2004). Additionally, accuracy and speed of word generation in naming tasks is significantly reduced in older people, suggesting a change in self-monitoring and word selection in planned speech (Belke & Meyer, 2007; Tsang & Lee, 2003). Finally, dysfluency of speech appears to increase with age; a reduction in speech flow, utterance rate and higher instances of filler word indicate an overall slowing of speech production (Horton et al., 2010) This suggests that continued, fluent language production is important in the maintenance of social relationships, because worsening language production will prevent effective communication and social engagement.

Experimental tasks that target specific domains of cognition are important as language and executive functions are distinct cognitive domains that can change differentially due to ageing or disease (Smith & Baltes, 1993). This has been observed in research with individuals with language deficits due to brain injuries (aphasia); patients with preserved brain regions associated with language perform outperform patients with aphasia on verbal tests of executive function, however this difference between patients is not seen non-verbal tasks of executive function (Reitan, 1960) These are not solely language-based deficits; traumatic brain injuries often displays overlap in structural damage of language and executive function brain regions (Keil & Kaszniak, 2002) often resulting in cognitive changes more commonly associated with disruption to frontal brain structures (Glosser & Goodglass, 1990; Murray et al., 1997). Consequently, those with aphasia have demonstrated decreased ability in attention, response generation and inhibition, and general non-verbal cognitive tasks (Fucetola et al., 2009; Schumacher et al., 2019; Villard & Kiran, 2015). However, in studies of neurologically healthy populations the two domains are often conflated through use of overlapping methods of measurement, such as verbal fluency tasks. This is particularly of note as ageing is often associated with decreased performance in verbal fluency tasks, but without additional differentiation between the language and executive function domains it is difficult to establish where cognitive declines that trigger the change in task performance stem from (Gonzalez-Burgos et al., 2019).

This conflation likely occurs due to an overlap in the network of processes that underpin both language and executive functions. For example, language comprehension is well preserved in later-life, however the addition of attentional demands, such as difficult listening or reading conditions, significantly reduces comprehension scores in older people (Gao et al., 2012; Peelle et al., 2010). This decline in language comprehension performance when demands are increased on attentional allocation demonstrates a functional link between linguistic and executive functions within the brain. Though there are clearly shared processes at play, it is important, in some cases, to attempt a more distinct separation of the cognitive abilities to ensure full understanding of the effects of age-related changes on outcome of interest. If a clear distinction between domains cannot be made, then it is not clear what is driving the cognitive support for social participation. Similarly, age-related deterioration of brain structures in frontal regions that are associated with both language and executive functions contribute to word finding difficulties (Shafto et al., 2007) as language production relies on selecting appropriate words and phonemes from conflicting choices and executive function facilitates/control these choices (Gehring & Knight, 2000).

Social Factors and Ageing

Preserving cognitive function over the lifespan is important for maintaining effective social engagement, and so prevent or reduce isolation and loneliness, a significant issue in older populations (Sin et al., 2020) Beyond cognition, ageing presents many challenges that can hamper social connection, including loss of loved ones, increased mobility issues and declines in physical health (Brummett et al., 2001; Hess, 2001). This is often compounded by isolation affecting one's mental and physical health, increasing the risk of heart and metabolic diseases, strokes, depression, anxiety and issues with sleep (Cacioppo & Cacioppo, 2014). The very serious consequences of reduced ability to take part in meaningful social interactions highlight the importance of preserving cognitive functions that facilitate those connections. The current study examines the relationships between social engagement and the specific aspects of cognition needed for effective social interaction, hypothesising that language and executive functioning are important for maintaining on-going social interactions in ageing populations.

Socio-economic status (SES) can also be highly influential on both preservation of cognitive skills and social participation in later life, as such mapping the interactions between on three factors is key in understanding the underlying interactions. Research has found links between lower educational attainment and cognitive outcomes, particularly highlighting the variability of cognitive performance dependent on life stage and cognitive domain (Zahodne et al., 2015). Furthermore, educational attainment has been found to have mediating effects of social isolation on cognitive ageing (Ardila et al., 2000). Greater feelings of social connectivity have also been associated with preservation of cognitive functions in later life (Ybarra et al., 2008). The three-way relationship has been evidenced further in previous research has demonstrated discrete, age-related difference in the associations between SES, language, memory (related to executive function through working memory), general cognitive ability, and social engagement, where older participants showed greater number and complexity of mediating socio-cognitive relationships than younger adults (Kearney et al., submitted).

There is an increasing literature on the interwoven networks of SES, cognition, and social interaction, but due to the lack of cognitive specificity discussed above more in-depth investigation is needed. The current study extends the extant research by using Confirmatory Factor Analysis (CFA) and Structural Equation Modelling (SEM) on data collected as part of the Cambridge Centre of Ageing and Neuroscience (Cam-CAN) cohort, drawing from the second stage of data (N = 700; (Shafto, Tyler, Dixon, Taylor, Rowe, et al., 2014)). Cam-CAN is a large, cross-sectional dataset that includes distinct measures of executive function and language processes, as well as measures of SEs and social engagement.

Use of tasks that provide greater specificity of cognitive skill offer the opportunity to further explore the link between specific aspects of cognition and social participation. To investigate the distinct facets of executive function, we included the Hotel task, drawing on one's task-switching, action planning, and self-monitoring (Shallice & Burgess, 1991) ;the Cattell task which draws from fluid intelligence, and a proverb comprehension task, which requires abstraction skills (Shafto, Tyler, Dixon, Taylor, Matthews, et al., 2014). Language production was tested using a picture priming task which assesses phonological and semantic access and retrieval. Language comprehension was measured using a sentence acceptability judgement task, whereby participants indicated whether a sentence made grammatical sense either in syntactic or semantic conditions (Rodd et al., 2010). The use of more specific tests as part of the second stage of the Cam-CAN study enabled further investigation of whether it is the shared or different aspects of language and executive function that are related to social participation. It is most likely that social participation relies on a combination of both domains, but with greater specificity those relationships can be more clearly understood. Thus, the current study fills an important gap in our current understanding about the relationship between cognition and social participation across adulthood by exploring multiple specific measures of language (both production and comprehension) and executive functions. This will allow a greater degree of separation between language and executive functions, which in turn will better define the associations between these cognitive domains and measures of both SES and social engagement.

The key hypothesis of the current study is that there will be relationships between cognition and social engagement that mirror those found by Kearney et al (submitted), and that those associations will be greater in number and mediating role in the older population. Further, we anticipated that the greater specificity of cognitive performance will provide a more detailed relationship between language, executive function, and social engagement, as influenced by socioeconomic background.

Methods

Participants

Participants were sampled from the second stage of the Cambridge Centre for Ageing and Neuroscience (Cam-CAN) study (for recruitment protocol details see the Cam-CAN protocol, Shafto et al., 2014). The participants included in the second stage of data collection were a subset (N = 700, 91.3% British native) from the first stage of data collection (N= 3000) and were included based on MMSE scores (over 24 required) and have no contraindications for MRI or MEG (magnetoencephalography). Participants that had a history of neurological pathologies were excluded from analysis. For this analysis participants (N = 509, female = 264) were included based on completion of all language and executive function-based behavioural tasks (see table 1 for task details), then divided into two age-based sub-groups; Under 50 years old n = 228 (female = 121), Over 50 n = 283 (female = 144). Ethical approval for the original Cam-Can study was obtained from the Cambridgeshire 2 (now East of England - Cambridge Central) Research Ethics Committee. Participants gave written informed consent.

Cognitive Behavioural Measures

In this analysis, a number of behavioural measures of cognitive ability were derived. These tasks probed specific elements of language and executive functions individually, see Table 1 for brief overview.

Cognitive Variable Name in SEM model	Task Description
Executive Function	Deviation from optimum time (2 minutes) to complete each of the 5 tasks in the Hotel Task in seconds. Negatively coded to reflect that a greater amount of time spent on a task indicated poorer performance. normalised using percentage of maximum.
Fluid Intelligence	Cattell's Culture Fair Score (maximum score of 46). Positively coded, higher score reflects better performance. Normalised using percentage of maximum.
Abstraction	Proverb Comprehension score (maximum score of 6), higher score reflects better performance normalised using percentage of maximum.
Sentence Comprehension	Proportion of correct "unacceptable" responses, higher score reflects better performance. Normalised using percentage of maximum.
Speech Production	Number of correct naming responses, higher score reflects better performance normalised using percentage of maximum.

Table 1: Cognitive Variables included in SEM model, including the Cam-CAN cognitive behavioural measures they were derived from and how they were derived.

Language Measures[2]

This study analysed the following measures of speech production and language comprehension.

Picture Naming Task. This task tapped into language production by presenting participants with 200 images of common items whose names were either one or two syllables long, in a pseudorandom order. A fixation point was presented for 500 milliseconds, followed by an object for 750 milliseconds which the participants named aloud, followed by a blank screen for 1000 milliseconds. The participants were instructed to name the items as quickly and accurately as possible and were scored for accuracy. Number of correct responses was calculated, normalised using the percentage of the maximum possible score of 400 correct responses.

Sentence Comprehension Task. This task required the participant to make a judgement of acceptability of spoken phrases some of which were semantically or syntactically ambiguous, probing the participant's language comprehension. The participants heard 224 phrases in pseudo-random order presented across two blocks; 126 grammatically correct sentences, 42 of which are unambiguous e.g., "painful knees heal" or "glittering jewels were", 42 contain syntactically ambiguous phrases e.g., "cutting boards is" and 42 contain semantically ambiguous phrases e.g., "private coaches transport". The participants heard 98 grammatically incorrect sentences e.g., "clinging children are", to prevent all choices from being grammatically correct. Participants heard the sentences read in a female voice up to the point of ambiguity (e.g., "private coaches…"), followed by a male voice 200ms later, that would disambiguate the phrase (e.g., "transport"). Ambiguous phrases all had at least two possible structures or meanings, half of which were dominant interpretations and half were subordinate interpretations. For this analysis the proportion of correct "Acceptable" responses (60% of trials) was calculated for each participant, which was then translated to a deviation from the correct number of

[2] Tip-of-the-Tongue (ToT): This task was also considered for analysis in this research however, it was found in both the Under 50 and Over 50 groups there was not sufficient variance in ToT score to include the measure in this study.

“Acceptable” responses (proportion of unacceptable responses/0.6), this score was then used in analysis.

Executive Function Measures

The executive function measures were also collected as part of the second stage of the Cam-CAN data collection. The following tasks were included in this analysis as they probed a range of executive processes reflecting fluid intelligence, abstraction, task-switching and mental control.

Cattell's Culture Fair Task. This task probed Fluid Intelligence, believed to support mental control and complex goal-oriented behaviour, using a battery of non-verbal puzzles. These puzzles required the participant to complete a series of drawings, classify images based on a given rule, complete a sequence of matrices and identify a pattern that fulfilled a given condition. The participant did this using pen-and-paper and multiple choice responses, the test was then scored by the experimenter for a maximum score of 46, a normalised score was then computed using percentage of the maximum possible score of 46 correct responses.

Proverb Comprehension Task. This task examines a particular aspect of executive functions, Abstraction, which allows for the derivation of meaning from abstract concepts, such as proverbs e.g., “*Still waters run deep*”. The participants were shown three consecutive proverbs on a screen, then asked to explain the meaning of each one. The verbal responses were recorded and scored out of two; 0 for incorrect answers, 1 for concrete meanings and 2 for abstract meanings, the maximum score being 6. A normalised score was then computed using percentage of the maximum possible score.

The Hotel Task. This task was used to explore complex planning and self-management during multitasking, a distinct factor of Executive Function. The participants were given five physical, fictional tasks from the Hotel Task; writing out bills, sorting money, proofreading, sorting mixed playing cards and alphabetizing labels (Manly et al., 2002). The tasks were described to the participants, who were then instructed to attempt all five of the tasks, spending as much time as possible on each one, over the course of ten minutes. Importantly, the whole task cannot be completed within the allotted time; each of the individual tasks would require more than ten minutes to complete. The aim of the task is that the participant effectively manages their time by allocating 2 minutes to each task. A clock, facing away from the participant, was available for them to look at whenever they wished. The experimenter recorded the time taken on each task and the participant was given a prompt after five minutes if they had only attempted one task. The analysis in this study used the participant’s time deviation, which is time beyond from the ideal time spent on each task in seconds, normalised to the percentage of the maximum possible time deviation that was available to the participants (920 seconds).

Socioeconomic Measures

Socioeconomic measures were collected in the initial data collection of Cam-CAN (Stage 1), for this analysis Educational attainment and Average Household Income were used, other measures were considered for analysis but due to missing and homogenous data patterns were deemed inappropriate in this instance. Participants’ Educational Attainment was derived using a culmination score of qualifications achieved based on the Life Experience Questionnaire score (Valenzuela & Sachdev, 2007), see supplementary material for full details). Average Household Income was scored 1-5 based on total household income before tax (see Cam-CAN protocol: Shafto et al., 2014).

Social participation Measures

Social Participation measures were constructed using socialisation questionnaire data from the first wave of Cam-CAN data collection (see table 2). This analysis used confirmatory factor analysis (CFA) factors outlined in Kearney et al., (submitted), this present study replicated the factor structure found to be appropriate in the previous research. The Under 50 sample had 3 social participation factors: Social participation, Contact with Family and Contact with Friends (Figure 1). The Over 50 sample also replicated the original study with 3 social participation factors: Social Participation, Synchronous communication and Asynchronous communication (Figure 2). The factors from this analysis were used as the social engagement variables in the present study.

CFA Variable Name	Variable Name
S1*	Total Number of Social Activities
S2*	Total Time Spent at Social Activities
S3†	How often see relatives to speak to?
S4†	How often speak to relatives over phone?
S5†	How often text/email relatives?
S6†	How often to friends/family visit you?
S7†	How often speak to friends over phone?
S8†	How often text/email friends?

*Table 2. Questionnaire measures used in confirmatory factor analysis for both Under and Over 50 groups. * S1 and S2 are both derived from a single item in the Cam-CAN dataset "Attend any meetings/groups/classes? How Often?" † Participants chose from the following responses: 1. Never 2. Daily 3. 2-3 times a week 4. At least weekly 5. At least monthly 6. Less often 7. Don't know 8. No answer 9. Not asked*

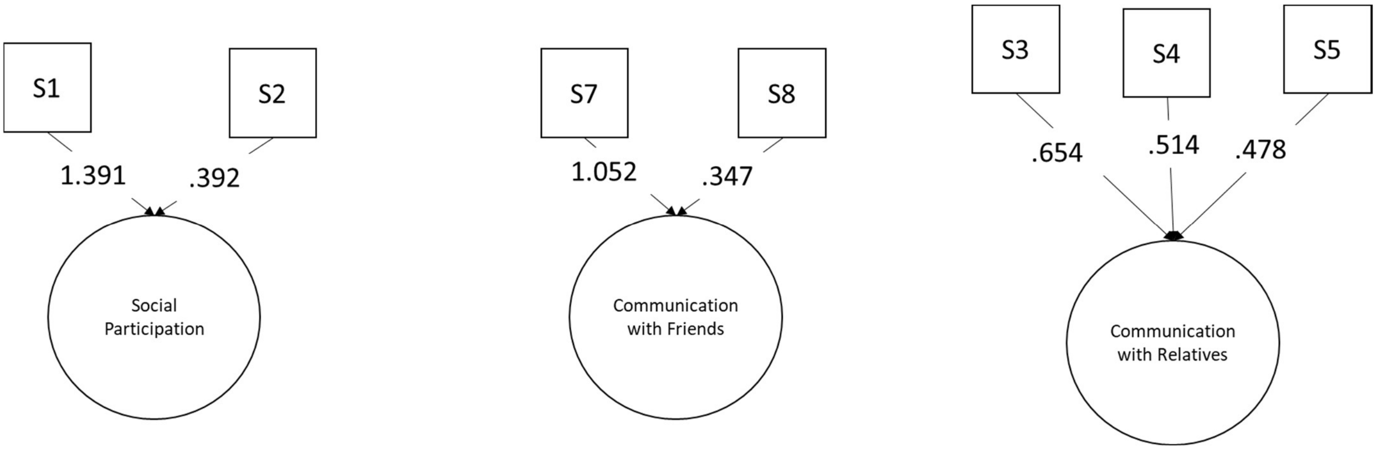


Figure 1: CFA factor loading of Social Engagement items for the Under 50 sub-group

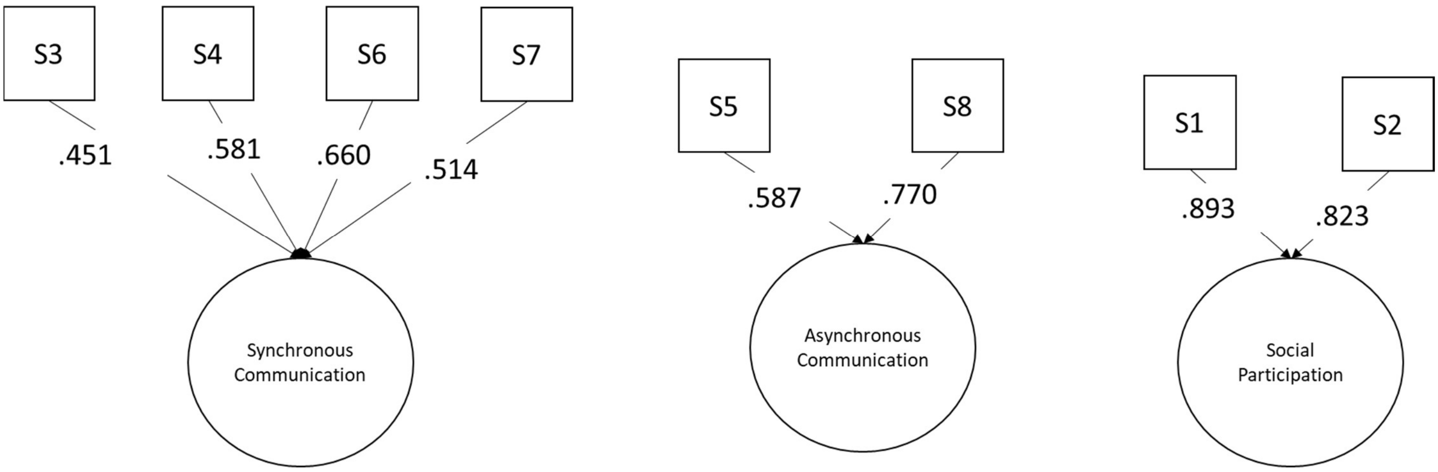


Figure 2: CFA factor loading of Social Engagement items for the Over 50 sub-group.

Statistical Analysis

Structural Equation Modelling (SEM) was used to examine the interactions between SES, language, and executive function measures, and social engagement in Under and Over 50 years old sub-groups. The models were tested using Mplus version 8.4 (Muthen and Muthen, 2019), using maximum likelihood estimation with robust standard error (Hu & Bentler, 2009). Absolute model fit was evaluated using comparative fit index (CFI), Tucker-Lewis Index (TLI), and root mean square error of approximation (RMSEA), with CFI and TLI greater than 0.95 and RMSEA less than 0.05 are considered to be a good indication of model fit (Schreiber et al., 2006).

Results

Under 50 Model

The Under 50 model was found to be a good fit for the data, x2 (44) = 68.315, p <.01; RMSEA = 0.050, 90% CI [0.025, 0.073], p <.5; CFI = 0.921, TLI = 0.839.

Educational Attainment and Average Household Income were correlated (r=0.149, p= <0.05). Abstraction was correlated with Fluid Intelligence (r =0.138, p= <0.05), Speech Production (r= 0.164, p= <0.05), and Executive Function (r= 0.137, p= <0.05).

All cognitive measures were found to have significant associations with one or more of the SES measures (Figure 3): Sentence Comprehension, Speech Production, Fluid Intelligence and Abstraction were found to interact with Educational Attainment. Executive Function and Abstraction were associated with Average Household Income. One measure of cognition, Abstraction, was found to have a direct association with Communication with Relatives (Table 3)

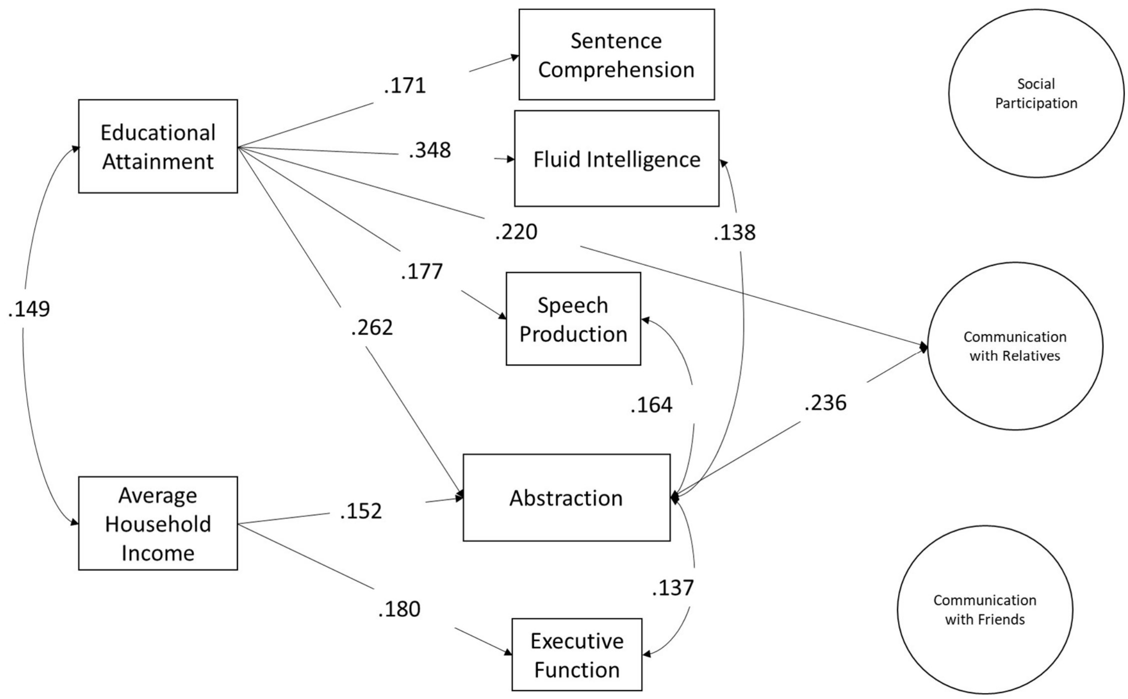


Figure 3: Full SEM model of Under 50 sub-group

Direct Paths		Coefficients		95% CI	
		Beta	S.E	Lower	Upper
Sentence Comprehension (SynSem task)	**Educational Attainment**	0.171	0.066	0.001	0.342
Speech Production (Picture Naming)	**Educational Attainment**	0.177	0.067	0.005	0.348
Fluid Intelligence - Mental Control (Cattell Task)	**Educational Attainment**	0.348	0.061	0.192	0.504
Communication with Relatives	**Educational Attainment**	0.220	0.092	-0.018	0.457
Fluid Intelligence – Abstraction (Proverb Comprehension)	**Educational Attainment**	0.262	0.063	0.100	0.424
	Average Household Income	0.152	0.066	-0.019	0.322
	Communication with Relatives	0.236	0.091	0.003	0.469
Executive Function (Hotel Task)	**Average Household Income**	0.180	0.068	0.006	0.354

Table 3. Significant direct pathways in Under 50 SEM

One social engagement measure was found to have an association with a SES measure: Communication with Relatives showed a direct relationship with Educational Attainment. This same social measure was associated with the cognitive measure of Abstraction, and further mediation modelling also showed that Abstraction score mediated the relationship between Educational Attainment and Communication with Relatives (see Table 4).

Indirect Paths			Coefficients		95% CI	
SES Measure (A)	**Mediating Cognitive Measure (B)**	**Social Factor (C)**	***Beta***	***SE***	***Lower Limit***	***Upper Limit***
Educational Attainment	**Abstraction**	**Communication with Relatives**	0.062	0.028	-0.010	0.134

Table 4. Significant indirect pathways in Under 50 model

Social Participation and Communication with Friends were found to be independent of SES and cognitive measures for the Under 50 sub-group.

Over 50 Model

The model fit for Over 50 data was found to be good; x2 (61) = 109.406, p <.0001; RMSEA = 0.053, 90% CI [0.037, 0.069], p <.5; CFI = 0.908, TLI = 0.842.

In this model Educational Attainment and Average Household Income were correlated (r = 0.284, p = <.001). Speech Production and Fluid Intelligence were correlated (r=0.382, p=<0.001). Social Participation was correlated with Synchronous Communication (r=0.442, p=<0.001) and negatively correlated with Asynchronous Communication(r= -0.170, p=<0.05).

Several cognitive measures had relationships with both SES measures in this model (Figure 4). Both Speech Production and Fluid Intelligence were associated with Educational Attainment and Household Income. Additionally, Sentence Comprehension was related to Educational Attainment, Abstraction was related to Average Household Income. Executive Function had no significant interaction with either SES measure. Two social engagement measures were directly associated with SES measures: Asynchronous communication with Educational Attainment and Social Participation negatively with Average Household Income (Table 5).

Both of these SES-Social associations were additionally mediated by cognitive factors: Abstraction was found to mediate the relationship between Social Participation and Average Household Income, and Fluid Intelligence mediated the connection between Asynchronous Communication and Educational Attainment (Table 6.). Synchronous Communication was also found to have no direct or mediated associations with any SES and cognitive measures in this model.

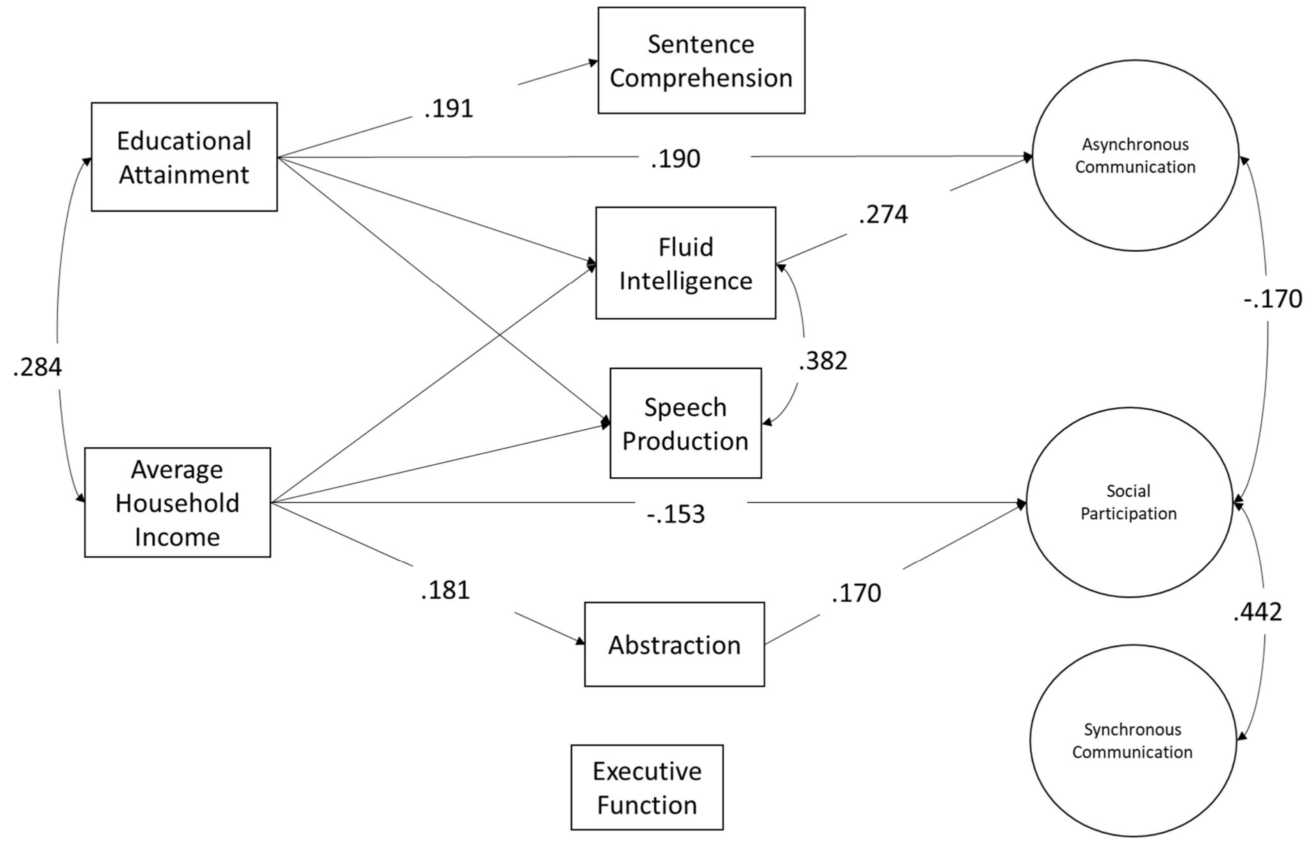


Figure 4: Full SEM model of Over 50 sub-group

Direct Paths		Coefficients		95% CI	
		Beta	S.E	Lower	Upper
Sentence Comprehension (SynSem task)	Educational Attainment	0.191	0.057	0.046	0.337
Asynchronous Communication	Educational Attainment	0.190	0.081	-0.019	0.399
Speech Production (Picture Naming)	Educational Attainment	0.219	0.050	0.090	0.347
	Average Household Income	0.156	0.055	0.015	0.297
Fluid Intelligence - Mental Control (Cattell Task)	Educational Attainment	0.232	0.055	0.089	0.374
	Average Household Income	0.149	0.057	0.037	0.296
	Asynchronous Communication	0.274	0.78	0.073	0.475
Fluid Intelligence – Abstraction (Proverb Comprehension)	Average Household Income	0.182	0.053	0.044	0.319
	Social Participation	0.170	0.65	0.003	0.337
Social Participation	Average Household Income	-0.153	0.067	-0.326	0.021

Table 5. Significant Direct Pathways of Over 50 SEM

Indirect Paths			Coefficients		95% CI	
SES Measure (A)	Mediating Cognitive Measure (B)	Social Factor (C)	*Beta*	*SE*	*Lower Limit*	*Upper Limit*
Educational Attainment	Fluid Intelligence	Asynchronous Communication	0.064	0.023	0.005	0.122
Average Household Income	Abstraction	Social Participation	0.031	0.014	-0.005	0.67

Table 6. Significant Indirect Pathways in Over 50 SEM

Discussion

This study investigated the connections between cognitive domains and social engagement, and how these associations are influenced by socioeconomic background, in two age groups (younger and older adults). This study used targeted measures of language production, comprehension, and executive function to investigate whether these domains demonstrate different patterns of decline as part of the ageing process, and if the cognitive domains tapped by these tasks mediate the relationships between SES and social engagement differently. Using confirmatory factor analysis (CFA) and structural equation modelling (SEM), we demonstrated clear differences between the two age groups in (1) the structure of social engagement, and (2) the relationships between social and cognitive variables. Specifically, among younger participants, measures of cognition had more direct relationships with Educational Attainment than with Average Household Income. Additionally, only one social engagement factor was associated with a measure of SES (Communication with Relatives and Educational Attainment), a relationship that was mediated by Abstraction. In contrast, among the older participants, the direct connections between measures of cognition and SES measures were distributed more evenly, as were direct and indirect social engagement and SES connections. The complex interactions observed in the Over 50 group suggests that cognition is more generally supported by SES, and that cognitive mediation domains can underpin some social engagement in older people.

We found a difference in how social interaction is represented in the age groups. The factor structure in the CFA of the Under 50 group was characterised by the people to be communicated with, either Family (indicated by questions such as "How often do you see your family to speak too?" loading on to this factor or Friends (indicated by questions such as "How often text/email friends?". The factor structure in the Over 50 group was different, being characterised by how the communication occurred, either Asynchronously where questions regarding email or text loaded together regardless of social bond or Synchronously where questions regarding seeing someone in person or talking on the phone loaded onto the factor together, a finding that is supported by previous research (Kearney et al., submitted).

We also found that among the younger adults, cognitive measures had four direct connections with Educational Attainment, whereas Average Household Income had only two. The cognitive measures associated with Educational Attainment were across several measures, suggesting education influences multiple cognitive domains in this age group. Furthermore, the social engagement factor Communication with Relatives was also directly associated with Educational Attainment, a relationship that was mediated by the cognitive measure of Abstraction, suggesting that this facet of social engagement is influenced by Educational Attainment, and that Abstraction can facilitate this relationship. For older adults, there was a uniform pattern of direct associations between measures of cognition and SES: Sentence Comprehension, Fluid Intelligence and Speech Production were found to be directly associated with Educational Attainment; Fluid Intelligence, Speech Production and Abstraction were associated with Average Household Income. This suggests that, for older adults, all of the cognitive domains examined in this study are influenced more evenly by life factors. Among the older group, there was also an evenly distributed direct and indirect relationships between social engagement and SES; Asynchronous Communication with Educational Attainment and Social Participation with Average Household Income. Additionally, these interactions were mediated by Fluid Intelligence and Abstraction, respectively. The complexity of the interactions in the model of the Over 50 group indicates that cognitive domains are supported by broader SES factors, and the cognitive processes can further reinforce the relationships between social engagement and SES.

Educational Attainment and Sentence Comprehension were associated in both the Under 50 and Over 50 group. In both populations this could reflect the relationship between reading comprehension and school performance as those with lower reading comprehension at age 11 years have been found to perform significantly lower on educational tests than peers with good reading comprehension (Ricketts et al., 2014). However, in the older cohort this may also reflect an influence of working memory, as research suggests that language processing is supported by working memory, particularly if the sentence is syntactically complex or semantically implausible (Yoon et al., 2015). Previous research has also found that language and working memory group together in factor analyses in older participants, and that joint language and working memory factor is also associated with education (Kearney et al., submitted). There is also evidence that one's ability to mentally switch from one thing to another also predicts one's sentence comprehension scores (Goral et al., 2011). Both working memory and task switching domains are found to decline with age (De Beni & Palladino, 2010) which may contribute to declining language processing ability. Educational attainment may therefore increase the longevity of these abilities and support them into older age.

We also found direct relationships between Educational Attainment and Speech Production in both the younger and old age groups. This element of cognition was measured using a picture naming task, and similarly to sentence comprehension, relies on memory for the retrieval of appropriate words (Baddeley, 2003), and in later life is often subject to decline (Tsang & Lee, 2003). However, one's level of education is highly associated with vocabulary, which typically builds into mid-life and is usually relatively untouched by ageing related declines, especially if vocabulary task itself is formatted to avoid memory confounds (such as multiple choice answers) (Verhaeghen, 2003), which may be why the relationship between Educational Attainment and Speech production is observed in both groups.

Additionally, both age groups had direct relationships between Educational Attainment and Fluid Intelligence. This finding supports evidence that Fluid Intelligence is strongly related to reading and mathematics ability, an association that increases with task complexity and age (Peng et al., 2019). We did not find this connection in the younger cohort; however, this relationship was observed in the older cohort. This association may reflect that higher income jobs require flexibility in thinking as the individual tasks in this measure require some level of mental shifting and control that could be associated with high-income careers and lifestyles. Average Household Income was also found the be associated with Abstraction, or the ability to think in a conceptual manner, beyond literal meaning. Both of these associations are likely due to how, in this age group, higher income is associated with more managerial positions that would require a person to shift between task-oriented work and people-oriented problem solving that requires a significant flexibility in thinking to be successful. This association between Average Household Income and Abstraction was also observed in the Under 50 group, may reflect similar mechanisms to the ones proposed in the Over 5 group, that; higher paid jobs may covertly select for abstraction skills. A similar relationship was found between Educational Attainment and Abstraction, which was not observed in the older group, this may be because high paid professions require further education when they did not in the past. It might also be because the older population are more familiar with the proverbs used in this task than younger participants, an occurrence that has been demonstrated to a greater extent in school children (Nippold et al., 2001; Resnick, 1982).

The Over 50 age group also showed associations between Average Household Income and Speech Production, which was not observed in the Under 50 group. While Speech Production can be affected by memory deficits, previous research has found an association between income and greater vocabulary in older adults, especially those that were able to pursue higher education (Educational Attainment was found to be highly correlated with Average Household Income in this group) (Zahodne et al., 2015) this suggests an interaction between resource availability and cognition that becomes increasingly influential in later life. This resource-cognition interaction can also be seen in the association between Average Household Income and Fluid Intelligence in this group, as discussed above, though it is not necessarily clear from this research whether high fluid intelligence and abstraction ability drives the pursuit of high income jobs, or if these factors are bolstered by such professions.

The Over 50 group did not show any associations with Executive Functions, unlike the Under 50 group, perhaps due to the neurological ageing driving increased variability in this domain. Executive functions in this study are underpinned by attentional-shifting and working memory, cognitive skills that are often subject to age-related deterioration (Clarys et al., 2009; Wascher et al., 2012), due to changes in frontal brain structures cause being ageing (Wingfield & Grossman, 2006). The analysis of the younger group, however, did find a connection between Average Household Income and Executive Functions. This relationship might underscore the importance of resources in support cognition, as there is evidence to show that childhood family income is associated with executive function (Deer et al., 2020) a relationship that could still be influential as individuals in the Under 50 population enter the workforce.

Perhaps surprising is that neither Under 50 or Over 50 group showed relationships between language measures and social engagement factors, or the more targeted measure of Executive Function (the Hotel task) and social engagement factors, initially hypothesised in this research to support social ability. Instead, in both groups, Abstraction had a direct and mediating relationship with a social engagement factor, Educational Attainment to Communication with Relatives in the Under 50 groups and Average Household Income to Social Participation in the Over 50 group. While the relationships in the two groups are mediating different SES-to-social engagement relationships, the direct and indirect paths observed in these models may be indicative of high-order cognitive function supporting ongoing social skills. That is, language processing in itself is not necessarily needed to support social connection, but the ability to reason in less concrete, more creative ways is. Indeed, research has found that higher levels of abstract thought is associated with reduction in prejudicial thinking in politically conservative individuals (Luguri et al., 2012). In the Over 50 group, Fluid Intelligence was also found to be a mediating factor between Educational Attainment and Asynchronous Communication (no direct relationship was observed between Fluid Intelligence and Asynchronous Communication), which may reflect a similar relationship between high-order cognition and social connection. Again, basic language production is not necessarily needed for on-going asynchronous conversation, instead it is the ability to task-switch and improved cognitive control that supports this. Previous research has also indicated mediating relationships between similar elements of cognition, Educational Attainment, and Asynchronous Communication that may also indicate that this communication method is more effortful as age increases (Kearney et al., submitted).

Educational Attainment was directly associated with Asynchronous Communication, an association supported by previous research (Kearney et al., submitted). This relationship may occur as those that pursue higher education are more likely to move away from their place of birth, increasing the geographical range of family and friends (Leopold et al., 2012), and in turn, increasing the reliance on texting or emailing to stay in touch. Additionally, asynchronous communication is commonplace in professions associated with higher levels of education, which could support adopting the use of email in a more social setting for an older population.

Average Household Income was negatively associated with Social Participation in the Over 50 group, however, when this relationship is mediated by Abstraction the relationship is positive. This could be due to high-income positions increasing social isolation due to high demands on time and energy, and Abstraction ability can mediate this effect, perhaps due the reasons discussed above, whereby higher levels of abstract thinking facilitates social connection beyond potential social barriers (Luguri et al., 2012).

There are limitations to this study, firstly the data presented here is cross-sectional in nature, which constrains any conclusions about the casual nature of the relationships we found in this study. While we can assert that we were able to find differences in the relationships observed in this cohort of participants based on their ages, we cannot be certain that the associations we found were due to the ageing process. This issue highlights a need for longitudinal research into the associations characterised here, so that the precise nature of the interactions between ageing, cognition and social engagement can be established. Additionally, there are potentially unmeasured elements across the factors used in this study that we have not been able to account for, such as proximity to familial support, years lived in the UK or distinct memory measures.

Our initial prediction for this research was that we would find greater interaction between SES, cognition, and social engagement in both models. The research presented here has found relationships between SES and cognition, but the number of mediating relationships are smaller than expected. This may be due to elements of cognition not included in this analysis, such as memory, or perhaps because the Fluid Intelligence and Abstraction measures encompass deeper aspects of cognition while the measures of language are more basic. To this end, future work should look to break down the more complex facets of these functions or look to probe them more deeply with neuroimaging measures to highlight the underlying neurological mechanisms.

Overall, we have demonstrated that the representation of social engagement at the factor level was different for the younger adults (Under 50 years) compared to the older adults (Over 50 years) in this study. Further, relationships between SES measures, cognition, and social factors differ in the younger and older age groups. These findings highlight differences in socialisation priorities in the age groups and suggest that SES and social connections draw from more cognitive support in later life. We have shown that while language and executive functions have significant overlap as cognitive processes, these cognitive domains show different patterns of association with SES measures and social engagement factors in the younger and older samples of this study, suggesting that reliance on language and executive functions is different in the two age groups. It is unlikely that these cognitive domains can be fully untangled, but it is an important consideration in both language and executive research that the measures accurately reflect the cognitive processes of interest and acknowledge the limitations caused by linguistic-executive overlaps. The differences between groups in the relationships between SES and cognition point to a shift in how cognition supports social engagement in later life, suggesting that there is a greater reliance on income to support cognitive ability. This finding highlights an area that could be of importance for intervention; financial support of people with lower-SES throughout the life course may mitigate income-cognition disparities and help bolster cognitive preservation in older age. Similarly, the increased number of cognitively mediated pathways in the Over 50 group underscores the importance of maintaining cognitive ability into the later years, to sustain fulfilling social engagement and reduce loneliness and social isolation (Rozanova et al., 2012).

To conclude, we have evidenced meaningful differences in social interaction in younger and older adult populations, demonstrating a modality versus interactive partner difference. This research also found age-group differences in associations between measures of SES and cognition and social engagement; Educational Attainment was found to be most influential in the Under 50 population, whereas Educational Attainment and Average Household Income were equally influential on cognition and social engagement in the Over 50 population.

Statement of Ethical Approval

Ethical approval for the original Cam-CAN study was obtained from the Cambridgeshire 2 (now East of England - Cambridge Central) Research Ethics Committee. Participants gave written informed consent.

Conflict of interest

The authors declare no conflicts of interest

Contributions

Josephine Kearney: Conceptualization, Methodology, Formal analysis, Writing - Original Draft, Visualization.

*Pamela Qualte*r: Validation, Writing - Review & Editing, Supervision.

*Ca*m-CAN: Investigation, Resources.

Jason R Taylor: Validation, Writing - Review & Editing, Supervision

References

Alvarez, J. A., & Emory, E. (2006). Executive function and the frontal lobes: A meta-analytic review. In *Neuropsychology Review* (Vol. 16, Issue 1, pp. 17–42). https://doi.org/10.1007/s11065-006-9002-x

Ardila, A., Ostrosky-Solis, F., Rosselli, M., & Gomez, C. (2000). Age-Related Cognitive Decline During Normal Aging: The Complex Effect of Education. *Archives of Clinical Neuropsychology*, *15*(6), 495–513. https://doi.org/10.1093/arclin/15.6.495

Baddeley, A. (2003). Working memory and language: an overview. *Journal of Communication Disorders*, *36*(3), 189–208. https://doi.org/10.1016/S0021-9924(03)00019-4

Belke, E., & Meyer, A. S. (2007). Single and multiple object naming in healthy ageing. *Language and Cognitive Processes*, *22*(8), 1178–1211. https://doi.org/10.1080/01690960701461541

Borgeest, G. S., Henson, R. N., Shafto, M., Samu, D., & Kievit, R. A. (2020). Greater lifestyle engagement is associated with better age-adjusted cognitive abilities. *PLOS ONE*, *15*(5), e0230077. https://doi.org/10.1371/journal.pone.0230077

Brummett, B. H., Barefoot, J. C., Siegler, I. C., Clapp-Channing, N. E., Lytle, B. L., Bosworth, H. B., Williams, R. B., & Mark, D. B. (2001). Characteristics of Socially Isolated Patients With Coronary Artery Disease Who Are at Elevated Risk for Mortality. *Psychosomatic Medicine*, *63*(2), 267–272. https://doi.org/10.1097/00006842-200103000-00010

Buchsbaum, B. R., Greer, S., Chang, W. L., & Berman, K. F. (2005). Meta-analysis of neuroimaging studies of the Wisconsin Card-Sorting Task and component processes. *Human Brain Mapping*, *25*(1), 35–45. https://doi.org/10.1002/hbm.20128

Burke, D. M., MacKay, D. G., Worthley, J. S., & Wade, E. (1991). On the tip of the tongue: What causes word finding failures in young and older adults? *Journal of Memory and Language*, *30*(5), 542–579. https://doi.org/10.1016/0749-596X(91)90026-G

Burke, D. M., & Shafto, M. A. (2004). Aging and Language Production. *Current Directions in Psychological Science*, *13*(1), 21. https://doi.org/10.1111/J.0963-7214.2004.01301006.X

Burke, D. M., & Yee, P. L. (1984). Semantic priming during sentence processing by young and older adults. *Developmental Psychology*, *20*(5), 903–910. https://doi.org/10.1037/0012-1649.20.5.903

Cacioppo, J. T., & Cacioppo, S. (2014). Social Relationships and Health: The Toxic Effects of Perceived Social Isolation. *Social and Personality Psychology Compass*, *8*(2), 58–72. https://doi.org/10.1111/spc3.12087

Cacioppo, J. T., Hawkley, L. C., Ernst, J. M., Burleson, M., Berntson, G. G., Nouriani, B., & Spiegel, D. (2006). Loneliness within a nomological net: An evolutionary perspective. *Journal of Research in Personality*, *40*(6), 1054–1085. https://doi.org/10.1016/j.jrp.2005.11.007

Clarys, D., Bugaiska, A., Tapia, G., & Baudouin, A. (2009). Ageing, remembering, and executive function. *Https://Doi.Org/10.1080/09658210802188301*, *17*(2), 158–168. https://doi.org/10.1080/09658210802188301

De Beni, R., & Palladino, P. (2010). Decline in working memory updating through ageing: Intrusion error analyses. *Http://Dx.Doi.Org/10.1080/09658210244000568*, *12*(1), 75–89. https://doi.org/10.1080/09658210244000568

Deer, L. K., Hastings, P. D., & Hostinar, C. E. (2020). The Role of Childhood Executive Function in Explaining Income Disparities in Long-Term Academic Achievement. *Child Development*, *91*(5). https://doi.org/10.1111/cdev.13383

Fucetola, R., Connor, L. T., Strube, M. J., & Corbetta, M. (2009). *Unravelling nonverbal cognitive performance in acquired aphasia*. https://doi.org/10.1080/02687030802514938

Gao, X., Levinthal, B. R., & Stine-Morrow, E. A. L. (2012). The Effects of Ageing and Visual Noise on Conceptual Integration during Sentence Reading. *Quarterly Journal of Experimental Psychology*, *65*(9), 1833–1847. https://doi.org/10.1080/17470218.2012.674146

Gehring, W. J., & Knight, R. T. (2000). Prefrontal-cingulate interactions in action monitoring. *Nature Neuroscience*, *3*(5), 516–520. https://doi.org/10.1038/74899

Glosser, G., & Goodglass, H. (1990). Disorders in executive control functions among aphasic and other brain-damaged patients. *Journal of Clinical and Experimental Neuropsychology*, *12*(4), 485–501. https://doi.org/10.1080/01688639008400995

Gonzalez-Burgos, L., Hernández-Cabrera, J. A., Westman, E., Barroso, J., & Ferreira, D. (2019). Cognitive compensatory mechanisms in normal aging: A study on verbal fluency and the contribution of other cognitive functions. *Aging*, *11*(12), 4090–4106. https://doi.org/10.18632/aging.102040

Goral, M., Clark-Cotton, M., Spiro, A., Obler, L. K., Verkuilen, J., & Albert, M. L. (2011). The Contribution of Set Switching and Working Memory to Sentence Processing in Older Adults. *Experimental Aging Research*, *37*(5), 516–538. https://doi.org/10.1080/0361073X.2011.619858

Hess, T. M. (2001). Ageing-related influences on personal need for structure. *International Journal of Behavioral Development*, *25*(6), 482–490. https://doi.org/10.1080/01650250042000429

Holtzman, R. E., Rebok, G. W., Saczynski, J. S., Kouzis, A. C., Doyle, K. W., & Eaton, W. W. (2004). Social network characteristics and cognition in middle-aged and older adults. *Journals of Gerontology - Series B Psychological Sciences and Social Sciences*, *59*(6), P278–P284. https://doi.org/10.1093/geronb/59.6.P278

Horton, W. S., Spieler, D. H., & Shriberg, E. (2010). A Corpus Analysis of Patterns of Age-Related Change in Conversational Speech. *Psychology and Aging*, *25*(3), 708. https://doi.org/10.1037/A0019424

Hu, L., & Bentler, P. M. (2009). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Https://Doi.Org/10.1080/10705519909540118*, *6*(1), 1–55. https://doi.org/10.1080/10705519909540118

Juncos-Rabadán, O., Facal, D., Rodríguez, M. S., & Pereiro, A. X. (2010). Lexical knowledge and lexical retrieval in ageing: Insights from a tip-of-the-tongue (TOT) study. *Language and Cognitive Processes*, *25*(10), 1301–1334. https://doi.org/10.1080/01690961003589484

Kearney, J. F., Qualter, P., Cam-CAN & Taylor, J. R. (submitted). *Age-related differences in higher-order cognitive mediation of socioeconomic status and social engagement: A Structural Equation Modelling Study* .

Keil, K., & Kaszniak, A. W. (2002). Examining executive function in individuals with brain injury: A review. *Aphasiology*, *16*(3), 305–335. https://doi.org/10.1080/02687030143000654

Laver, G. D., & Burke, D. M. (1993). Why do semantic priming effects increase in old age? A meta-analysis. *Psychology and Aging*, *8*(1), 34–43. http://www.ncbi.nlm.nih.gov/pubmed/8461113

Leopold, T., Geissler, F., & Pink, S. (2012). How far do children move? Spatial distances after leaving the parental home. *Social Science Research*, *41*(4), 991–1002. https://doi.org/10.1016/j.ssresearch.2012.03.004

Luguri, J. B., Napier, J. L., & Dovidio, J. F. (2012). Reconstruing Intolerance. *Psychological Science*, *23*(7), 756–763. https://doi.org/10.1177/0956797611433877

Manly, T., Hawkins, K., Evans, J., Woldt, K., & Robertson, I. H. (2002). Rehabilitation of executive function: Facilitation of effective goal management on complex tasks using periodic auditory alerts. *Neuropsychologia*, *40*(3), 271–281. https://doi.org/10.1016/S0028-3932(01)00094-X

Murray, L. L., Holland, A. L., & Beeson, P. M. (1997). Auditory Processing in Individuals With Mild Aphasia. *Journal of Speech, Language, and Hearing Research*, *40*(4), 792–808. https://doi.org/10.1044/jslhr.4004.792

Muthén, L. K., & Muthén, B. O. (1998-2011). Mplus User's Guide. Sixth Edition. Los Angeles, CA: Muthén & Muthén

Nippold, M. A., Allen, M. M., & Kirsch, D. I. (2001). Proverb Comprehension as a Function of Reading Proficiency in Preadolescents. *Language, Speech, and Hearing Services in Schools*, *32*(2), 90–100. https://doi.org/10.1044/0161-1461(2001/009)

Peelle, J. E., Troiani, V., Wingfield, A., & Grossman, M. (2010). Neural Processing during Older Adults' Comprehension of Spoken Sentences: Age Differences in Resource Allocation and Connectivity. *Cerebral Cortex*, *20*(4), 773–782. https://doi.org/10.1093/cercor/bhp142

Peng, P., Wang, T., Wang, C. C., & Lin, X. (2019). A meta-analysis on the relation between fluid intelligence and reading/mathematics: Effects of tasks, age, and social economics status. *Psychological Bulletin*, *145*(2), 189. https://doi.org/10.1037/BUL0000182

Reitan, R. M. (1960). The Significance of Dysphasia for Intelligence and Adaptive Abilities. *The Journal of Psychology*, *50*(2), 355–376. https://doi.org/10.1080/00223980.1960.9916453

Resnick, D. A. (1982). A developmental study of proverb comprehension. *Journal of Psycholinguistic Research*, *11*(5), 521–538. https://doi.org/10.1007/BF01067497/METRICS

Ricketts, J., Sperring, R., & Nation, K. (2014). Educational attainment in poor comprehenders. *Frontiers in Psychology*, *5*(MAY), 445. https://doi.org/10.3389/FPSYG.2014.00445/BIBTEX

Rodd, J. M., Longe, O. A., Randall, B., & Tyler, L. K. (2010). The functional organisation of the fronto-temporal language system: Evidence from syntactic and semantic ambiguity. *Neuropsychologia*, *48*(5), 1324–1335. https://doi.org/10.1016/J.NEUROPSYCHOLOGIA.2009.12.035

Rozanova, J., Keating, N., & Eales, J. (2012). Unequal Social Engagement for Older Adults: Constraints on Choice. *Canadian Journal on Aging / La Revue Canadienne Du Vieillissement, 31*(1), 25-36. doi:10.1017/S0714980811000675

Rypma, B., Prabhakaran, V., Desmond, J. E., & Gabrieli, J. D. (2001). Age differences in prefrontal cortical activity in working memory. *Psychology and Aging*, *16*(3), 371–384. http://www.ncbi.nlm.nih.gov/pubmed/11554517

Schreiber, J. B., Stage, F. K., King, J., Nora, A., & Barlow, E. A. (2006). Reporting structural equation modeling and confirmatory factor analysis results: A review. In *Journal of Educational Research* (Vol. 99, Issue 6, pp. 323–338). Routledge. https://doi.org/10.3200/JOER.99.6.323-338

Schumacher, R., Halai, A. D., & Ralph, M. A. L. (2019). Assessing and mapping language, attention and executive multidimensional deficits in stroke aphasia. *Brain: A Journal of Neurology* , *142*, 3202–3216. https://doi.org/10.1093/brain/awz258

Shafto, M. A., Burke, D. M., Stamatakis, E. A., Tam, P. P., & Tyler, L. K. (2007). On the tip-of-the-tongue: Neural correlates of increased word-finding failures in normal aging. *Journal of Cognitive Neuroscience*, *19*(12), 2060–2070. https://doi.org/10.1162/jocn.2007.19.12.2060

Shafto, M. A., Tyler, L. K., Dixon, M., Taylor, J. R., Rowe, J. B., Cusack, R., Calder, A. J., Marslen-Wilson, W. D., Duncan, J., Dalgleish, T., Henson, R. N., Brayne, C., Bullmore, E., Campbell, K., Cheung, T., Davis, S., Geerligs, L., Kievit, R., McCarrey, A., … Matthews, F. E. (2014). The Cambridge Centre for Ageing and Neuroscience (Cam-CAN) study protocol: A cross-sectional, lifespan, multidisciplinary examination of healthy cognitive ageing. *BMC Neurology*, *14*(1). https://doi.org/10.1186/s12883-014-0204-1

Shafto, M. A., Tyler, L. K., Dixon, M., Taylor, J. R., Rowe, J. B., Cusack, R., Calder, A. J., Marslen-Wilson, W. D., Duncan, J., Dalgleish, T., Henson, R. N., Brayne, C., & Matthews, F. E. (2014). The Cambridge Centre for Ageing and Neuroscience (Cam-CAN) study protocol: a cross-sectional, lifespan, multidisciplinary examination of healthy cognitive ageing. *BMC Neurology*, *14*(1), 204. https://doi.org/10.1186/s12883-014-0204-1

Shallice, T., & Burgess, P. W. (1991). Deficits In Strategy Application Following Frontal Lobe Damage In Man. *Brain*, *114*(2), 727–741. https://doi.org/10.1093/brain/114.2.727

Sin, E., Shao, R., & Lee, T. M. C. (2020). The executive control correlate of loneliness in healthy older people. *Aging and Mental Health*, 1–8. https://doi.org/10.1080/13607863.2020.1749832

Smith, J., & Baltes, P. B. (1993). Differential Psychological Ageing: Profiles of the Old and Very Old. *Ageing and Society*, *13*(4), 551–587. https://doi.org/10.1017/S0144686X00001367

Tisserand, D. J., & Jolles, J. (2003). On the involvement of prefrontal networks in cognitive ageing. *Cortex; a Journal Devoted to the Study of the Nervous System and Behavior*, *39*(4–5), 1107–1128. http://www.ncbi.nlm.nih.gov/pubmed/14584569

Tsang, H.-L., & Lee, T. M. C. (2003). The effect of ageing on confrontational naming ability. *Archives of Clinical Neuropsychology*, *18*(1), 81–89. https://doi.org/10.1093/arclin/18.1.81

Valenzuela, M. J., & Sachdev, P. (2007). Assessment of complex mental activity across the lifespan: development of the Lifetime of Experiences Questionnaire (LEQ). *Psychological Medicine*, *37*(7), 1015–1025. https://doi.org/10.1017/S003329170600938X

Verhaeghen, P. (2003). Aging and vocabulary scores: a meta-analysis. *Psychology and Aging*, *18*(2), 332–339. https://doi.org/10.1037/0882-7974.18.2.332

Villard, S., & Kiran, S. (2015). Between-session intra-individual variability in sustained, selective, and integrational non-linguistic attention in aphasia. *Neuropsychologia*, *66*, 204–212. https://doi.org/10.1016/j.neuropsychologia.2014.11.026

Wascher, E., Schneider, D., Hoffmann, S., Beste, C., & Sänger, J. (2012). When compensation fails: Attentional deficits in healthy ageing caused by visual distraction. *Neuropsychologia*, *50*(14), 3185–3192. https://doi.org/10.1016/J.NEUROPSYCHOLOGIA.2012.09.033

Wingfield, A., & Grossman, M. (2006). Language and the Aging Brain: Patterns of Neural Compensation Revealed by Functional Brain Imaging. *Journal of Neurophysiology*, *96*(6), 2830–2839. https://doi.org/10.1152/jn.00628.2006

Ybarra, O., Burnstein, E., Winkielman, P., Keller, M. C., Manis, M., Chan, E., & Rodriguez, J. (2008). Mental exercising through simple socializing: Social interaction promotes general cognitive functioning. *Personality and Social Psychology Bulletin*, *34*(2), 248–259. https://doi.org/10.1177/0146167207310454

Yoon, J., Campanelli, L., Goral, M., Marton, K., Eichorn, N., & Obler, L. K. (2015). The Effect of Plausibility on Sentence Comprehension Among Older Adults and its Relation to Cognitive Functions. *Experimental Aging Research*, *41*(3), 272–302. https://doi.org/10.1080/0361073X.2015.1021646

Yuan, P., & Raz, N. (2014). Prefrontal cortex and executive functions in healthy adults: A meta-analysis of structural neuroimaging studies. In *Neuroscience and Biobehavioral Reviews* (Vol. 42, pp. 180–192). Elsevier Ltd. https://doi.org/10.1016/j.neubiorev.2014.02.005

Zahodne, L. B., Stern, Y., & Manly, J. J. (2015). Differing effects of education on cognitive decline in diverse elders with low versus high educational attainment. *Neuropsychology*, *29*(4), 649. https://doi.org/10.1037/NEU0000141

Language, Executive Functions, and Social Inclusion in Ageing: An EEG Study

Josephine Kearney (University of Manchester), Pamela Qualter (University of Manchester), Jason R Taylor (University of Manchester).

Abstract

Declines in cognition caused by ageing present considerable challenges that can affect one's social bonds in later life. In this study we explored the impact of ageing on the neurological features of language and executive functions using electroencephalography (EEG), as well as probing feelings of social inclusion in young (20-40 years old) and older (60-80 years old) adults. Inhibitory control was measured using the Stop Signal task, in which participants were required to inhibit a prepotent response if a stopping signal was presented shortly after the stimulus. Set-shifting ability was measured using the Wisconsin Card Sorting Task (WCST), in which participants had to select a card to match a set based on an unknown rule. Language production ability and error monitoring were measured using the Spoonerism of Laboratory-Induced Predisposition (SLIP) task, in which participants vocalised linguistically challenging word pairs. In the Stop Signal task, while performance measures were similar across groups, older adults had a significantly reduced P300 amplitude compared to the young group for inhibited responses and as well as a more global distribution in amplitude. Older adults were found to have poorer performance in the WCST but showed little difference in mid-frontal theta (3-7Hz) amplitude in correct or incorrect responses, whereas young adults showed an enhanced theta power for incorrect responses in this task. In the SLIP task older participants showed a reduced left-frontal positivity in correct verbal responses, with a similar pattern observed in young adults' correct responses. This left-frontal positivity was modulated by right-parietal negativity in young adults, a relationship not seen in the older participants. No correlations were found between these EEG measures and social measures, though this may be due to the small sample size used in this pilot study. These findings demonstrate age-related differences in neurological measures across the three cognitive domains explored, suggesting that these cognitive processes are more effortful and recruit more global neural resources in older adults.

Introduction

The life-course is defined by constant changes: in early life we develop the cognitive and social skills needed to learn and interact with the world; in adolescence and early adulthood these skills are refined, and more complex skills are developed; and in mid-life these skills become crystalised and then in later-life some of these skills begin to show decline (Zelazo et al., 2004). The loss of cognitive ability due to age can have serious ramifications for other aspects of one's life, with recent work (Kearney et al., submitted; Kearney et al., in preparation) showing it impacts the development and maintenance of social relationships that help prevent social isolation and loneliness in the later years of life. Social isolation and loneliness have been found to have significant impact on health outcomes such as cardiovascular disease, stroke, sleep disturbances, anxiety, and depression (Cacioppo & Cacioppo, 2014). Therefore, deepening our knowledge of the age-related changes in cognitive mechanisms and their potential influence on social engagement is an important step in developing approaches to lessen the societal impact of isolation and loneliness. The current research investigates the relationship between feelings of social inclusion and neurophysiological measures of language and executive functioning using electroencephalography (EEG) in two distinct age groups (20-40 years old and 60-80 years old). The study explores the neurophysiological and behavioural differences between younger and older adults across cognitive and social domains. In making a clear differentiation between language and executive functions we are able to investigate the social effects of age-related cognitive decline in more precise detail.

Age-related decline can significantly affect executive functions, behaviourally and neurologically, because the frontal and prefrontal cortices that these functions rely on are particularly sensitive to structural and functional changes that occur with ageing (Tisserand & Jolles, 2003). The most apparent of these changes is often a decline in working memory, necessary for executive functioning tasks that require high levels of attention and control. Studies have demonstrated that older people have increased difficulty in attending to relevant information when presented simultaneously with distracting but irrelevant information in memory tasks (De Beni and Palladino, 2010). Other research has shown older participants that scored poorly on measures of executive functioning (particularly mental updating that requires monitoring and manipulation of information in one's working memory) made fewer recognition responses and performed worse on memory tasks (Clarys et al., 2009). Neuroimaging studies have shown differences in activation of the frontal regions in older populations; in tasks where, younger participants only show activation in the left hemisphere, older participants have more global activation distribution (Reuter-Lorenz et al., 2000). This might suggest that as some specialised brain areas decline, others are recruited to compensate for diminishing resources to maintain performance (Kirova et al., 2015), but see alternative explanations (Cabeza, 2001), which we return to in the Discussion.

Working memory is not the only facet of executive functioning affected by ageing. Older participants have been found to have a reduced capacity for directing attention under increasing distraction loads, compared to younger participants, suggesting that attentional allocation becomes less efficient with age (Wascher et al., 2012). Research using electroencephalography (EEG) has shown that in tasks that require continuous information processing (regulative control) older participants had greater electrophysiological activity in frontal channels compared to younger participants (West & Schwarb, 2006). This suggests that in ageing, as the structure of the brain changes, particularly frontal regions employed in these processes, so do the functional processes, perhaps to compensate for the structural shift in ageing.

Some research has found that older participants perform as well as their younger counterparts in tasks that require reading comprehension and sentence processing ability (Burke & Yee, 1984; Laver & Burke, 1993), suggesting that language comprehension does not deteriorate with age. However, when reading and listening conditions become more taxing with the introduction of distractors, there is a marked decline in performance in older participants (Gao et al., 2012; Peelle et al., 2010). This strongly suggests that the cognitive processing of language becomes more challenging as we age. Age-related changes in language production are particularly apparent in word finding tasks, in which older adults often show increased rates of tip of the tongue (TOT) word finding difficulties (Evrard, 2002; Juncos-Rabadán et al., 2010). This experience of TOT in older populations is especially true when words are rare or less frequently used by the individual, and older adults often make fewer attempts to produce "persistent alternates," i.e., words that share some features with the target but are not correct (Burke et al., 1991). Ageing is also associated with reduction in accuracy and response time in naming tasks (Belke & Meyer, 2007; Tsang & Lee, 2003), and a disruption of speech fluency, producing more filler words and taking significantly longer pauses throughout conversation (Horton, 2010). Such difficulties in speech production are likely due to a reduced capacity to retrieve phonological information, due to the connections between linguistic components being significantly weakened by age (Burke & Shafto, 2004).

As discussed above, executive functions and language draw on similar brain regions and cognitive mechanisms. Indeed, both processes are often explored using the same tasks, such as categorical or semantic fluency tasks, where the participant is asked to generate as many words as possible under time constraints, either in a category (often animals) or starting with a certain letter, respectively. In these tasks linguistic ability is needed to generate the words and executive ability is needed to facilitate recall, produce the response, monitor past responses, and inhibit incorrect ones (Shao et al., 2014). However, conflating the two cognitive processes in this way could be detrimental to our knowledge of the deterioration of these processes, as such this research aims to use methodologies that allow for a clearer differentiation between the two cognitive domains. Studies investigating neural components of executive functions show considerable overlap with regions also involved in language process, in particular the anterior cingulate cortex (ACC) and prefrontal cortex (Kikyo et al., 2002; Maril et al., 2001) and further research found that age-related structural decline in those regions also lead to language, especially word finding, difficulties (Shafto et al., 2007). Indeed, working memory is an important component of language in both production and comprehension; it is needed for word selection and processing of incoming information (Baddeley, 2003; Baddeley & Hitch, 1974). This can be seen in reduced word production response times in naming tasks with older participants (Piai & Roelofs, 2013).

One such shared neurological characteristic is a regulatory feature in self-monitoring for potential errors (Botvinick et al., 2001; Masaki et al., 2001). Errors are an expected caveat of language and behaviour, provided that those errors are infrequent, and one is aware of making them. Awareness of errors is key to being able to appropriately adjust and allow correct speech or behaviour so that one may be understood. However, with the decline in language and executive domains in ageing the effort required for effective 'error-monitoring' increases (West & Schwarb, 2006) and the instances of errors increases with ageing (Belke & Meyer, 2007; Birdi et al., 1997). Such errors and how we process them can be explored using electrophysiological techniques, as the initial temporal processing of errors in the brain is rapid (O'Connell et al., 2007). An event related potential (ERP) known as error-related negativity (ERN) has been detected in the brain in both language tasks and non-verbal tests of executive function (Ganushchak & Schiller, 2008; Masaki et al., 2001; Pailing & Segalowitz, 2004), that require overt responses, typically peaking at around 100ms post-error. This is mirrored somewhat by Correct Response Negativity (CRN), which follows a similar time course subsequent to a correct response (Vidal et al., 2000), the amplitude of which can be modified by confidence (Miltner et al., 1997) and attention allocation (Matsuhashi et al., 2021). Though currently it is not clear if the ERN or CRN are affected by age-related changes, however, if ageing is accompanied by increased errors, one might predict a change in this neurological feature.

Executive function processing tasks that require the inhibition of a response (usually a motor response such as a key press), such as the Stop-Signal task, evoke a negative deflection in EEG signal at approximately 200ms post-stimulus onset (Huster et al., 2020). This is believed to reflect a number of executive function elements, depending on component topography; more posterior N200 reflects attentional control (Folstein & Van Petten, 2007) and tasks that made greater demands on cognitive control elicited a more anterior N200

(Folstein & Van Petten, 2007)Additionally, Increased response pressure has shown increased(Band et al., 2003), participants with high N200 amplitudes made fewer errors (Schmajuk et al., 2006). There is also some evidence to suggest that the N200 observed in language processing in association with lexical selection and inhibition of response in bilingual participants (Martín et al., 2010). Similarly, to the N200, the P300 is associated with response inhibition in the stop-signal, or go-nogo tasks (Huster et al., 2013), research suggests that successful inhibition of a response is characterised by an early peak in the P300 component (Ramautar et al., 2004).

The decline in executive functioning and language processing likely contributes to changes in a person's performance in both language and executive function abilities, and corresponding changes in neurological behaviours are to be expected. Research has shown that older participants demonstrate a reduction in posterior P300 amplitudes and increased latency in auditory and visual odd-ball tasks (Fjell & Walhovd, 2001; O'Connell et al., 2012). Additionally, The N200 has shown similar effects of ageing, the amplitude decreasing in older adults (Enoki et al., 1993). These findings suggest that ageing is associated with a slowing of executive processes across multiple task modalities.

Such changes in cognitive ability with age can have far reaching repercussions for those that experience them. A perceived inability to effectively communicate can often leave older people with increasing feelings of social isolation and loneliness (Burke & Shafto, 2004). Reducing feelings and perceptions of isolation in older adults is important as such feelings have been shown to be detrimental to people's physical health (Cornwell & Waite, 2009). Previous research has shown that isolation contributes to higher mortality rates, increased risk of infection, depression, and general cognitive decline (Brummett et al., 2001; Cohen et al., 1997; Heikkinen & Kauppinen, 2004). This suggests that being able to maintain social interaction, and so reduce isolation, in later years is important for increased feelings of wellbeing in later life. Evidence suggests that higher levels of social participation, engagement in leisure activities, diversity of social contacts and greater frequency of contact with friends and family are all associated with a lower risk of cognitive decline (Bassuk et al., 1999; Fabrigoule et al., 1995; Zunzunegui et al., 2003). Additionally, research has shown that there are impacts on cognition based on quality of social interaction; living alone and having no contacts increased risk of dementia, but there was no increased risk related to infrequent but fulfilling social contact (Fratiglioni et al., 2000). Such findings suggest that, while social interaction is vital for maintaining cognitive health, the quality of social interactions should not be overlooked.

There is also evidence to support the theory that social interactions have a direct consequence for cognitive domains in older populations. Cognition is often considered in terms of "use it or lose it," meaning that without the regular social interaction and the cognitive demands of using language or executive functions the domains can decline (Ryan, 1995). Indeed, research with participants over 85 years old showed that those with greater diversity in their social interactions and who took part in a greater number of social activities had better language skills than those with less diversity (Keller-Cohen et al., 2006). Research has also found that cognition is important to support on-going communication with friends and family in older people, particularly when that communication may be more cognitively effortful (Kearney et al., submitted). Further research has found that effortful social communication is underpinned by high-order cognitive functions such as abstract thinking and mental-control (Kearney et al., in preparation). This suggests a bidirectional relationship between social interaction and cognition, as not only does maintaining social participation help to maintain cognitive ability in later life, but cognition supports on continuing social engagement.

Recent research has found that preservation of cognitive skills into later life predicts lower reports of perceived loneliness in older people (Sin et al., 2020), suggesting that greater preservation of cognitive skills affects how connected older people feel to others. The increasing social isolation and loneliness can have serious effects on mental and physical health problems during old age, including increasing the risk of depression, sleep disturbances, cardio-vascular disease, diabetes, and stroke (Cacioppo & Cacioppo, 2014; Cacioppo & Hawkley, 2003; Christiansen et al., 2021; Hawton et al., 2011)

Existing research has demonstrated that ageing is dominated by changes in cognitive domains and neurological processes that can have serious repercussions for one's ability to maintain meaningful social engagement, which has potential impacts for one's mental and physical health. The current study aims to characterise cognitive change using EEG measures in language and executive functioning domains and the relationship between these domains and social inclusion. This research will employ the Wisconsin Card Sorting Task (WCST) to examine updating and regulative control (Berg, 1948), Stop Signal to examine response inhibition (Eagle et al., 2008) and the Spoonerisms of Laboratory Induced Predisposition (SLIP) task to examine speech errors (Motley & Baars, 1976). We will explore their shared neurological characteristics while reducing shared task demands, with the aim of determining if the shared characteristics are differentially affected by the ageing process. .The key hypotheses of this study are that brain activity related to language and executive function processing will be different in younger and older populations and that the brain differences seen in older adults will be related to perception of loneliness or social inclusion.

Methods

Participants

33 right handed participants (26 female) with no history of neurological disorders and with normal or corrected to normal vision were recruited to take part in this study. The participants were recruited from two age groups, younger adults (20-40 years old) and older adults (60-80 years old). Younger participants were recruited using University of Manchester's SONA participant recruitment system (an online platform to recruit undergraduate psychology students who are compensated with course credit) and social media advertising, participants not recruited using SONA received £20 for taking part. Older participants were recruited using adverts in local University of the Third Age newsletters and social media, participants received £20 for taking part. Participants were excluded for incomplete or invariant data; seven participants' data showed no variance in task response (same key pressed in all trials) and five participants had missing data in either social inclusion measures or EEG data (N=12). Younger adults retained in the analysis (N = 10) were aged between 20-40 years (mean = 21.4 years, SD = 2.1 years). Older adults retained in the analysis (N = 11) were aged between 60- 80 years (mean = 69.8 years, SD = 5.3 years)

The study was conducted according to the declaration of Helsinki, with ethical approval from the University of Manchester Research Ethics Committee (2021-12350-20455), all participants provided informed consent.

Task and Procedure

The participants completed three questionnaires investigating various elements of social engagement and inclusion.

Lubben Social Network Scale 18 (LNLS-18); 18 items, a self-reported measure of social engagement that probes participants' levels of perceived social support from friends, family, and more distant social interactions (neighbours) (Lubben et al., 2006; Lubben, 1988).

UCLA Loneliness Scale,(Russell, 1996); 20-item scale that measures participant's self-reported feelings of social isolation. Participants rate statements of social experiences 1 (Never) – 4 (Often).

Multidimensional Scale of Perceived Social Support (MSPSS) (Zimet et al., 1988); 12-item self-report scale of perceived quality of social support from friends and family. Items are rated on a 5-point Likert scale from 1 (Very Strongly disagree) to 7 (Very Strongly Agree).

Participants also completed the Montreal Cognitive Assessment (MoCA) (Nasreddine et al., 2005) to establish that the participants were not cognitively impaired. . The MoCA allows for a brief assessment of memory, visuospatial skill, attention, language, abstract thinking, and orientation.

Participants completed four experimental tasks designed to probe language production, comprehension, set-switching and inhibitory control. EEG was recorded throughout all tasks, which were administered via PC with participants sat approximately 1 metre away. For all tasks participants were instructed to respond as quickly and accurately as possible.

Response inhibition was investigated using the Stop-Signal task; Participants were instructed to press the left arrow key on a keyboard when a left-pointing arrow was presented on a computer screen, to press the right arrow key when a right-pointing arrow was presented, and to not respond when a red square was presented after a brief (50ms) display of one of the directional response arrows (IMAGE). The stimulus was presented for 500ms or until the participant responded (if a response was required), if an incorrect response was given "MISTAKE" as error feedback appeared on the screen for 1000ms.

Language production was investigated using the Spoonerism of Laboratory-Induced Predisposition (SLIP) task. 55 word pairs were displayed on the screen, one pair at a time) and participants were instructed to silently read the pairs to themselves (Figure 1). A cue to read the following word pair aloud occurred after 1, 2 or 4 trials. Word pairs were displayed for 500ms, speech prompt and vocal recording duration was 1000ms. Participants' vocalisations were recorded using a web camera microphone.

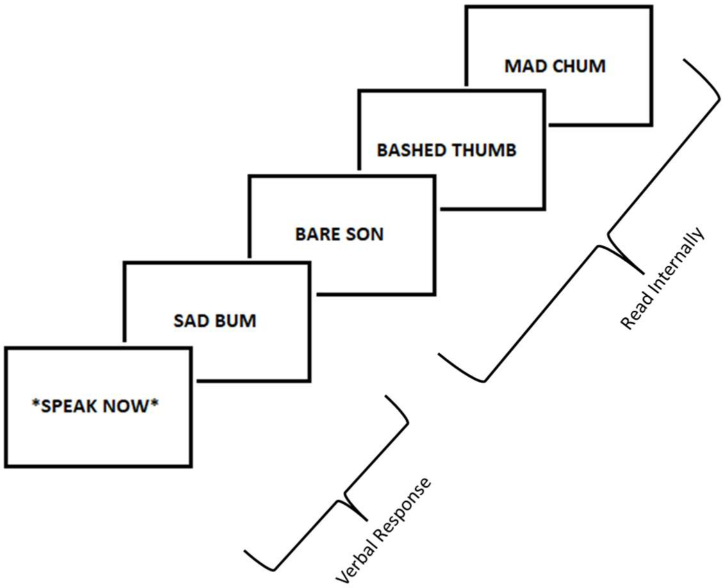


Figure 1: SLIP stimuli presentation

The Wisconsin Card Sorting Task (WCST) evaluated set-switching. Participants were presented with five cards and were instructed to match the bottom card to one of the cards in the top row based on one of three potential matching rules (colour, shape, number) (Figure 2). The rule by which the participant should match the bottom card to the top changed after the participant correctly responded five times in a row, the participant was not informed of the rule change. Participants were instructed to press "D," "F", "J" or "K" on a keyboard to indicate their answer. Card presentation timed out after 5000ms, which was recorded as an incorrect response. The response was followed by a red fixation cross if an incorrect response was given or a green fixation cross if a correct response was given.

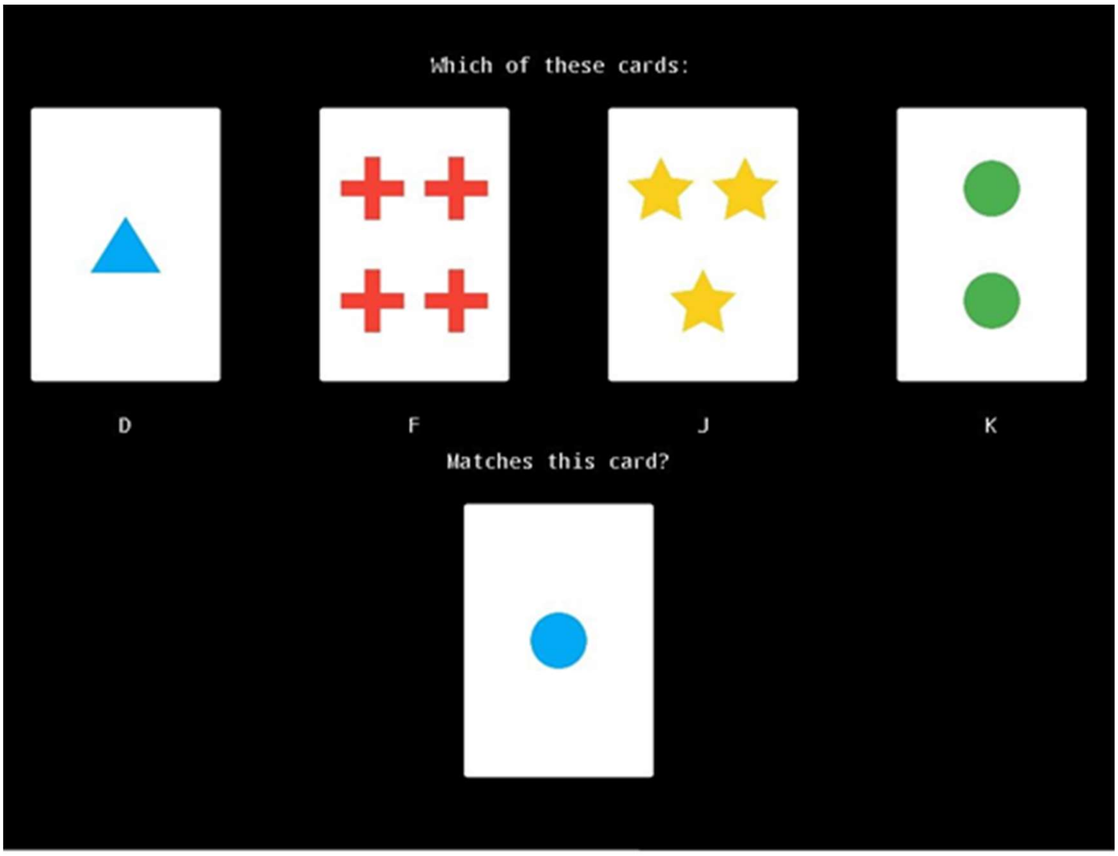


Figure 2: WCST stimuli presentation

EEG recording

EEG data was captured using a BioSemi ActiveTwo 64 channel array, with electrodes at the left and right mastoid for offline re-referencing. The vertical and horizontal electrooculograms (EOG) were recorded from superciliary arch and zygomatic bone around the right eye and left and right outer canthi to capture blinking and eye movement. Electromyography (EMG) was captured from left and right locations on larynx to capture signals caused by participant's vocalisations. EEG, EOG and EMG were recorded continuously at a sampling frequency of 512 Hz, with an online high-pass filter of 0.16Hz and low-pass filter of 100hz.

EEG Analysis

Preprocessing. All data were subject to a common preprocessing pipeline: data were high-pass filtered at 0.1Hz to remove drift, downsampled to 200Hz to reduce file size, low-pass filtered at 100Hz to remove high-frequency noise (but to retain some high-frequency information for artefact signal detection). Blink artefact signals were removed from the data using principal spatial components, whereby blinks were identified automatically, epoched, averaged, and subjected to singular value decomposition (SVD). The first spatial component of this averaged blink data was projected out of the continuous data. Individual trials were epoched according to trial definition files created for each participant for each task; Stop Signal and SLIP tasks were epoched 1000ms from stimuli onset, baseline corrected -100ms. For time-frequency analysis WCST were epoched 2000ms from stimuli onset, baseline corrected -400ms.

ERP analysis. Blink-cleaned, epoched data were averaged over epochs by condition to create ERPs. A 30Hz low-pass filter was applied, bad trials (absolute amplitude >100uV on EEG channels) were rejected. Linear contrasts of conditions were computed to establish difference-wave ERPs. Visual inspection of the grand average data of the tasks was conducted to establish appropriate time windows and channels for further analysis, this was carried out separately for each age group so that the location and time window selected reflected the optimal peak signal for each participant group.

Time-frequency analysis. For the WCST task, the frequency-domain amplitude of blink-cleaned, epoched (-400 to 2000ms) data was computed using Morlet wavelets (integer frequencies from 2 to 48Hz, 5 cycles constant time-window width). Time-frequency data were then cropped to -100 to 600ms to remove edge effects, log-transformed and re-scaled relative to baseline power, then averaged across trials (i.e., averages represent *total* power, the sum of evoked and induced power). The grand average data of younger and older participants were subject to individual visual inspection to identify the optimal channel and time window for further analysis.

Statistical analyses. For Stop Signal and SLIP tasks, time window data was extracted from the time windows of interest at the channels of interest, for the young and older groups and each condition separately. For the Wisconsin Card Sorting Task spectral amplitude was extracted for a time and frequency window of interest for each condition at the channels of interest.

Two-way ANOVAs were conducted to investigate the interactions between condition and age in Stop Signal, SLIP and WCST. Three-way ANOVAs were also conducted on Stop Signal and WCST to investigate interactions between condition, age, and channel location.

To probe age differences in behavioural performance, independent samples t-tests (between age groups) were conducted on social inclusion measures, cognitive task accuracy, and task response time. Relationships between brain measures of cognition and social inclusion were investigated using Pearson's correlations, separately for each age group.

Results

Stop Signal Task

Behavioural results. A two-tailed t-test revealed no significant between group differences in the Stop Signal accuracy ($t(20)=1.041$, $p=>0.05$, [2.82]) or response time ($t(20)=-1.99$, $p=>0.05$, [-66.57]).

EEG results. Differences between age groups across tasks were observed in visual inspections of the data; time-window data of the Stop Signal Task showed a positive increase in amplitude in left parietal regions from 300ms for young participants (Fig 3), with topographic data showing a positive peak in the signal around PO3 for both conditions independently, though amplitude was greater for Inhibit than Respond (figure 4).

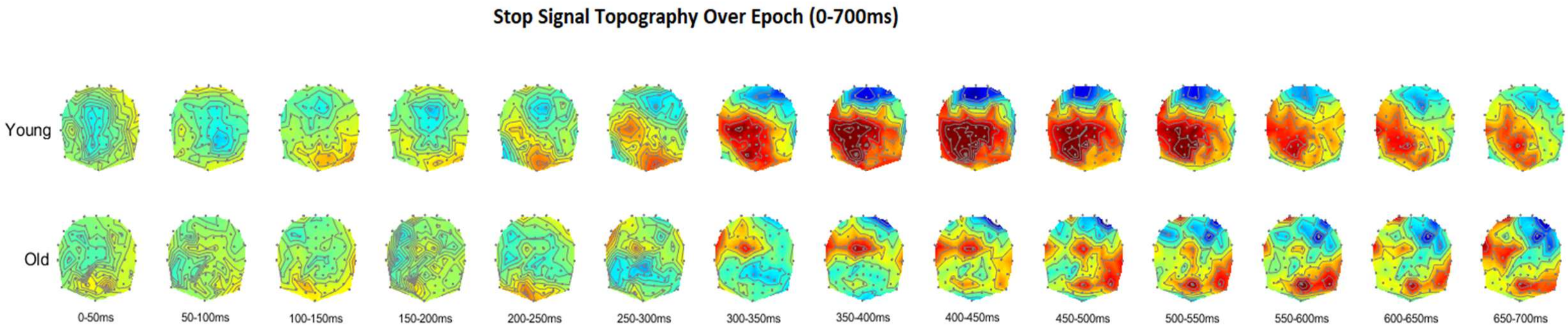


Figure 3: Inhibit Response – Response difference over time (0-700ms) in Young and Older participants

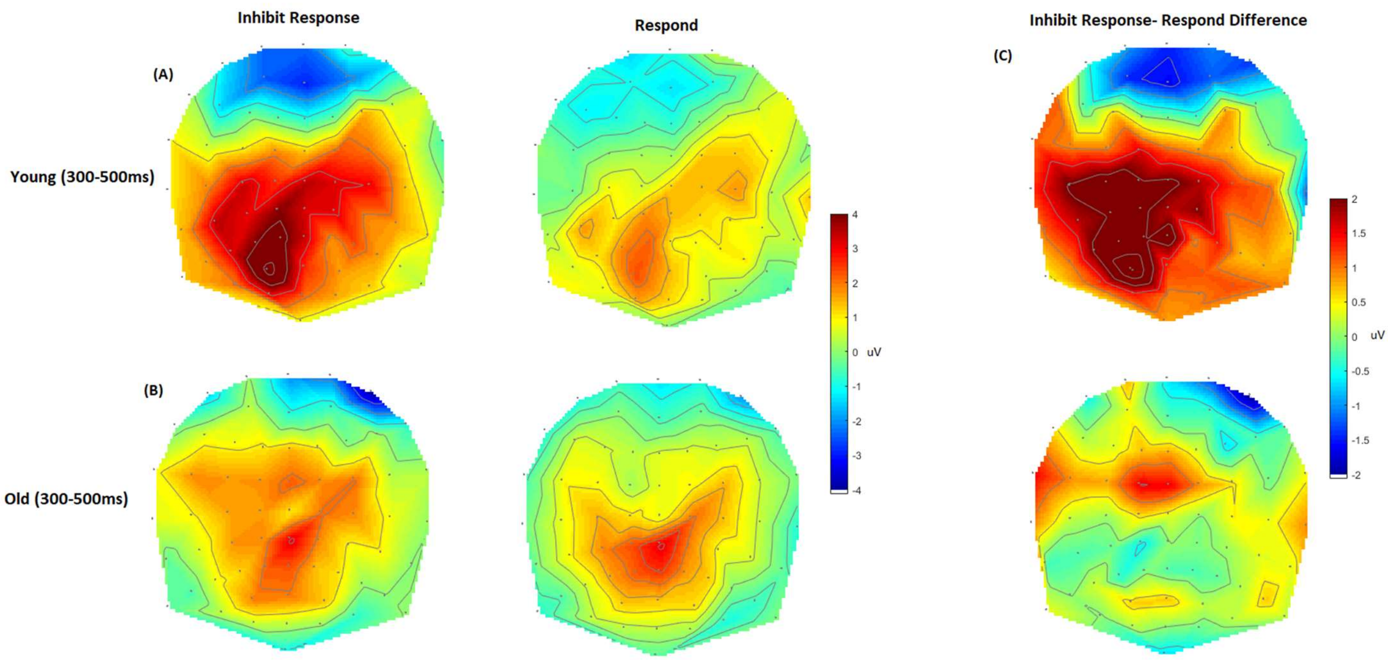


Figure 4: Topographies of time-window average (300-500ms) ERP amplitude for Young (top row) and Older (bottom row) participants (grand average) in Stop Signal task. (A) Young Participants Inhibit Response and Respond conditions; (B) Older Participants Inhibit Response and Respond conditions; (C) Condition Difference (Inhibit–Respond).

The same inspection of the older participants' data showed a positive peak was between 100-600ms around central-parietal channels for each condition independently, with the difference between conditions showing a frontal positive peak between 300-400 Ms at FCz (Figure 4).

ERPs on channels selected based on peak difference in younger (PO3) and older (FCz) groups are shown in Figure 5. Clear early visual ERPs are evident in both groups, with no apparent modulation by condition. A sustained condition difference (Inhibit > Respond) appears to emerge around 300ms on the frontal channel in both groups, and on the parietal channel in the young adults only (a small opposite effect appears to be present in the older adults' parietal data). This pattern is clear in the overlaid difference waveforms (Figure 5 (c)): Younger adults showed a condition difference at FCz and PO3, whereas old adults showed condition difference at FCz only.

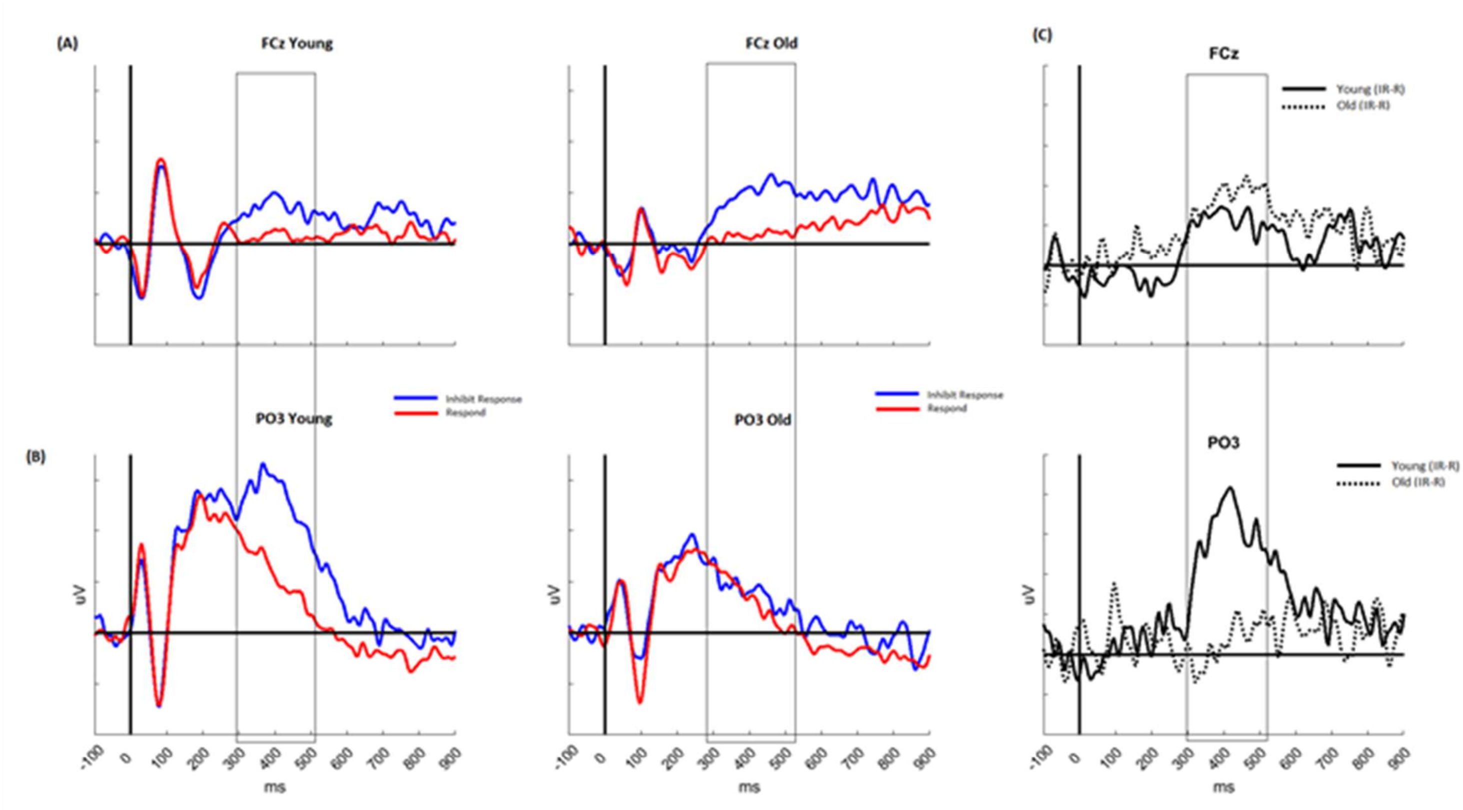


Figure 5: ERPs of Inhibit Response and Respond conditions at FCz (top) and PO3 (bottom) for all participants (grand average) in Stop Signal task in the Stop Signal Task. (A) ERPs at FCz of Inhibit Response and Respond Conditions in Younger and Older participants; (B) ERPs at PO3 of Inhibit Response and Respond Conditions in Younger and Older participants; (C) ERPs of Inhibit Response-Respond condition Difference (Young and Older). Note: IR = Inhibit response; R = Respond.

A two-way mixed ANOVA of within subject effects of the Stop Signal data on channels FCz and PO3 in time-windows 300-500 Ms in young and older adults (table 1) showed a significant effect of channel location (p=<0.005), P300 for inhibition had greatest difference at FCz for both groups, PO3 was found to have a great amplitude change between channels across conditions. A significant interaction between age and channel location (p=0.05); P300 amplitude at PO3 was found to be significant for the young adults only for both Inhibit and Respond conditions, this confirms that channels selected for analyses in young and older participants were appropriate. An effect of condition on amplitude (p=<0.05) was also found; the Inhibit condition elicited a larger P300 amplitude than the Respond condition in both young and older adults.

	Type III Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Condition	40.012	1	40.012	13.925	0.001*	0.423
Condition * Age Group	8.051	1	8.051	2.802	0.111	0.129
Location	117.826	1	117.826	10.822	0.004*	0.363
Location * Age Group	49.091	1	49.091	4.509	0.047*	0.192
Condition * location	1.475	1	1.475	0.578	0.457	0.030
Condition * Location * Age Group	0.218	1	0.218	0.085	0.773	0.004
Between-Subject Effects	42.489	1	42.489	3.073	0.096	0.139

Table 1: three-way ANOVA of within and between subject effects on amplitude in Stop Signal task

SLIP

Behavioural Results. A two-tailed t-test found no between group differences were observed in SLIP task accuracy (t(20)=1.47, P=>0.05 [7.47]).

EEG Results The visual inspection of the topography of the correct-incorrect responses over the course of the epoch (0-400ms) of the SLIP task showed the young participants showed a positive signal distribution with a left lateralized frontal onset at 100ms, that became more broadly distributed to include central and parietal areas over the epoch (figure 6). The older participant topography showed a similar positive left frontal peak, though the amplitude was reduced and focal to the left frontal areas in this group (figure 6).

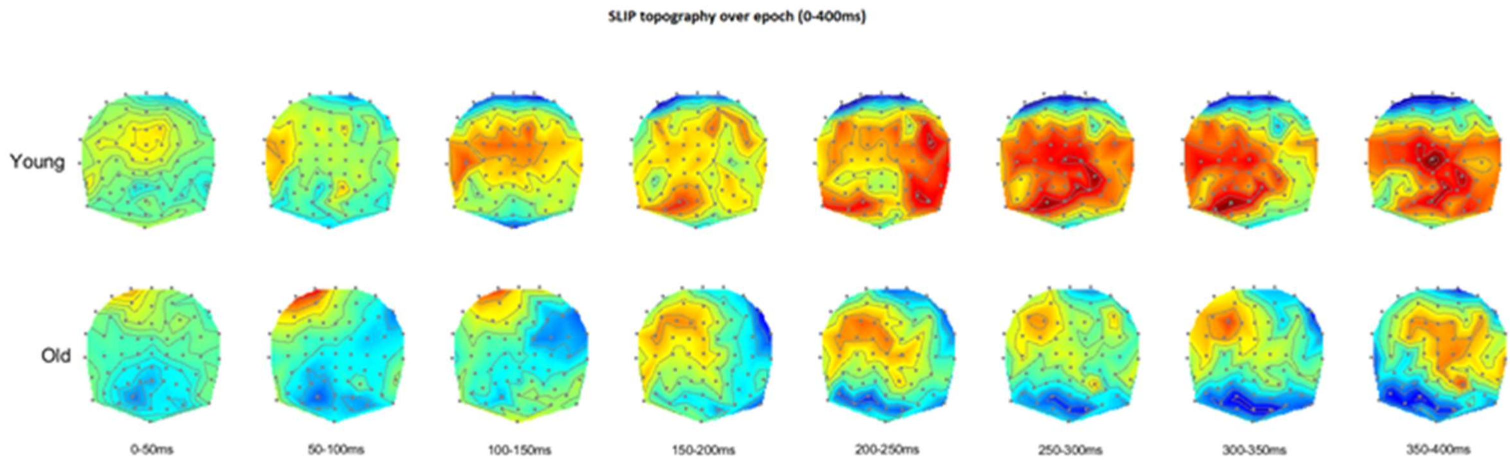


Figure 6: Incorrect-Correct response difference over time (0-400ms) in Young and Older participants

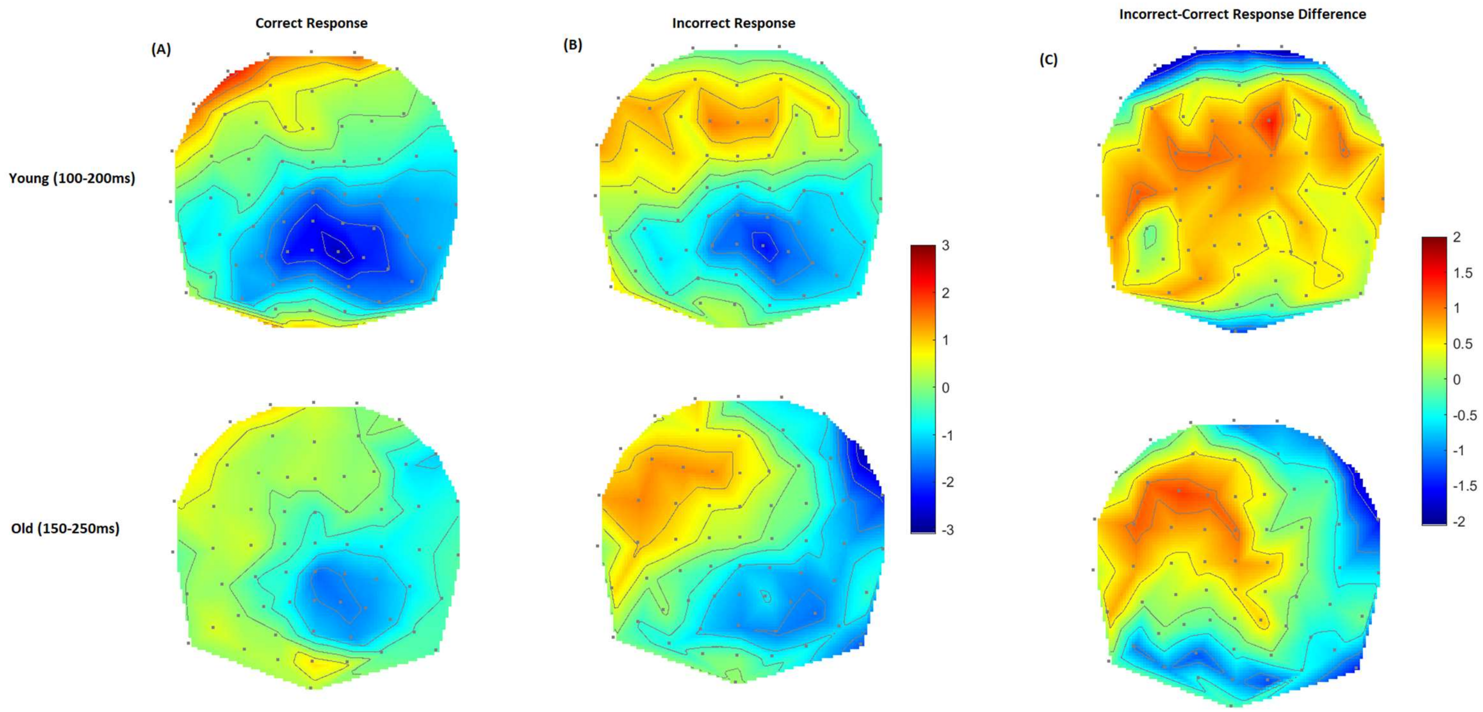


Figure 7: Topographies of time-window average (100-200ms) ERP amplitude for Young and Older participants (grand average) in SLIP task. (A) Young Participant Correct and Incorrect Responses condition; (B) Older Participant Correct and Incorrect Responses; (C) Response condition Difference (Incorrect-Correct).

In the Incorrect condition (figure 7, (B)), topographies for the young and older participants were similar, with left-frontal positivity and right-parietal negativity. In the Correct conditions (figure 7, (A)), the young group's posterior negativity was enhanced, and frontal positivity reduced, resulting in a widespread Incorrect>Correct effect in the difference topography (figure 7 (C)); in the older group the left-frontal positivity was also reduced, but the right parietal negativity did not appear modulate, resulting in a left-frontal Incorrect>Correct pattern on the difference topography (figure 7 (B and C)) (see supplementary for ERP array for this task).

	Type III Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Condition	1.691	1	1.691	1.136	0.3	0.056
Condition * Age Group	18.039	1	18.039	12.125	0.002*	0.39
Between-subject effects	11.768	1	11.768	3.207	0.089	0.144

Table 2: two-way ANOVA of within and between subject effects on amplitude in SLIP task

A two-way mixed ANOVA of within subject effects on amplitude (channel FCz in young, F5 in older based on peak difference location, time-window 100-200 Ms in young, 150-250 in older group) of the SLIP task (table 2) showed a significant interaction between condition and age ($P<=0.005$); showing that young participants had an enhanced negative amplitude response compared to the older participant group.

Wisconsin Card Sorting Task

Behavioural results. A two-tail t-test showed that there was a significant difference between young and older participants in accuracy in the WCST (t(19)=4.35, p=<0.001, [35.89]), no differences between groups were found for response time for this task (t(19)=-1.289, p=0.220, [-396.57])]

EEG results. Visual inspection of the WCST topographies for Correct responses only between 3-7Hz (theta band) (Figure 8) showed that the both groups had a sustained low-amplitude mid-frontal region which onset around 200ms in young participants and around 300 Ms in older participants. The older participants also showed positive peaks in bilateral anterior channels and midline occipital channels, a pattern suggestive of eye movement artefact (hence ignored in subsequent analysis in favour of the expected mid-frontal theta modulation).

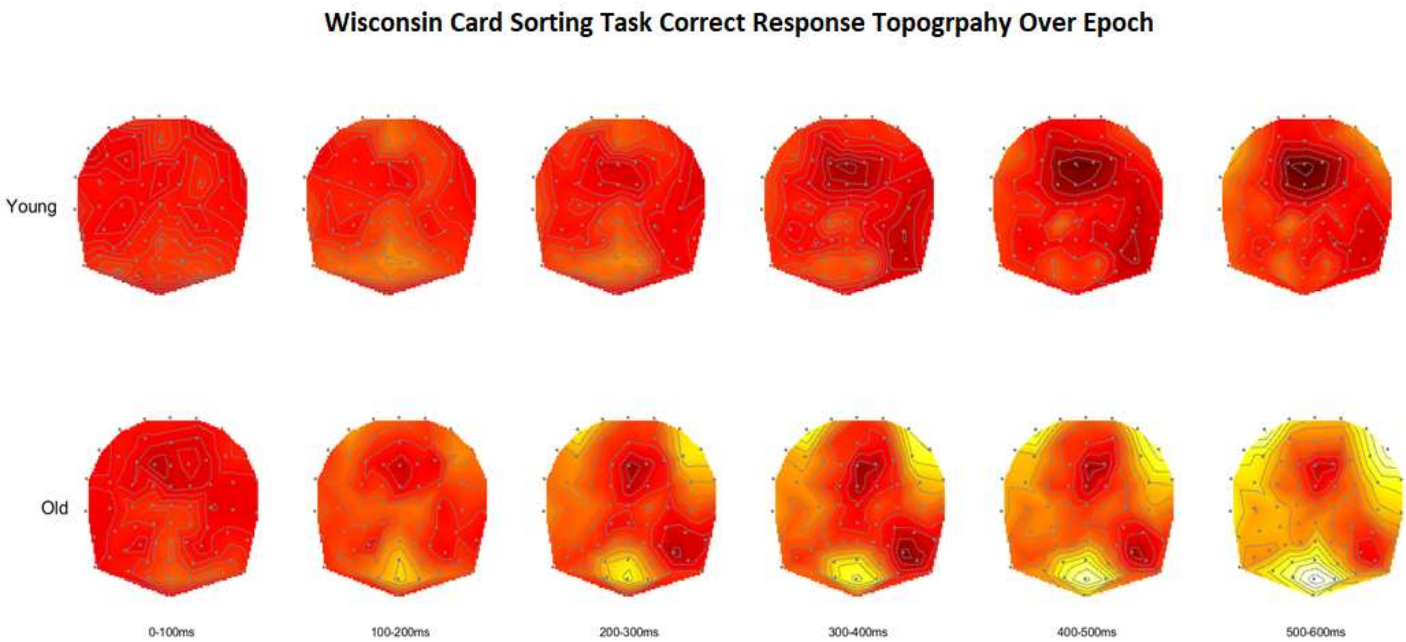


Figure 8: Topographies of time-frequency-window average (4-7Hz, Young = 200-500ms, Older=300-600ms) amplitude for Young and Older participants (grand average) in WCST task. (A) Correct Responses condition; (B) Incorrect Responses; (C) Difference (Correct-Incorrect).

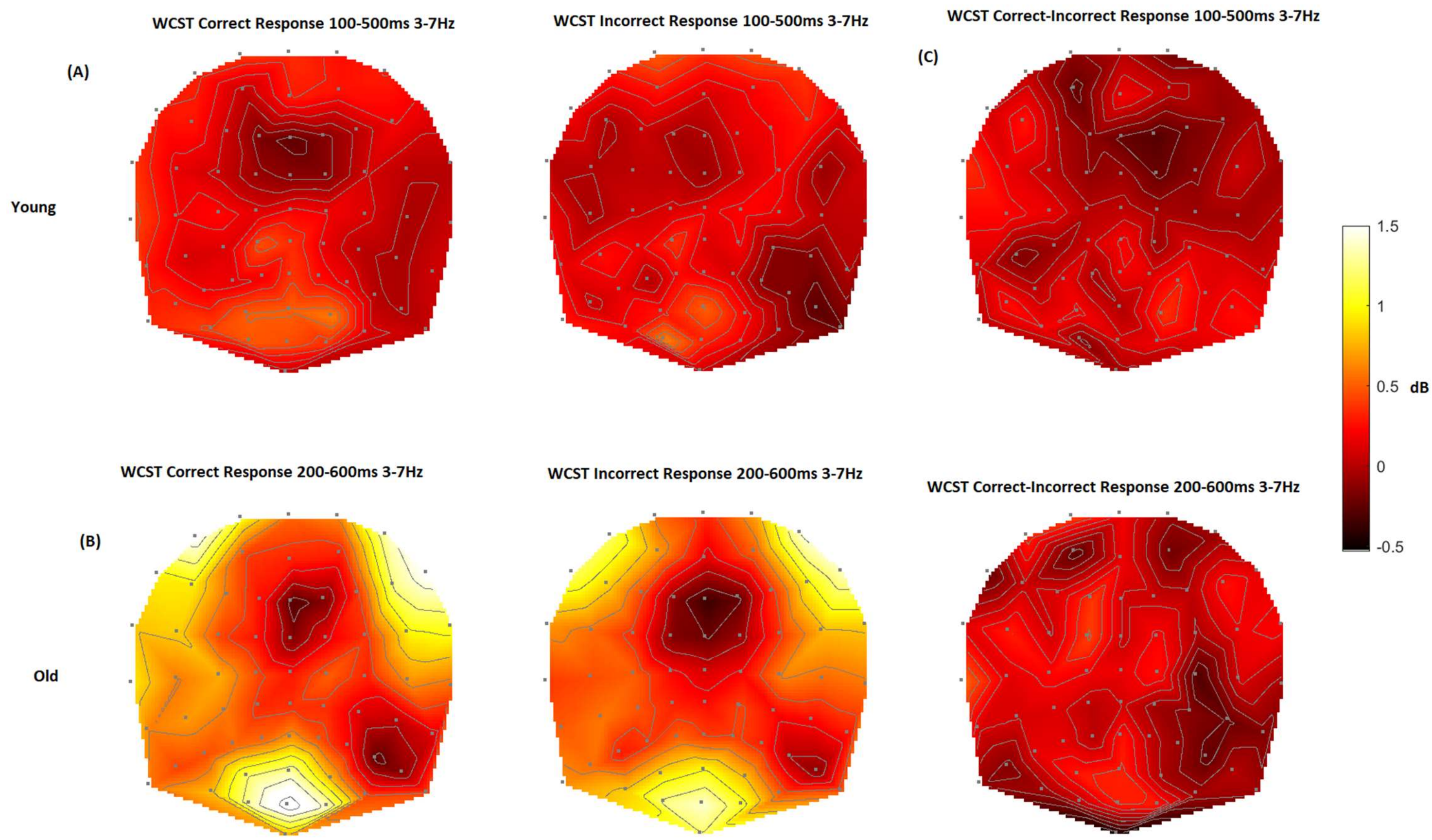


Figure 9: Topographies of time-frequency-window average (4-7Hz, Young = 200-500ms, Older=300-600ms) amplitude for Young and Older participants (grand average) in WCST task. (A) Correct Responses condition; (B) Incorrect Responses; (C) Difference (Correct-Incorrect).

Inspection of power spectra for the young participants showed higher theta power (3-7Hz) in incorrect response relative to correct responses (figure 9 (a)), resulting in decreased theta amplitude in the difference topography (Correct<Incorrect) (figure 9, (c)). The older participant group had low theta amplitude in both incorrect and correct conditions, as such no difference was observed. Increased power amplitude was also seen in the beta frequency (12-30Hz); as this was observed in both groups at the end of the epoch this likely reflects motor artefacts of no interest. Increased alpha power (8-12Hz) was only observed in older participants, which may reflect increased effort of attentional shifting (Huizeling et al., 2021); however, consistent with our a priori predictions, the analysis focuses on mid-frontal theta.

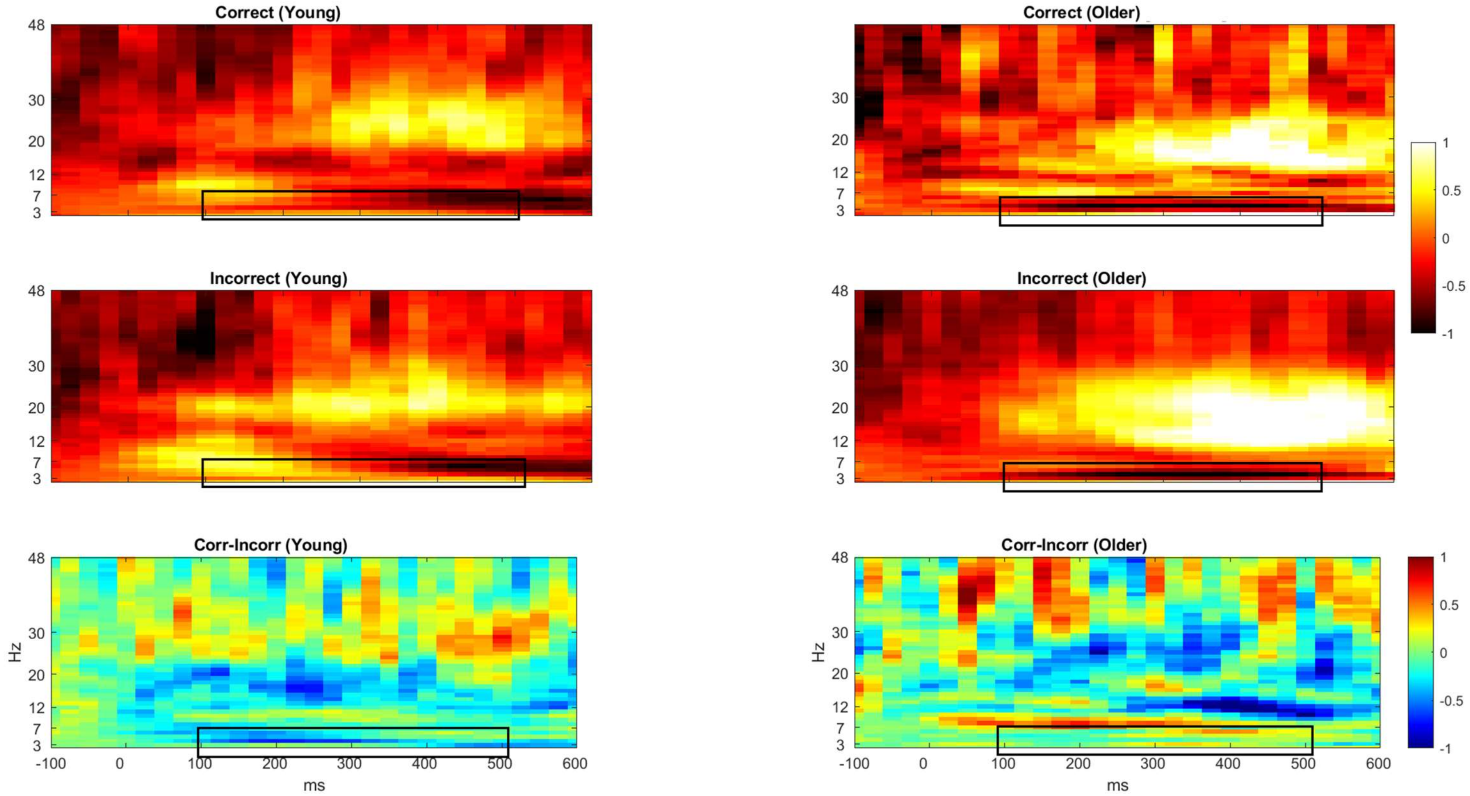


Figure 10: Power spectra for the Correct and Incorrect responses at Fz of Young and Older participants (grand average) in WCST task. (A) Correct responses; (B) Incorrect Responses; (C) Condition Differences (Correct-Incorrect).

A three-way mixed ANOVA of within subject effects on amplitude found no significant effect of condition or age in this task.

Social Inclusion

A two-tailed t-test found no differences between age groups in the MSPSS (t(20)=0.734, p=>0.05[0.05]), LSNS (t(20)=-1.488,p=>0.05[-0.10]) or UCLA (t(20)=-0.899, p=>0.05 [-0.01]), for descriptive statistics see supplementary materials.

Interactions Between Cognition and Social Inclusion

No correlations were found between the EEG components and any of the social inclusion measures (see supplementary materials). Correlations found no relationship between task performance and power amplitude or ERP amplitude in any of the tasks (for descriptive statistics see supplementary materials).

Discussion

We investigated the associations between cognition, quantified using electrophysiological recording, and social inclusion in two age groups, and found differential patterns of brain activity between groups. The behavioural performance data showed few differences between age groups in response time or accuracy, though it was found that younger participants performed better than older participants in the WCST, and no differences were found in self-reported feelings of social inclusion. However, the electrophysiological data showed a number of brain differences between young and older participants across three measures of cognition, particularly in measures of executive function. Older participants were found to have a more centralised foci of the P300 component in the Stop Signal task, whereas for the younger participants P300 amplitude was greatest in posterior channels. The amplitude of this component was significantly smaller in older participants than that of the younger participants, showing less of a difference between conditions. The amplitude difference of inhibit response versus response conditions in the older participants was found to be correlated with measures of social support. Older adults also showed a significant difference from the younger sample in the WCST; while both groups were found to have a significant reduction in theta power around mid-frontal regions. Finally, older participants showed weaker global amplitude compared to younger participants in the SLIP task in both correct and incorrect responses. These findings indicate differences between younger and older adults in the cognitive underpinnings of language and executive functioning, and that in older participants inhibitory control is associated with greater feelings of social support.

We found no behavioural distinctions in Stop Signal task performance between the younger and older participants, indicating that performance in this task was not subject to ageing effects. However, a number of differences were observed in the EEG data; younger participants showed a greater peak in P300 amplitude around posterior channels for trials where responses were to be inhibited than those that required a response. In older participants there was little difference in amplitude between conditions, though examining the difference between condition amplitude indicated a greater P300 peak in front channels. A three-way ANOVA showed that the effects of channel location and condition on amplitude were significant in both groups.

No significant age differences were found in performance in the SLIP task, though visual inspection of the EEG data showed that younger participants had a great positive amplitude distribution across the scalp and greater negative posterior peak for correct responses compared to the older participants. A two-way ANOVA also found an interactive effect of response condition and age on amplitude in this task. The initial aim of this task had been to characterise error-related negativity in a linguistic task, however, while we found a negative peak in amplitude in this task it was greatest in trials where a correct response was given. Previous research has found a reduction in ERN in older participants, which may reflect a compensatory mechanism in tasks designed to produce behavioural errors (Hoffmann & Falkenstein, 2011). Alternatively, these findings may reflect Correct Response Negativity (CRN), which follows a similar time course subsequent to a correct response (Imhof & Rüsseler, 2019), as the number of errors found in the behavioural data of this study were minimal. CRN amplitude has been found to increase when participants are instructed to respond rapidly (Files et al., 2021), as they were for this study, implying that the increase in correct negativity seen in both groups is reflective of response time. This research was not able to replicate findings of reduced in performance in accuracy and response time in linguistic tasks (Belke & Meyer, 2007; Horton et al., 2010; Tsang & Lee, 2003), perhaps as the older participants primarily came from high-SES backgrounds which has been pervious associated with maintenance of verbal fluency and language production in later life (Kearney et al., submitted; Kearney et al., in prep). Analysis of the behavioural performance data in the WCST showed significant age differences in accuracy in this task, consistent with previous research in age differences in WCST performance (Rhodes, 2004). Investigation of the EEG data showed that older participants' frontal theta peak had a later onset and a more positive general distribution across the scalp than that of younger participants (figure 8 and figure 9). Younger participants showed a greater decrease in theta power around mid-frontal channels for correct responses over incorrect responses, whereas older participants showed the opposite effect of condition response mid-frontal theta power (figure 10). Further statistical analysis of the EEG data showed a significant effect of channel location on frequency amplitude, as well as an interaction of age and peak channel location supporting the visual differences. The differences in theta power observed in younger and older adults in this research are supported by previous research where ageing has been associated with greater suppression of theta power in frontal regions than younger adults in motor response tasks (Yordanova et al., 2020). Furthermore, it has been proposed that when presented with stimuli that require internal monitoring of a response (like the WCST) theta power modulation in the mid-frontal cortex supports effective inhibition of incorrect responses (Cohen et al., 2013; Kaiser et al 2019). This may suggest that theta suppression in older adults affects task performance; however, in this study we did not find a relationship between theta amplitude and task performance in either group. We also observed increased alpha power in the older participants only, alpha dysregulation is often associated with inhibitory control and refocusing of attention in older adults (Huizeling et al., 2021), which in this study may reflect the increased attentional effort needed for this task by older participant group.

This research has found that linguistic ability demonstrated comparatively few influences of age, ageing had a more significant effect on behavioural and neurocognitive measures of executive functions (West et al, 2010), though no relationship was found between the social inclusion measures and EEG components. This is likely due to the sample size, as previous findings in behavioural evidence have indicated that executive functions, specifically mental control, and abstract thinking, support ongoing asynchronous communication in older adults (Kearney et al., in prep). Such findings are important for directing future research surrounding the relationships between cognitive decline and social connection in older people and way in which we can tackle social isolation and loneliness in this population. Interventions should look to target the facets of executive functions highlighted in this research, so that they are maintained well into old age and can facilitate meaningful and rewarding social connections.

This research highlights an interesting point of contention in surrounding neuro-cognitive ageing research; it remains unclear what drives the underlying mechanisms of cognitive change in ageing. Research consistently finds that brain activity becomes increasingly generalised in older populations compared to hemisphere specific activation in younger adults, known as Hemispheric Asymmetry Reduction in Old Adults (HAROLD) (Cabeza, 2002). Research using fMRI has shown older participants had additional recruitment of prefrontal regions in visual perception tasks typically only associated with activation in the occipital cortex (Grady et al., 1994). Studies investigating inhibitory control have found bilateral activation of the prefrontal cortex (PFC) in older participants, whereas PFC activation in younger participants was right lateralized (Nielson et al., 2002). Similar findings have been made using EEG, where older adults have demonstrated bilateral N1 ERP effects, traditionally associated with left greater effects in electrodes over the left hemisphere (Zhao et al., 2012). This shift to generalised activation has been observed across domains (Grady et al., 2000.; Heuninckx et al., 2008), but there is some contention about whether this reflects a compensatory mechanism that offsets cognitive declines, or de-differentiation which indicate poor recruitment of specialised brain regions (Cabeza, 2001). Some research has suggested that findings of enhanced regional recruitment when a task is performed successfully would indicate compensatory brain behaviour (Heuninckx et al., 2008). Indeed, in the present study we found more widespread patterns of neural activity in older participants that support the HAROLD theory; however, there was no correlation between ERP and power amplitudes in the brain data and behavioural measures of performance, which may offer support for dedifferentiation and reduction in recruitment of specialised brain regions in these measures.

When designing the study careful consideration was given to the appropriate tests to be carried out to identify possible relationships between neurological and social inclusion measures. Two-way and three-way ANOVAs were deemed most appropriate for analysis, as the data was obtained from two groups that were balanced for the number of participants. The data from this sample was normally distributed, as such, non-parametric tests were deemed unnecessary in the analysis of this study. In this study the use of ANOVAs allowed for the investigation into the potential multi-way interactions between the measure of interest: experimental condition, electrode location, and participant age.

There are some limitations with the research we present here, namely the small sample size and narrow demographic population. However, the issue of statistical power is somewhat mitigated by the number of trials; ERPs have been shown to be temporally across ten trials per participant, though 15 trials is recommended in case of potential data loss (Larson et al., 2010; Boudewyn et al., 2018). As between group comparisons require a greater number of trials (Larson & Carbine, 2017) this study used over 100 trials in each experimental component to maximise statistical power. Therefore, while we acknowledge that the sample is limited, the trial design has been able to address potential issues with statistical power of the EEG data. The small sample size did, however, affect our ability to establish possible significant relationships between the cognition and social inclusion data. The EEG features (channels, time windows and frequency windows) are chosen for analysis based on visual inspection, which has the potential to create selection biases and inflate Type 1 errors for the AVONAs. However, the purpose of this method was to choose the best feature with the data for correlations with the social inclusion measures, though we acknowledge that interpretation of the findings should be cautious. This study also had limited scope in terms of demographic diversity, as participants in both younger and older groups had some level of higher education and came from high income backgrounds or households. While we did attempt to reach a diverse population throughout the recruitment phase, respondents that reached the point of participation predominantly had high-SES. In future research we would aim to reach a more diverse, representative population, an important aim when conducting research to avoid the pitfalls of generalising potentially niche findings of a homogenous sample to a wider population. Reduced sample diversity is compounded by the fact that, due to the current nature of EEG research, only those that could travel to the testing facilities could take part. This greatly restricted the sample, excluding participants with reduced mobility, an issue that greatly affects that older population, when studying social engagement in these populations presents a serious limitation. Advances in EEG recording equipment mean that in future travelling to meet the participant is more feasible, which considerably broadens the participant populations for studies such as this.

In conclusion, we have established a number of age-related differences in the underlying neurocognitive mechanisms of language and executive functions, using both ERP and time-frequency analysis of EEG data. We evidenced that older participants showed fewer condition differences and a reduction in amplitude in the P300 component in inhibition responses, and greater incorrect-response theta power suppression than younger participants and reduced negative amplitude response compared to younger adults. Though we found fewer significant differences than predicted, we suggest further investigation with a larger sample to probe these findings and potential interactions further.

Conflict of interest

The authors declare no conflicts of interest

Contributions

Josephine Kearney: Conceptualization, Data Collection, Methodology, Formal analysis, Writing - Original Draft, Visualization.

*Pamela Qualte*r: Validation, Writing - Review & Editing, Supervision.

Jason R Taylor: Validation, Writing - Review & Editing, Supervision

Appendix 1

Glossary of Terms

Term	Definition
Correct Response Negativity (CRN)	Negative EEG component associated with correct responses given by the participant approximate 100 Ms post-response.
Canthi	Point at the corner of the eye where the upper and lower eyelids meet.
Electroencephalography	Non-invasive method to record spontaneous neuro-electrical activity using electrodes placed at the scalp
Electrooculogram	Method used to measure corneo-retinal potential between the front and back of the eye. Used to capture eye movement and blinking.
Epoch	Time window extracted from continuous EEG data for analysis
Error Related Negativity (ERN)	A negative deflection in the EEG signal associated with incorrect responses to stimuli, occurring approximately 80 Ms post-response.
Event Related Potential	Electrophysiological response in the brain to a sensory, cognitive, or motor event, measured using EEG.
Frontal lobe	Brain structure located at the front of the cerebral cortex, included the prefrontal cortex, premotor and primary motor cortex.
Hippocampus	Brain structure that plays a role in memory, particularly consolidating short-term memory to long-term memory
Insular (BA 13)	Region of the cerebral cortex within the lateral sulcus that plays aa role in motor control and perception.
Ipsilateral	Referring to the side of the body on the same to the brain hemisphere where activity is observed.
Lateralised	Function or effect that is observed on one side of the brain
Mid-frontal Theta	Oscillatory activity in the theta frequency band observed around the front midline of the scalp, associated with increased concentration in cognitive tasks.
Montage	File that defines the order/arrangement of EEG and reference electrodes.
Nasion	Craniometric landmark where the nose meets the brow bone
Occipital lobe	Brain structure at the back of the cerebral cortex, contains the visual cortex.
Parietal lobe	Brain structure between the frontal and occipital lobes, contains the somatosensory cortex.
Pre-auricular Area	Craniometric point at the front of the external ear structure.

Pre-frontal Cortex	Region of the brain at the front of the frontal cortex.
P3	Positive ERP component associated with decision making and reaction speed that is observed 250-500ms post-stimulus presentation.
Superciliary Arch	Brow ridge, located above the eye sockets
Temporal Lobe	Brain structure located under the frontal and parietal lobes. Associated with sensory processing, visual memory, and language.
Time Frequency	Analysis of EEG data that allows for the characterisation of temporal changes in frequency, power, and phase of brain oscillations.
Topography	A display of the spatial distribution of the electrical activity captured in the EEG data
Working Memory	Limited capacity store for temporary holding of information for processing.
Zygomatic Bone	Prominent bone of the cheek and outer eye socket

References

Baddeley, A. (2003). Working memory and language: an overview. *Journal of Communication Disorders*, *36*(3), 189–208. https://doi.org/10.1016/S0021-9924(03)00019-4

Baddeley, A. D., & Hitch, G. (1974). Working Memory. *Psychology of Learning and Motivation - Advances in Research and Theory*, *8*(C), 47–89. https://doi.org/10.1016/S0079-7421(08)60452-1

Band, G. P. H., Ridderinkhof, K. R., & van der Molen, M. W. (2003). Speed-accuracy modulation in case of conflict: the roles of activation and inhibition. *Psychological Research*, *67*(4), 266–279. https://doi.org/10.1007/s00426-002-0127-0

Bassuk, S. S., Glass, T. A., & Berkman, L. F. (1999). Social Disengagement and Incident Cognitive Decline in Community-Dwelling Elderly Persons. *Annals of Internal Medicine*, *131*(3), 165. https://doi.org/10.7326/0003-4819-131-3-199908030-00002

Belke, E., & Meyer, A. S. (2007). Single and multiple object naming in healthy ageing. *Language and Cognitive Processes*, *22*(8), 1178–1211. https://doi.org/10.1080/01690960701461541

Berg, E. A. (1948). A Simple Objective Technique for Measuring Flexibility in Thinking. *The Journal of General Psychology*, *39*(1), 15–22. https://doi.org/10.1080/00221309.1948.9918159

Birdi, K., Pennington, J., & Zapf, D. (1997). Ageing and errors in computer-based work: An observational field study. *Journal of Occupational and Organizational Psychology*, *70*(1), 35–47. https://doi.org/10.1111/j.2044-8325.1997.tb00629.x

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review*, *108*(3), 624–652. http://www.ncbi.nlm.nih.gov/pubmed/11488380

Boudewyn, M. A., Luck, S. J., Farrens, J. L., Kappenman, E. S., & Megan Boudewyn, C. A. (n.d.). *How many trials does it take to get a significant ERP effect? It depends*. https://doi.org/10.1111/psyp.13049

Brummett, B. H., Barefoot, J. C., Siegler, I. C., Clapp-Channing, N. E., Lytle, B. L., Bosworth, H. B., Williams, R. B., & Mark, D. B. (2001). Characteristics of Socially Isolated Patients With Coronary Artery Disease Who Are at Elevated Risk for Mortality. *Psychosomatic Medicine*, *63*(2), 267–272. https://doi.org/10.1097/00006842-200103000-00010

Burke, D. M., MacKay, D. G., Worthley, J. S., & Wade, E. (1991). On the tip of the tongue: What causes word finding failures in young and older adults? *Journal of Memory and Language*, *30*(5), 542–579. https://doi.org/10.1016/0749-596X(91)90026-G

Burke, D. M., & Shafto, M. A. (2004). Aging and Language Production. *Current Directions in Psychological Science*, *13*(1), 21. https://doi.org/10.1111/J.0963-7214.2004.01301006.X

Burke, D. M., & Yee, P. L. (1984). Semantic priming during sentence processing by young and older adults. *Developmental Psychology*, *20*(5), 903–910. https://doi.org/10.1037/0012-1649.20.5.903

Cabeza, R. (2001). Cognitive neuroscience of aging: Contributions of functional neuroimaging. *Scandinavian Journal of Psychology*, *42*(3), 277–286. https://doi.org/10.1111/1467-9450.00237

Cabeza, R. (2002). Hemispheric asymmetry reduction in older adults: The HAROLD model. *Psychology and Aging*, *17*(1), 85. https://doi.org/10.1037/0882-7974.17.1.85

Cacioppo, J. T., & Cacioppo, S. (2014). Social Relationships and Health: The Toxic Effects of Perceived Social Isolation. *Social and Personality Psychology Compass*, *8*(2), 58–72. https://doi.org/10.1111/spc3.12087

Cacioppo, J. T., & Hawkley, L. C. (2003). Social Isolation and Health, with an Emphasis on Underlying Mechanisms. *Perspectives in Biology and Medicine*, *46*(3), S39–S52. https://doi.org/10.1353/PBM.2003.0063

Christiansen, J., Lund, R., Qualter, P., Andersen, C. M., Pedersen, S. S., & Lasgaard, M. (2021). Loneliness, Social Isolation, and Chronic Disease Outcomes. *Annals of Behavioral Medicine*, *55*(3), 203–215. https://doi.org/10.1093/abm/kaaa044

Clarys, D., Bugaiska, A., Tapia, G., & Baudouin, A. (2009). Ageing, remembering, and executive function. *Https://Doi.Org/10.1080/09658210802188301*, *17*(2), 158–168. https://doi.org/10.1080/09658210802188301

Cohen, S., Doyle, W. J., Skoner, D. P., Rabin, B. S., & Gwaltney, J. M. (1997). Social Ties and Susceptibility to the Common Cold. *JAMA: The Journal of the American Medical Association*, *277*(24), 1940. https://doi.org/10.1001/jama.1997.03540480040036

Cornwell, E. Y., & Waite, L. J. (2009). Social Disconnectedness, Perceived Isolation, and Health among Older Adults. *Journal of Health and Social Behavior*, *50*(1), 31–48. https://doi.org/10.1177/002214650905000103

Eagle, D. M., Baunez, C., Hutcheson, D. M., Lehmann, O., Shah, A. P., & Robbins, T. W. (2008). Stop-Signal Reaction-Time Task Performance: Role of Prefrontal Cortex and Subthalamic Nucleus. *Cerebral Cortex*, *18*(1), 178–188. https://doi.org/10.1093/cercor/bhm044

Enoki, H., Sanada, S., Yoshinaga, H., Oka, E., & Ohtahara, S. (1993). The effects of age on the N200 component of the auditory event-related potentials. *Cognitive Brain Research*, *1*(3), 161–167. https://doi.org/10.1016/0926-6410(93)90023-X

Evrard, M. (2002). Ageing and Lexical Access to Common and Proper Names in Picture Naming. *Brain and Language*, *81*(1–3), 174–179. https://doi.org/10.1006/BRLN.2001.2515

Fabrigoule, C., Letenneur, L., Dartigues, J. F., Zarrouk, M., Commenges, D., & Barberger-Gateau, P. (1995). Social and leisure activities and risk of dementia: a prospective longitudinal study. *Journal of the American Geriatrics Society*, *43*(5), 485–490. http://www.ncbi.nlm.nih.gov/pubmed/7730528

Files, B. T., Pollard, K. A., Oiknine, A. H., Khooshabeh, P., & Passaro, A. D. (2021). Correct response negativity may reflect subjective value of reaction time under regulatory fit in a speed-rewarded task. *Psychophysiology*, *58*(9). https://doi.org/10.1111/PSYP.13856

Fjell, A. M., & Walhovd, K. B. (2001). P300 and neuropsychological tests as measures of aging: Scalp topography and cognitive changes. *Brain Topography*, *14*(1), 25–40. https://doi.org/10.1023/A:1012563605837/METRICS

Folstein, J. R., & Van Petten, C. (2007). Influence of cognitive control and mismatch on the N2 component of the ERP: A review. *Psychophysiology*, *0*(0), 070915195953001-??? https://doi.org/10.1111/j.1469-8986.2007.00602.x

Fratiglioni, L., Wang, H.-X., Ericsson, K., Maytan, M., & Winblad, B. (2000). Influence of social network on occurrence of dementia: a community-based longitudinal study. *The Lancet*, *355*(9212), 1315–1319. https://doi.org/10.1016/S0140-6736(00)02113-9

Ganushchak, L. Y., & Schiller, N. O. (2008). Motivation and semantic context affect brain error-monitoring activity: An event-related brain potentials study. *NeuroImage*, *39*(1), 395–405. https://doi.org/10.1016/j.neuroimage.2007.09.001

Gao, X., Levinthal, B. R., & Stine-Morrow, E. A. L. (2012). The Effects of Ageing and Visual Noise on Conceptual Integration during Sentence Reading. *Quarterly Journal of Experimental Psychology*, *65*(9), 1833–1847. https://doi.org/10.1080/17470218.2012.674146

Grady, C. L., Maisog, J. M., Horwitz, B., Ungerleider, L. G., Mentis, M. J., Salerno, J. A., Pietrini, P., Wagner, E., & Haxby, J. V. (1994). Age-related changes in cortical blood flow activation during visual processing of faces and location. *Journal of Neuroscience*, *14*(3), 1450–1462. https://doi.org/10.1523/JNEUROSCI.14-03-01450.1994

Grady, C. L., Mcintosh, A. R., Horwitz, B., & Rapoport, S. I. (n.d.). *AGE-RELATED CHANGES IN THE NEURAL CORRELATES OF DEGRADED AND NONDEGRADED FACE PROCESSING*. Retrieved March 26, 2023, from http://www.tandf.co.uk/journals/pp/02643294.html

Hawton, A., Green, C., Dickens, A. P., Richards, S. H., Taylor, R. S., Edwards, R., Greaves, C. J., & Campbell, J. L. (2011). The impact of social isolation on the health status and health-related quality of life of older people. *Quality of Life Research*, *20*(1), 57–67. https://doi.org/10.1007/s11136-010-9717-2

Heikkinen, R.-L., & Kauppinen, M. (2004). Depressive symptoms in late life: a 10-year follow-up. *Archives of Gerontology and Geriatrics*, *38*(3), 239–250. https://doi.org/10.1016/j.archger.2003.10.004

Heuninckx, S., Wenderoth, N., & Swinnen, S. P. (2008). Systems neuroplasticity in the aging brain: recruiting additional neural resources for successful motor performance in elderly persons. *The Journal of Neuroscience : The Official Journal of the Society for Neuroscience*, *28*(1), 91–99. https://doi.org/10.1523/JNEUROSCI.3300-07.2008

Hoffmann, S., & Falkenstein, M. (2011). Aging and Error Processing: Age Related Increase in the Variability of the Error-Negativity Is Not Accompanied by Increase in Response Variability. *PLOS ONE*, *6*(2), e17482. https://doi.org/10.1371/JOURNAL.PONE.0017482

Horton, W. S. (2010). Conversational Common Ground and Memory Processes in Language Production. *Http://Dx.Doi.Org/10.1207/S15326950dp4001_1*, *40*(1), 1–35. https://doi.org/10.1207/S15326950DP4001_1

Horton, W. S., Spieler, D. H., & Shriberg, E. (2010). A Corpus Analysis of Patterns of Age-Related Change in Conversational Speech. *Psychology and Aging*, *25*(3), 708. https://doi.org/10.1037/A0019424

Huizeling, E., Wang, H., Holland, C., & Kessler, K. (2021). Changes in theta and alpha oscillatory signatures of attentional control in older and middle age. *European Journal of Neuroscience*, *54*(1), 4314–4337. https://doi.org/10.1111/EJN.15259

Huster, R. J., Enriquez-Geppert, S., Lavallee, C. F., Falkenstein, M., & Herrmann, C. S. (2013). Electroencephalography of response inhibition tasks: Functional networks and cognitive contributions. *International Journal of Psychophysiology*, *87*(3), 217–233. https://doi.org/10.1016/j.ijpsycho.2012.08.001

Huster, R. J., Messel, M. S., Thunberg, C., & Raud, L. (2020). The P300 as marker of inhibitory control – Fact or fiction? *Cortex*, *132*, 334–348. https://doi.org/10.1016/J.CORTEX.2020.05.021

Imhof, M. F., & Rüsseler, J. (2019). Performance Monitoring and Correct Response Significance in Conscientious Individuals. *Frontiers in Human Neuroscience*, *13*. https://doi.org/10.3389/fnhum.2019.00239

Juncos-Rabadán, O., Facal, D., Rodríguez, M. S., & Pereiro, A. X. (2010). Lexical knowledge and lexical retrieval in ageing: Insights from a tip-of-the-tongue (TOT) study. *Language and Cognitive Processes*, *25*(10), 1301–1334. https://doi.org/10.1080/01690961003589484

Kaiser, J., Simon, N. A., Sauseng, P., & Schütz-Bosbach, S. (2019). Midfrontal neural dynamics distinguish between general control and inhibition-specific processes in the stopping of motor actions. *Scientific Reports 2019 9:1*, *9*(1), 1–11. https://doi.org/10.1038/s41598-019-49476-4

Kearney, J. F., Qualter, P., Cam-CAN & Taylor, J. R. (submitted). *Age-related differences in higher-order cognitive mediation of socioeconomic status and social engagement: A Structural Equation Modelling Study* .

Kearney, J. F., Qualter, P., Cam-CAN, & Taylor, J. R. (in preparation). *Age-related differences in higher-order cognitive mediation of socioeconomic status and social engagement: A Structural Equation Modelling Study* .

Keller-Cohen, D., Fiori, K., Toler, A., & Bybee, D. (2006). Social relations, language and cognition in the 'oldest old.' *Ageing and Society*, *26*(4), 585–605. https://doi.org/10.1017/S0144686X06004910

Kikyo, H., Ohki, K., & Sekihara, K. (2002). Temporal characterization of memory retrieval processes: An fMRI study of the "tip of the tongue" phenomenon. *European Journal of Neuroscience*, *14*(5), 887–892. https://doi.org/10.1046/j.0953-816X.2001.01711.x

Kirova, A. M., Bays, R. B., & Lagalwar, S. (2015). Working Memory and Executive Function Decline across Normal Aging, Mild Cognitive Impairment, and Alzheimer's Disease. *BioMed Research International*, *2015*. https://doi.org/10.1155/2015/748212

Larson, M. J., Baldwin, S. A., Good, D. A., & Fair, J. E. (2010). Temporal stability of the error-related negativity (ERN) and post-error positivity (Pe): The role of number of trials. *Psychophysiology*, *47*(6), no-no. https://doi.org/10.1111/j.1469-8986.2010.01022.x

Larson, M. J., & Carbine, K. A. (2017). Sample size calculations in human electrophysiology (EEG and ERP) studies: A systematic review and recommendations for increased rigor. *International Journal of Psychophysiology*, *111*, 33–41. https://doi.org/10.1016/j.ijpsycho.2016.06.015

Laver, G. D., & Burke, D. M. (1993). Why do semantic priming effects increase in old age? A meta-analysis. *Psychology and Aging*, *8*(1), 34–43. http://www.ncbi.nlm.nih.gov/pubmed/8461113

Lubben, J., Blozik, E., Gillmann, G., Iliffe, S., von Renteln Kruse, W., Beck, J. C., & Stuck, A. E. (2006). Performance of an Abbreviated Version of the Lubben Social Network Scale Among Three European Community-Dwelling Older Adult Populations. *The Gerontologist*, *46*(4), 503–513. https://doi.org/10.1093/geront/46.4.503

Lubben, J. E. (1988). Assessing social networks among elderly populations. *Family & Community Health*, *11*(3), 42–52. https://doi.org/10.1097/00003727-198811000-00008

Maril, A., Wagner, A. D., & Schacter, D. L. (2001). On the tip of the tongue: An event-related fMRI study of semantic retrieval failure and cognitive conflict. *Neuron*, *31*(4), 653–660. https://doi.org/10.1016/S0896-6273(01)00396-8

Martín, M. Cruz., Macizo, Pedro., & Bajo, Teresa. (2010). Time course of inhibitory processes in bilingual language processing. *British Journal of Psychology*, *101*(4), 679–693. https://doi.org/10.1348/000712609X480571

Masaki, H., Tanaka, H., Takasawa, N., & Yamazaki, K. (2001). Error-related brain potentials elicited by vocal errors. *NeuroReport*, *12*(9), 1851–1855. https://doi.org/10.1097/00001756-200107030-00018

Matsuhashi, T., Segalowitz, S. J., Murphy, T. I., Nagano, Y., Hirao, T., & Masaki, H. (2021). Medial frontal negativities predict performance improvements during motor sequence but not motor adaptation learning. *Psychophysiology*, *58*(1), e13708. https://doi.org/10.1111/PSYP.13708

Miltner, W. H. R., Braun, C. H., & Coles, M. G. H. (1997). Event-Related Brain Potentials Following Incorrect Feedback in a Time-Estimation Task: Evidence for a "Generic" Neural System for Error Detection. *Journal of Cognitive Neuroscience*, *9*(6), 788–798. https://doi.org/10.1162/jocn.1997.9.6.788

Motley, M. T., & Baars, B. J. (1976). Laboratory induction of verbal slips: A new method for psycholinguistic research. *Communication Quarterly*, *24*(2), 28–34. https://doi.org/10.1080/01463377609369216

Nasreddine, Z. S., Phillips, N. A., Badirian, V., Charbonneau, S., Whitehead, V., Collin, I., Cummings, J. L., & Chertkow, H. (2005). The Montreal Cognitive Assessment, MoCA: A Brief Screening Tool For Mild Cognitive Impairment. *Journal of the American Geriatrics Society*, *53*(4), 695–699. https://doi.org/10.1111/j.1532-5415.2005.53221.x

Nielson, K. A., Langenecker, S. A., & Garavan, H. (2002). Differences in the functional neuroanatomy of inhibitory control across the adult life span. *Psychology and Aging*, *17*(1), 56–71. https://doi.org/10.1037/0882-7974.17.1.56

O'Connell, R. G., Balsters, J. H., Kilcullen, S. M., Campbell, W., Bokde, A. W., Lai, R., Upton, N., & Robertson, I. H. (2012). A simultaneous ERP/fMRI investigation of the P300 aging effect. *Neurobiology of Aging*, *33*(10), 2448–2461. https://doi.org/10.1016/J.NEUROBIOLAGING.2011.12.021

O'Connell, R. G., Dockree, P. M., Bellgrove, M. A., Kelly, S. P., Hester, R., Garavan, H., Robertson, I. H., & Foxe, J. J. (2007). The role of cingulate cortex in the detection of errors with and without awareness: a high-density electrical mapping study. *European Journal of Neuroscience*, *25*(8), 2571–2579. https://doi.org/10.1111/j.1460-9568.2007.05477.x

Pailing, P. E., & Segalowitz, S. J. (2004). The error-related negativity as a state and trait measure: Motivation, personality, and ERPs in response to errors. *Psychophysiology*, *41*(1), 84–95. https://doi.org/10.1111/1469-8986.00124

Peelle, J. E., Troiani, V., Wingfield, A., & Grossman, M. (2010). Neural Processing during Older Adults' Comprehension of Spoken Sentences: Age Differences in Resource Allocation and Connectivity. *Cerebral Cortex*, *20*(4), 773–782. https://doi.org/10.1093/cercor/bhp142

Piai, V., & Roelofs, A. (2013). Working memory capacity and dual-task interference in picture naming. *Acta Psychologica*, *142*(3), 332–342. https://doi.org/10.1016/J.ACTPSY.2013.01.006

Ramautar, J. R., Kok, A., & Ridderinkhof, K. R. (2004). Effects of stop-signal probability in the stop-signal paradigm: The N2/P3 complex further validated. *Brain and Cognition*, *56*(2), 234–252. https://doi.org/10.1016/j.bandc.2004.07.002

Rhodes, M. G. (2004). Age-Related Differences in Performance on the Wisconsin Card Sorting Test: A Meta-Analytic Review. *Psychology and Aging*, *19*(3), 482–494. https://doi.org/10.1037/0882-7974.19.3.482

Russell, D. W. (1996). UCLA Loneliness Scale (Version 3): Reliability, Validity, and Factor Structure. *Journal of Personality Assessment*, *66*(1), 20–40. https://doi.org/10.1207/s15327752jpa6601_2

Ryan, R. M. (1995). Psychological Needs and the Facilitation of Integrative Processes. *Journal of Personality*, *63*(3), 397–427. https://doi.org/10.1111/j.1467-6494.1995.tb00501.x

Schmajuk, M., Liotti, M., Busse, L., & Woldorff, M. G. (2006). Electrophysiological activity underlying inhibitory control processes in normal adults. *Neuropsychologia*, *44*(3), 384–395. https://doi.org/10.1016/J.NEUROPSYCHOLOGIA.2005.06.005

Shafto, M. A., Burke, D. M., Stamatakis, E. A., Tam, P. P., & Tyler, L. K. (2007). On the tip-of-the-tongue: Neural correlates of increased word-finding failures in normal aging. *Journal of Cognitive Neuroscience*, *19*(12), 2060–2070. https://doi.org/10.1162/jocn.2007.19.12.2060

Shao, Z., Janse, E., Visser, K., & Meyer, A. S. (2014). What do verbal fluency tasks measure? Predictors of verbal fluency performance in older adults. *Frontiers in Psychology*, *5*, 772. https://doi.org/10.3389/fpsyg.2014.00772

Sin, E., Shao, R., & Lee, T. M. C. (2020). The executive control correlate of loneliness in healthy older people. *Aging and Mental Health*, 1–8. https://doi.org/10.1080/13607863.2020.1749832

Tisserand, D. J., & Jolles, J. (2003). On the involvement of prefrontal networks in cognitive ageing. *Cortex; a Journal Devoted to the Study of the Nervous System and Behavior*, *39*(4–5), 1107–1128.

Tsang, H.-L., & Lee, T. M. C. (2003). The effect of ageing on confrontational naming ability. *Archives of Clinical Neuropsychology*, *18*(1), 81–89. https://doi.org/10.1093/arclin/18.1.81

Wascher, E., Schneider, D., Hoffmann, S., Beste, C., & Sänger, J. (2012). When compensation fails: Attentional deficits in healthy ageing caused by visual distraction. *Neuropsychologia*, *50*(14), 3185–3192. https://doi.org/10.1016/J.NEUROPSYCHOLOGIA.2012.09.033

West, R., & Schwarb, H. (2006). The influence of aging and frontal function on the neural correlates of regulative and evaluative aspects of cognitive control. *Neuropsychology*, *20*(4), 468–481. https://doi.org/10.1037/0894-4105.20.4.468

West, R., Schwarb, H., & Johnson, B. N. (2010). The influence of age and individual differences in executive function on stimulus processing in the oddball task. *Cortex*, *46*(4), 550–563. https://doi.org/10.1016/J.CORTEX.2009.08.001

Yordanova, J., Falkenstein, M., & Kolev, V. (2020). Aging-related changes in motor response-related theta activity. *International Journal of Psychophysiology*, *153*, 95–106. https://doi.org/10.1016/J.IJPSYCHO.2020.03.005

Zelazo, P. D., Craik, F. I. M., & Booth, L. (2004). Executive function across the life span. *Acta Psychologica*, *115*(2–3), 167–183. https://doi.org/10.1016/J.ACTPSY.2003.12.005

Zhao, J., Li, S., Lin, S.-E., Cao, X.-H., He, S., & Weng, X.-C. (2012). Selectivity of N170 in the left hemisphere as an electrophysiological marker for expertise in reading Chinese. *Neuroscience Bulletin*, *28*(5), 577–584. https://doi.org/10.1007/s12264-012-1274-y

Zimet, G. D., Dahlem, N. W., Zimet, S. G., & Farley, G. K. (1988). The Multidimensional Scale of Perceived Social Support. *Journal of Personality Assessment*, *52*(1), 30–41. https://doi.org/10.1207/s15327752jpa5201_2

Zunzunegui, M.-V., Alvarado, B. E., Del Ser, T., & Otero, A. (2003). Social networks, social integration, and social engagement determine cognitive decline in community-dwelling Spanish older adults. *The Journals of Gerontology. Series B, Psychological Sciences and Social Sciences*, *58*(2), S93–S100. https://doi.org/10.1093/geronb/58.2.s93

Supplementary Materials

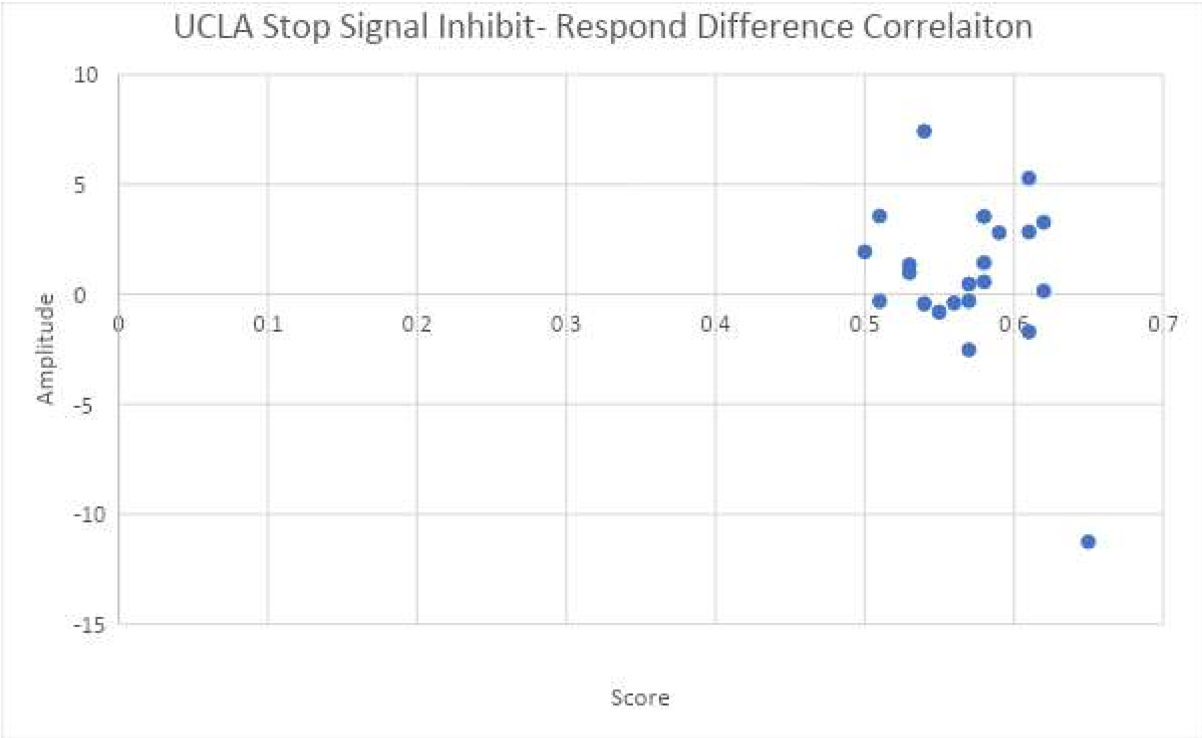
1. Descriptive statistics of UCLA, LSNS and MSPSS for both age groups

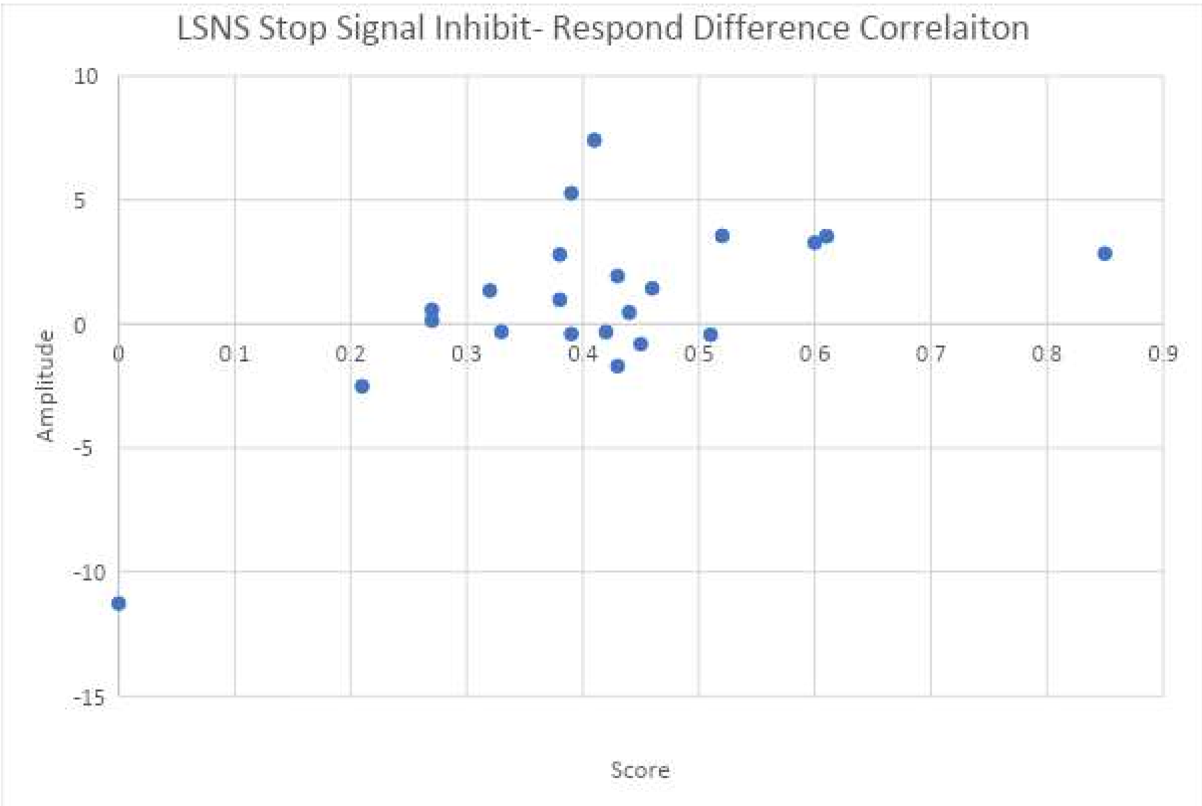
Social Questionnaire Descriptives		N	Mean	Std. Deviation
UCLA	Young	10	0.5610	0.03178
	Old	12	0.5767	0.04677
LSNS	Young	10	0.3570	0.07514
	Old	12	0.4583	0.20342
MSPSS	Young	10	0.7090	0.07430
	Old	12	0.6517	0.23679

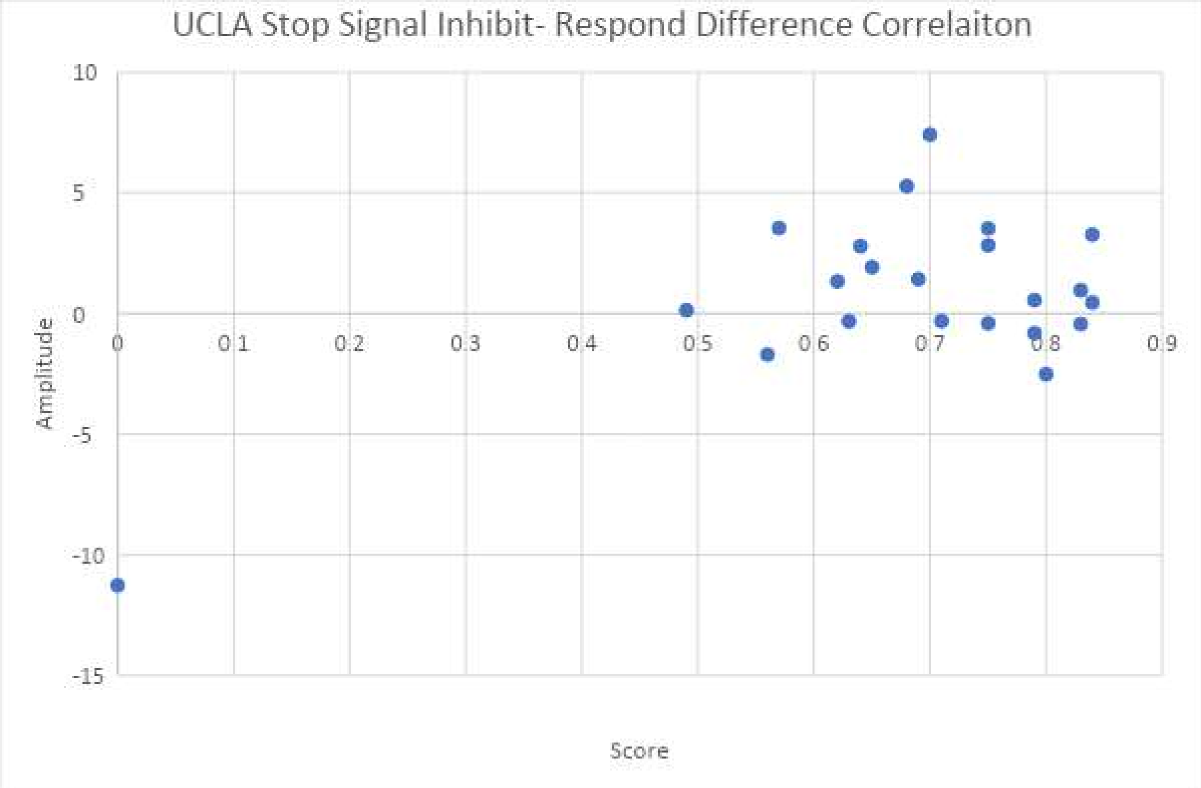
2. Descriptive statistics of behavioural measures for Wisconsin Card Sorting Task, SLIP Task, Stop Signal Task for both age groups

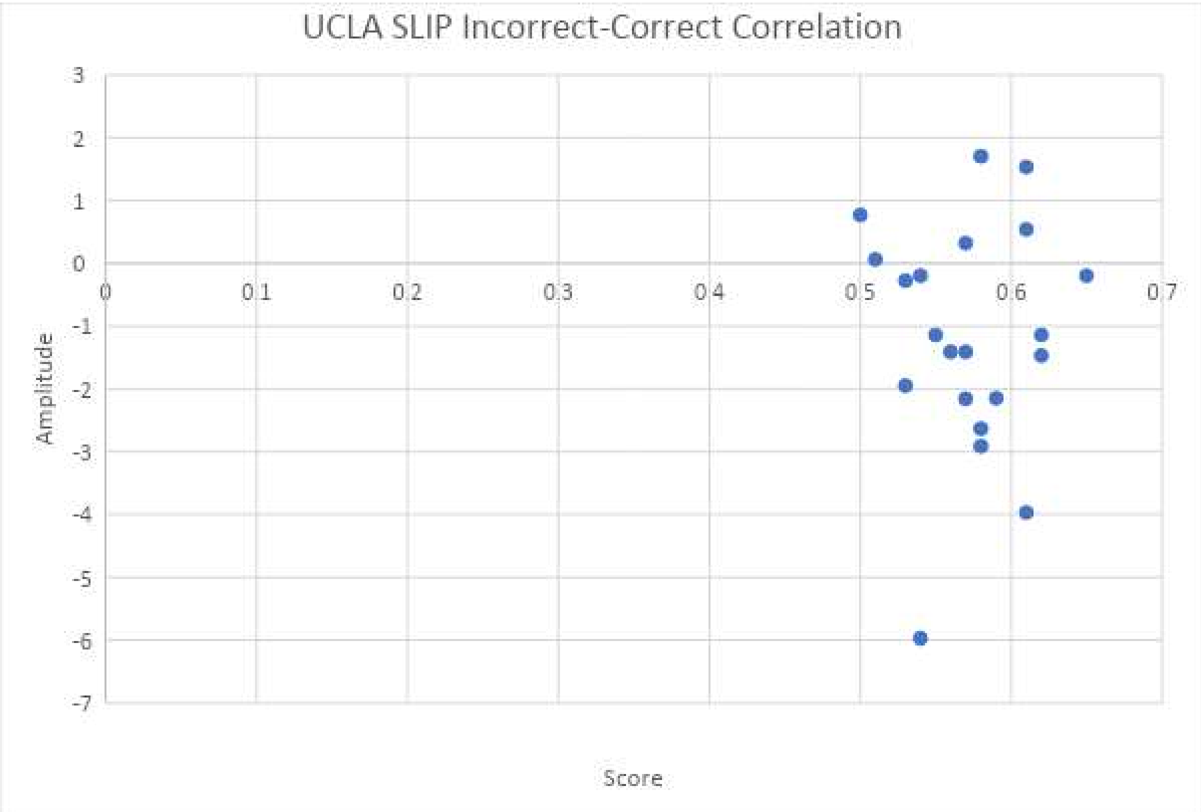
Behavioural Descriptives		N	Mean	Std. Deviation
WCST Response Time	Young	9	2276.7544	524.25908
	Old	12	2673.3267	816.91587
WCST Accuracy	Young	9	63.8889	10.89226
	Old	12	27.9948	22.73896
SLIP Accuracy	Young	10	86.1739	10.93372
	Old	12	78.6957	12.56022
Stop Signal Accuracy	Young	10	95.3788	4.75727
	Old	12	92.5505	7.39335
Stop Signal Response Time	Young	10	627.51	67.990
	Old	12	694.09	85.155

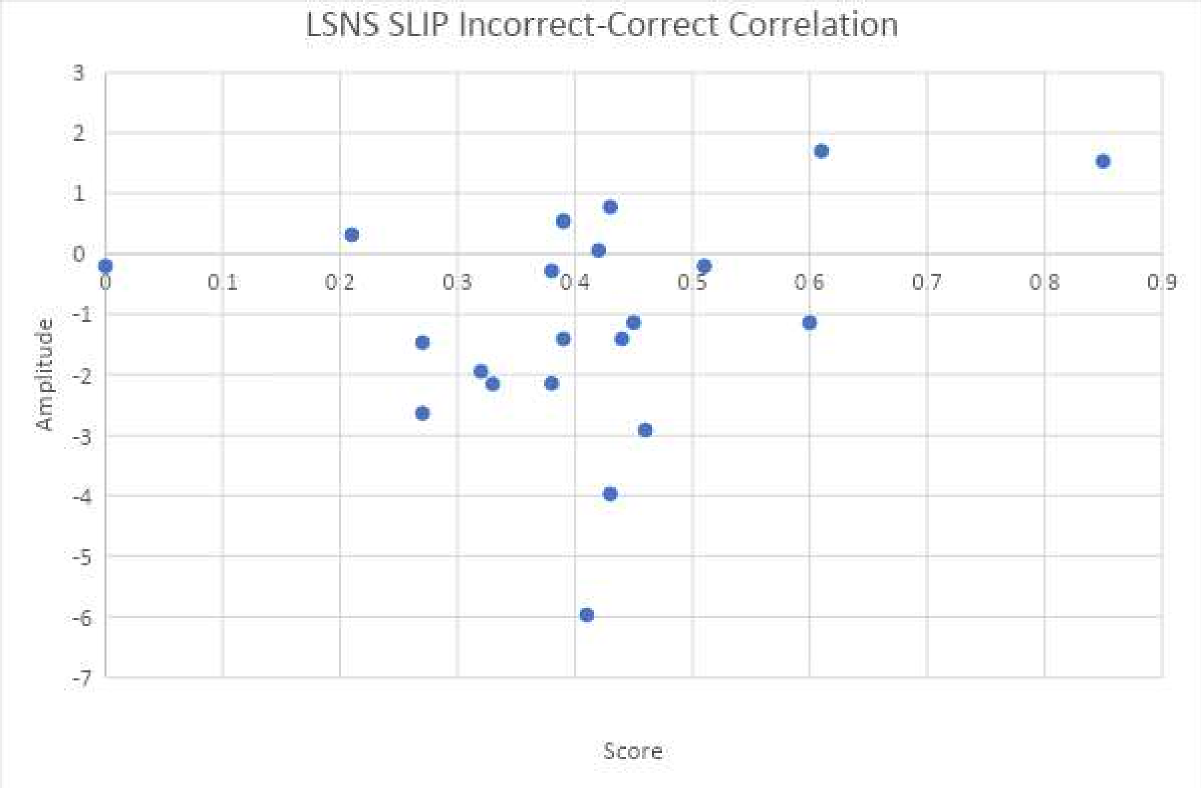
3. Correlation Scatter Plots Between ERP Amplitude and Questionnaire Score

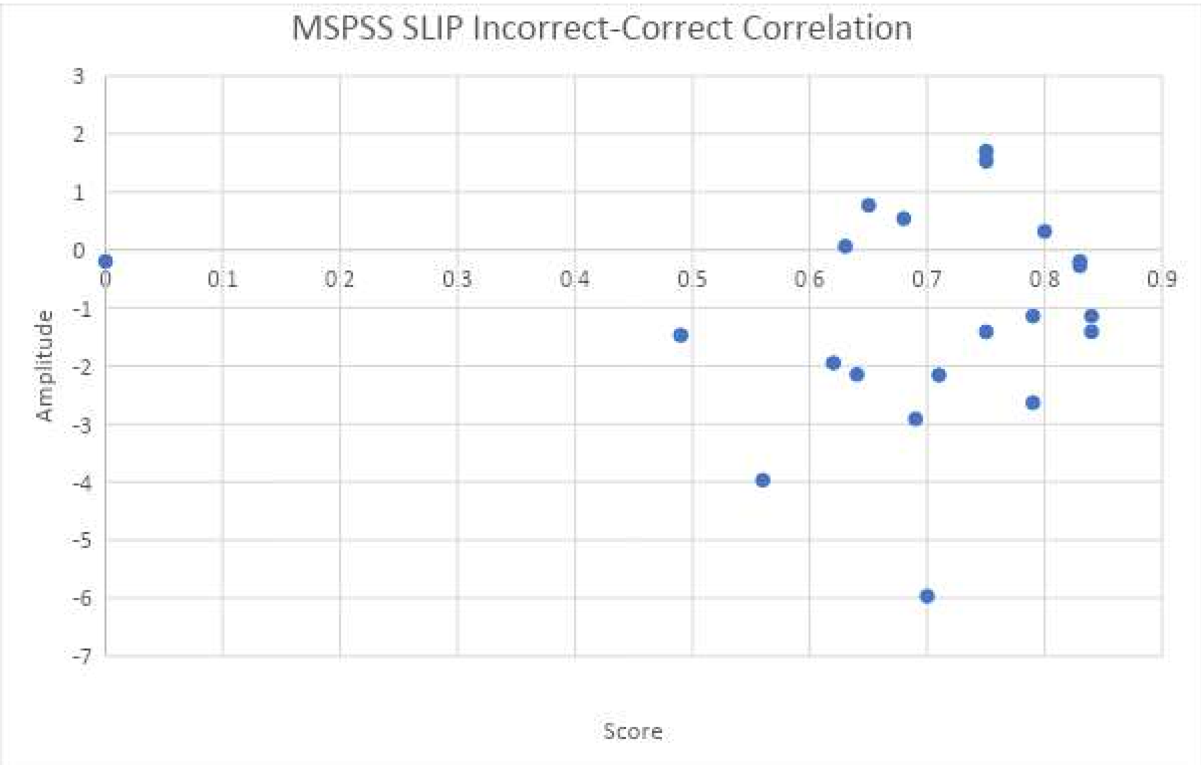


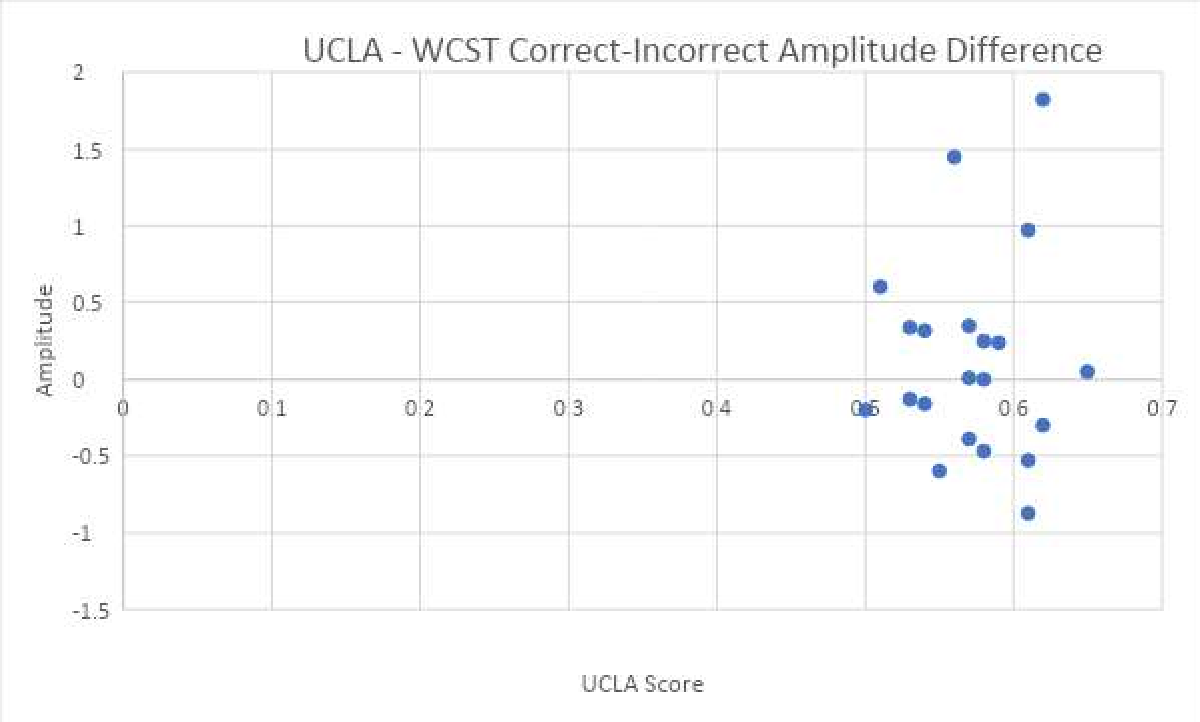


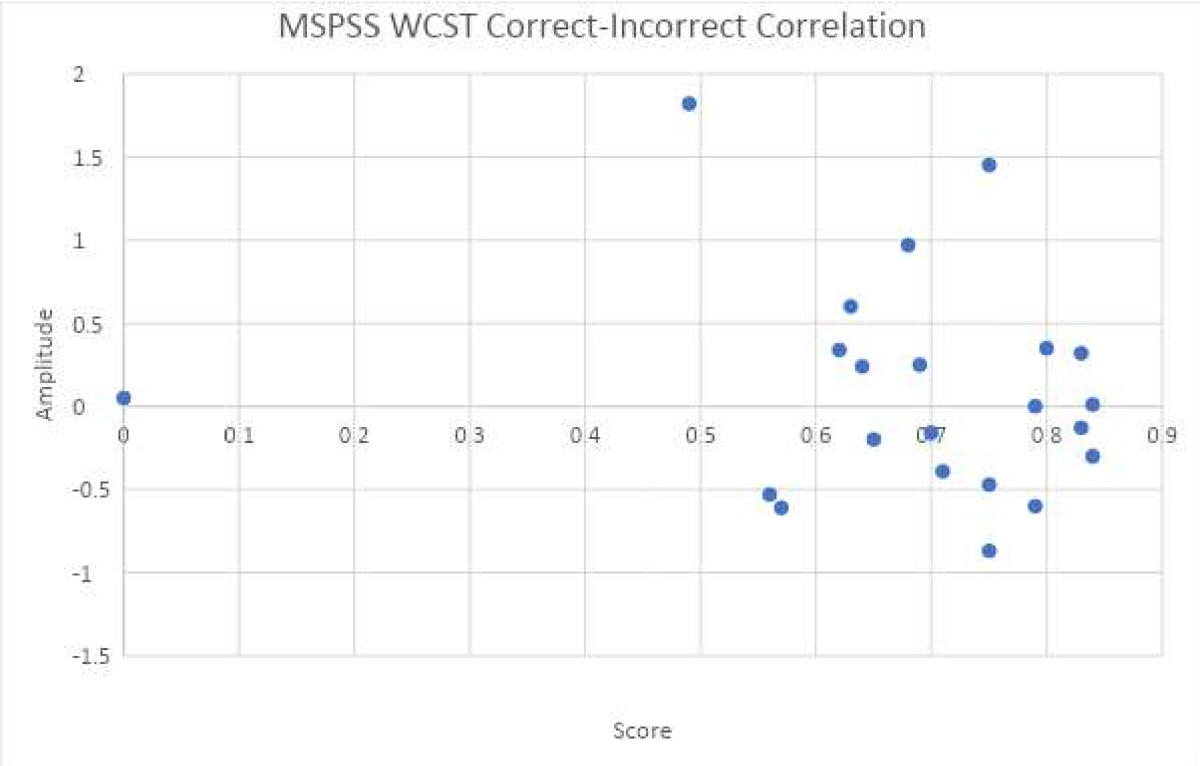

UCLA Stop Signal Inhibit- Respond Difference Correlaiton
10
5
0
-5
-10
-15
Amplitude
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Score

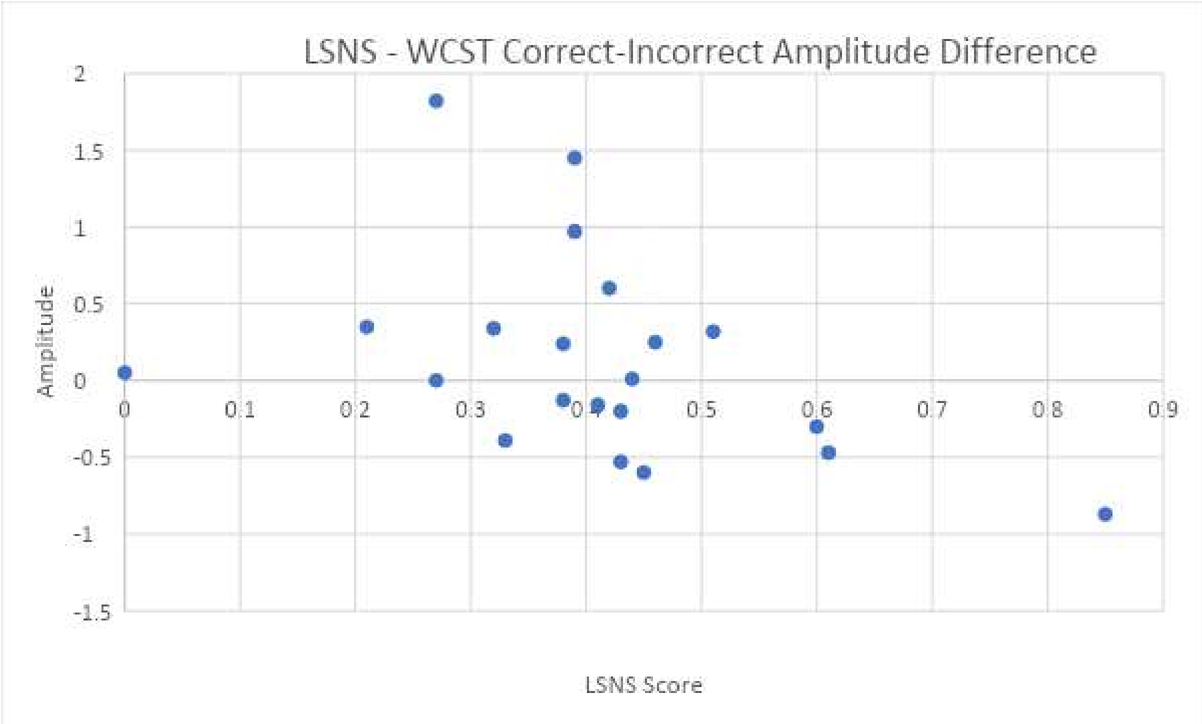

UCLA SLIP Incorrect-Correct Correlation
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
Amplitude
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Score


LSNS SLIP Incorrect-Correct Correlation
Amplitude
Score
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9


MSPSS SLIP Incorrect-Correct Correlation
Amplitude
Score
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9


UCLA - WCST Correct-Incorrect Amplitude Difference
Amplitude
UCLA Score
2
1.5
1
0.5
0
-0.5
-1
-1.5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7


MSPSS WCST Correct-Incorrect Correlation
Amplitude
Score
2
1.5
1
0.5
0
-0.5
-1
-1.5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9


LSNS - WCST Correct-Incorrect Amplitude Difference
Amplitude
2
1.5
1
0.5
0
-0.5
-1
-1.5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
LSNS Score

General Discussion

This thesis aimed to investigate the effects of age-related changes in cognition on the experience of social engagement and inclusion. The main predictions being that older people would have a greater reliance on cognitive support for social engagement than younger people, that cognitive processes would have different neuro-electrophysiological characteristics than their younger counterparts, and that said differences would indicate reduced social inclusion. Specific cognitive domains were explored because previous research demonstrated associations between cognition and social engagement using only generalised, behavioural measures of cognition, limiting our understanding of such an association. After all, it does not account for dissimilar declines in cognitive components. Cognitive ability declines at differing rates across domains, due to the non-linear deterioration of supporting brain structures (Fjell et al., 2013), making it crucial to examine cognitive domains in a more targeted way to fully understand the implications of their decline. Studies 1 and 2 of my thesis show the value of studying the association between cognition to social engagement in later life, while building a more cognitively nuanced framework for scientific exploration. Study 3 investigated the importance of more targeted measures within cognitive domains and highlighted the need to use more specific measures of social support and perceptions of social isolation, finding differences between younger and older neuro-electrophysiological signals in the brain. In this chapter, I discuss the overall findings of each of the studies within this thesis, and the implications this research has for the field and society. I also address a number of the potential limitations of this research.

Summary of Findings

Study 1 used data from the first wave of data collection for the Cam-CAN dataset (Shafto et al., 2014), a large, cross-sectional, adult-lifespan, population-representative dataset. The variables for use in analyses of this study were identified based on data available in the dataset (cognitive and social engagement measures) and variability of the sample (socioeconomic measures). Factor analyses of the cognitive variables indicated three cognitive factors that reflected different cognitive mechanisms between the age groups. Similarly, three social factors were established, and these were found to be reflective of either *who* was interacted with (Under 50 age group) or *how* the interaction occurred (Over 50 age group). Structural Equation Modelling of these factors for both groups revealed a number of direct interactions between measures of socioeconomic status and cognition, and socioeconomic status and social engagement in younger adults, but no mediating interaction between all three domains. The older adult sample, however, had several cognitively mediated pathways between socioeconomic status and social engagement. These findings demonstrate different patterns of representation in younger and older adults, as well as highlighting various measures of cognition as a key mediator in later life.

Study 2 built on the theories of Study 1, using the second wave of the Cam-CAN dataset, which collected targeted behavioural cognitive measures from a subset of the participant sample from the first wave of data collection. The participants of this study were split by age as in Study 1 (Under 50 years old and Over 50 years old), and the participant's socioeconomic measures from Study 1 were also used for this analysis. Confirmatory factor analysis of the social engagement measures in this dataset replicated the three-factor structure established in Study 1 for both the younger and older participant groups. Structural equation modelling in this study found that, in the younger population, cognition was primarily supported by Educational Attainment. This analysis also revealed a cognitively mediated pathway between Communication with Relatives and Educational Attainment, a three-way association that was not observed in the first study when cognitive measures were less specific. The same analysis of the older population showed a more equally distributed pattern of interaction between cognitive, social engagement and socioeconomic measures. Mediation analysis showed that Abstraction and Fluid Intelligence were important mediators between social engagement and

SES measures in this group. The findings of Study 2 support those of Study 1, in that social engagement was differentially represented in the two age groups, as well as demonstrating how more specific cognitive mediators can mediate social connection in younger and older adults.

Study 3 investigated the neurological underpinnings of the relationships observed in Study 1 and Study 2 by using specific experimental manipulations of language and executive functions while recording electroencephalography (EEG) and detailed questionnaires probing participants' experiences of social support and isolation. Behavioural measures alone revealed negligible differences between younger and older adults, young adults outperformed older adults only in mental shifting, but EEG data revealed several differences in neural components. In a test of inhibitory controls, when compared to younger counterparts, older adults were found to have more centralised P300 components, with significantly smaller amplitudes across conditions. Older adults showed an increase in theta power across the scalp and a mid-frontal theta power decrease in a task that probed mental shifting, whereas younger participants showed only a midfrontal theta decrease. Finally, in a language production task, older participants showed a weaker response amplitude across the scalp, with little condition variation compared to younger adults. Study 3 demonstrated the importance of measuring neural signatures of cognition, to go beyond behavioural findings, particularly when comparing age groups, as the behavioural evidence alone would not have indicated the group differences found here. With Study 1 and Study 2 as a theoretical foundation, Study 3 demonstrated a number of age-related differences in cognitive processing at the neuronal level that may be an important target for future research and intervention.

Ultimately, Study 1 demonstrated this cognition-social engagement relationship on a broad scale, across a large population, and Study 2 replicated those findings while increasing the specificity of cognitive measures to highlight the key associations between cognitive and social features. To complement these findings, Study 3 identified age differences in neural electrophysiological behaviour using extremely targeted neurological measures of cognition, though I was not able to find a relationship between neural and social inclusion measures. The stepwise evolution of the theories of age-related differences in cognition and social engagement across the studies presented here has allowed for targeted development of the methodologies to suitably investigate the underpinnings of the relationships identified.

Implications of this Research

The overall and independent findings of these studies are consistent with the existing literature surrounding cognition and social engagement. Measures relating to executive function were found to be uniquely associated with social support in older adults, suggesting that social relationships were supported by effective problem-solving and information processing (Krueger et al., 2009). Scores on verbal fluency and recall tasks have also been associated with loneliness and social isolation in older people, and this relationship is influenced by one's level of education (Shankar et al., 2013). Furthermore, other research with the Cam-CAN dataset has made similar connections between more generalised measures of executive function and social engagement over the life course (Borgeest et al., 2020), conceptualised differently from this current research. Studies 1 and 2 complement previous findings of cognitive-social engagement, as Study 3 was able to demonstrate differences between age groups in neural measures of executive function in ageing which may suggest that these facets may also affect social engagement.

The differences between the age groups observed in studies 1 and 2 of this research imply a shift to a greater reliance on cognitive ability in later life. Young, healthy adults are at their cognitive peak (Hartshorne and Germine, 2015), and the current findings suggest that social connection is not cognitively taxing for this group. For example, I found Communication with Friends to be independent of cognitive measures in young adults in both SEM studies, and I found no relationship between cognition and social support in Study 3. In contrast, my findings show that Social Participation and Asynchronous Communication were consistently associated with cognition among older adults. This may reflect the increased cognitive effort required to maintain social connections (Meiran and Gotler, 2010), where continuous demands are made on memory, verbal fluency, and the ability to switch between tasks (Burke and Shafto, 2004; Holtgraves and Kashima, 2008; Wascher et al., 2012).

The findings of these studies can be used to inform the direction of future research. I found that language ability, while associated with social engagement factors in SEM analysis and affected by age in Study 3, did not have the most influence on social factors throughout the research. Instead, executive functions were the most important in mediating social communication and participation in Study 1 and Study 2 and were found to be most affected by ageing in Study 3. Additionally, social engagement was found to be differentially represented in the two age groups in Studies 1 and 2, an important consideration when investigating factors that may influence one's social experiences. The research presented here showed that distinct aspects of social engagement were associated with cognition in discrete ways, suggesting that future work needs to consider (1) measuring the aspects of social engagement that are important for people at specific ages, and (2) that certain aspects of cognitive decline are linked to specific changes in social engagement during adulthood. Thus, future research should look to replicate the factor structures of social engagement that I found in Studies 1 and 2, to determine whether my findings are representative of the ageing population or specific to this cohort. This can then be used to further probe which social engagement factor is more significantly impacted by cognitive ageing and if such a relationship may be associated with loneliness or social isolation. Such work would have impacts on the measurement of social engagement and the development of interventions that focus on cognitive decline and its influence on social isolation.

Based on this evidence, the current findings are useful in guiding the development of societal and therapeutic interventions that target executive functions to social connections to actively prevent loneliness and social isolation. This research has shown that maintaining executive functions throughout the life course is important for continuing social connections and activity. In early life, it would be beneficial to focus on the key elements of executive function (inhibition, abstract thinking, and fluid intelligence) identified in this research as associated with social engagement. It would be of particular importance to support this development in school programmes for less advantaged children given research has repeatedly evidenced lower SES as being adversely associated with executive functioning (Lipina & Posner, 2012; Mezzacappa, 2004). In schoolchildren, such interventions could be gamified and implemented by educators in the classroom, as such interventions have been found to be successful for improving engagement in physical activity and intrinsic motivation (Beemer et al., 2019; Xu et al., 2021). Given my findings specifically, among older people it would be advantageous to actively maintain these functions in later-life by engaging in cognitively challenging activities alone or in social settings, and organisations that support older people should look to encourage and support this in older people. Levels of physical activity in older adults are often associated with both better cognitive performance and increased feelings of social support (Smith et al., 2017; Chu et al., 2015), so interventions in this age group should look to encourage increased and continuous physical activity where possible. This can be achieved, for example, at a local council level by offering free or reduced cost activities to at-risk groups; particularly activities such as swimming or gardening which have relatively low impacts on heart rate and joints.

The findings of the research presented here speak to the debate surrounding the precise underlying mechanisms of cognitive change in ageing. Research consistently finds that brain activity becomes increasingly generalised in older populations compared to hemisphere specific activation in younger adults, known as Hemispheric Asymmetry Reduction in Old Adults (HAROLD) (Cabeza, 2002). Research using fMRI has shown older participants have additional recruitment of prefrontal regions in visual perception tasks typically only associated with activation in the occipital cortex (Grady et al., 1994). Studies investigating inhibitory control have found bilateral activation of the prefrontal cortex (PFC) in older participants, whereas PFC activation in younger participants was right lateralized (Nielson et al., 2002). This shift to generalised activation has been observed across domains (Grady et al., 2000; Heuninckx et al., 2008), but there is some contention about whether this reflects a compensatory mechanism that offsets cognitive declines, or de-differentiation, which indicates poor recruitment of specialised brain regions (Cabeza, 2001). Some research has suggested that findings of enhanced regional recruitment when a task is performed successfully would indicate compensatory brain behaviour (Heuninckx et al.,2008). Indeed, in Study 3 of this thesis found more widespread patterns of neural activity in older participants that support the HAROLD theory, however there was no correlation between ERP and power amplitudes in the brain data and behavioural measures of performance, which may offer support for dedifferentiation and reduction in recruitment of specialised brain regions in these measures.

Methodological Considerations

While providing interesting new insights into the relationship between cognition and social engagement in ageing, this research is not without limitations. Perhaps the most significant issue is the sample size of the final study, which was reduced due to issues surrounding recruitment caused by the COVID-19 pandemic. Regardless of the impacts of COVID-19, establishing an appropriate sample size for research using EEG can be challenging. However, some of the issues with statistical power can be mitigated by the number of trials used in the research itself (Boudewyn et al., 2018). Research investigating error-related negativity ERPs has shown a temporally stable grand-average can be achieved with just 10 trials per participant, though recommended at least 15 trials to mitigate unforeseen data loss (Larson et al., 2010). Between group comparisons, such as the work presented here, do require a greater number of trials, with at least 30 trials for a stable ERP for between-subject comparisons (Larson & Carbine, 2017). In the design of the research paradigm presented here it was ensured that each task had over 100 trials to maximise statistical power. Therefore, I acknowledge the limited sample size of this research, but assert that the number of trials can go some way to address potential issues with statistical power when the participant sample is small in EEG research. The small sample size of Study 3 did, however, affect our ability to establish possible significant relationships between the cognition and social inclusion data. This study also had limited scope in terms of demographic diversity, because all participants in both younger and older groups had some level of higher education and came from high income backgrounds or households. Generalising potentially niche findings from a small sample to a wider population can overlook potential socioeconomic or cultural influences, and, although this is an issue, I had hoped to address with a broad recruitment strategy, the respondents primarily had a high-SES. In future research greater efforts would be made to reach a more diverse, representative population. Additionally, the study could only accept participants that were able to travel to the university, restricting the sample to participants without mobility issues, which, in an older population, and when studying social engagement, presents a serious limitation. It would be advantageous in future research to aim to be more mobile as researchers: travelling to meet the participant rather than expecting participants to travel to the research would considerably broaden the participant populations for studies such as this.

An additional challenge faced in Study 3 was the methodological choice of asking the participants to respond aloud in the SLIP task. Throughout the paradigm development I was conscious of the potential issue of response modality between language production and button press response errors in executive function tasks. Of particular interest to this research were the errors made in speech production and using an overt production task would be the most conceptually straightforward way to operationalise this. However, there is a particular challenge that arises when attempting to study overt speech using EEG; the electrical signals produced in the brain are minute compared to those made by muscle movements. Producing overt speech requires considerable muscle movements of the jaw, lips, and throat, all of which are close to electrode locations and are likely to interfere with the brain signal of interest in this study. This could be particularly true of the ERN as the component is a response-locked ERP, meaning that it will occur in relation to the participant's response to any given stimuli, in this case as they are giving a verbal response. Therefore, an important consideration will be to establish the most suitable method of removing artefacts from the data. Zhengid et al., (2018) trialled three such methods (canonical correlation analysis (CCA), independent component analysis (ICA) and low-pass filtering (high cut-off at 10Hz) but found that standard artefact rejection (visual inspection) was sufficient to demonstrate a clear ERN in an overt speech task. In fact, Zhengid and colleagues suggested that the artefacts caused by muscle movement were too small to be detected, particularly by CCA. However, this should still be approached with some caution and an appropriate artefact removal will be considered as part of the piloting process of this study. The verbal response also obfuscates the response onset, as such for analysis purposes the response was artificially time-locked to the onset of the speech prompt shown to the participant. This can create latency variability in event onset time used in epoching, as I was unable to establish the true onset time, which likely obscured the true characteristics of the ERPs in this task.

Studies 1 and 2 were also not without limitations, as the dataset used in both of these studies was not collected as part of this thesis, which meant the research questions that I was able to address using this data were of a limited scope. This was particularly true of the socioeconomic data in this dataset as I was unable to use a number of measures due to lack of variance in the data (e.g., place of birth), which resulted in a reduced number of SES measures and demographically homogeneous study sample. The Cam-CAN is also a cross-sectional dataset, which presents some challenges when investigating ageing and making comparisons between age groups compared to longitudinal research and datasets. While cross-sectional data is valuable in exploring the differences with cognitive and social engagement measures between age groups, it is unable to reveal potential changes in repeated measures of the same cohort over time. This tracking of individual change over time allows for the investigation of genetic, environmental, and biological factors that cannot be evaluated using cross-sectional data (Hofer et al., 2002). However, at least in the scope of the research here, the highly specific nature of cognitive measures we investigated are rarely found in large cohort, longitudinal studies, and it was precisely for this reason Cam-CAN was used in the secondary data analysis for studies 1 and 2.

The topics addressed above reflect the nature of the two sources of data I drew from in my thesis; primary data that I collected myself and secondary data collected on a much larger scale. These datasets have their own advantages and disadvantages that influence the questions I was able to address with them and the way in which I could analyse the data. Using secondary data in research allows for the exploration of a sample well beyond the size it would be feasible to effectively recruit as part of doctoral research, as the recruitment and data collection alone can take many years and a large team of researchers. This also means that secondary data has a greater number of variables available for analysis; often survey and health data, as in the Cam-CAN dataset, but an increasing number of datasets collect biometric data (e.g., English Longitudinal Study of Ageing (ELSA)). The larger sample (e.g., N=3000 in the first Cam-CAN wave, N = 700 in the second) of this size is likely to be more representative of the population from which it was taken than the smaller participant groups used in primary data collection. However, because secondary data has not been collected with a specific research question in mind (or certainly one specific to one's own research interests), the data is much broader in scope than primary data, and so the research question must also be less targeted in its aims.

There is also a lack of control over the quality of that data itself, though one would expect published datasets to have been subject to rigorous quality controls that do not mean that the data is in a suitable format or condition for immediate use (Hox and Boeije, 2005). In contrast, primary data collection can be tightly controlled to assure data quality; the paradigm and data collection methods can be targeted to a very niche research question. In this thesis collecting primary data allowed me to choose very precise tasks to obtain the neural measures associated with them. This was particularly true of the data captured in the SLIP task, as I collected speech outputs as well as electrophysiological data that is simply not available in secondary datasets. However, due to temporal and financial constraints, the period of data collection is often brief, and data not collected cannot be retrieved after the fact. In the case of Studies 2 and 3 of this research, it was identified after data collection (for Study 3) and analysis had ended that inclusion of a memory task would have been a beneficial addition to the dataset, but this cannot be added retrospectively.

Finally, while the studies in this thesis probe the influences of cognition on social engagement, these associations could be bi-directional. Previous research has shown the effects of socialisation on cognitive abilities throughout the life course (Adams and Blieszner, 1995; Keller-Cohen et al., 2006, Borgeest et al., 2021), as there is sufficient evidence to show the impact of loneliness on cognition, we believed it would be pertinent to investigate the converse relationship. Our findings in the research presented here are not contradicted by extant research, rather the findings complement this work and support the bidirectionality of the associations between cognition and social engagement. In the context of this thesis, I employed both primary and secondary data so that I could explore both the broad and narrow concepts of the thesis topics. The secondary data allowed me to establish a framework of the interactions between cognition and social engagement on a large scale, and the primary data collection enabled me to apply that framework to niche measures of cognition and specific feelings of social engagement in individuals. Combined, these approaches provided a more detailed examination of the cognitive and social factors of interest than if I had employed a more singular approach.

Conclusions

While the discussion above does present theoretical and methodological challenges for the research presented in this thesis, it does not negate the findings presented in this work and the contribution to the field of ageing research and our understanding of the complex interactions between cognition and social engagement in older people. It is vital that we extend our knowledge of such interaction to combat potential issues that arise as part of cognitive declines, such as increasing feelings of loneliness, to work towards improving the quality of life in older populations. This work has evidenced that with ageing comes a change in cognitive processing in behavioural and neurological measures in executive and linguistic domains. We have also shown that these cognitive domains, particularly executive functions, are important in supporting and facilitating social connections in older populations.

In conclusion, this research has identified age-related differences in cognition, at behavioural and neuronal levels, and associated such differences with social engagement. Studies 1 and 2 utilised a large-scale dataset to provide a broad framework for the differential associations between social engagement and cognition as influenced by socioeconomic status in younger and older adults. These studies found age-related differences in the representation of cognitive processes and social engagement, as well as age differences in the associations between these factors. In Study 3 I was able to elaborate on the underlying neurocognitive mechanisms of language and executive functions, using both ERP and time-frequency analysis of EEG data. By evidencing association across data modalities, this research provides robust evidence for neuro-cognitive changes in later-life, and cognitive-social associations that is of particular importance in older adults.

References

Banks, J., Batty, G. David, Breedvelt, J., Coughlin, K., Crawford, R., Marmot, M., Nazroo, J., Oldfield, Z., Steel, N., Steptoe, A., Wood, M., Zaninotto, P. (2021). English Longitudinal Study of Ageing: Waves 0-9, 1998-2019. [data collection]. 37th Edition. UK Data Service. SN: 5050, DOI: 10.5255/UKDA-SN-5050-24

Beemer, L. R., Ajibewa, T. A., Dellavecchia, G., & Hasson, R. E. (2019). A Pilot Intervention Using Gamification to Enhance Student Participation in Classroom Activity Breaks. *International Journal of Environmental Research and Public Health 2019, Vol. 16, Page 4082*, *16*(21), 4082. https://doi.org/10.3390/IJERPH16214082

Borgeest, G. S., Henson, R. N., Shafto, M., Samu, D., & Kievit, R. A. (2020). Greater lifestyle engagement is associated with better age-adjusted cognitive abilities. *PLOS ONE*, *15*(5), e0230077. https://doi.org/10.1371/journal.pone.0230077

Boudewyn, M. A., Luck, S. J., Farrens, J. L., Kappenman, E. S., & Megan Boudewyn, C. A. (n.d.). *How many trials does it take to get a significant ERP effect? It depends*. https://doi.org/10.1111/psyp.13049

Burke, D. M., & Shafto, M. A. (2004). Aging and Language Production. *Current Directions in Psychological Science*, *13*(1), 21–24. https://doi.org/10.1111/j.0963-7214.2004.01301006.x

Cabeza, R. (2001). Cognitive neuroscience of aging: Contributions of functional neuroimaging. *Scandinavian Journal of Psychology*, *42*(3), 277–286. https://doi.org/10.1111/1467-9450.00237

Cabeza, R. (2002). Hemispheric asymmetry reduction in older adults: The HAROLD model. *Psychology and Aging*, *17*(1), 85. https://doi.org/10.1037/0882-7974.17.1.85

Chu, C. H., Alderman, B. L., Wei, G. X., & Chang, Y. K. (2015). Effects of acute aerobic exercise on motor response inhibition: An ERP study using the stop-signal task. *Journal of Sport and Health Science*, *4*(1), 73–81. https://doi.org/10.1016/J.JSHS.2014.12.002

Grady, C. L., Maisog, J. M., Horwitz, B., Ungerleider, L. G., Mentis, M. J., Salerno, J. A., Pietrini, P., Wagner, E., & Haxby, J. V. (1994). Age-related changes in cortical blood flow activation during visual processing of faces and location. *Journal of Neuroscience*, *14*(3), 1450–1462. https://doi.org/10.1523/JNEUROSCI.14-03-01450.1994

Grady, C. L., Mcintosh, A. R., Horwitz, B., & Rapoport, S. I. (2000). *Age-Related Changes In The Neural Correlates Of Degraded And Nondegraded Face Processing*. Retrieved March 26, 2023, from http://www.tandf.co.uk/journals/pp/02643294.html

Hartshorne, J. K., & Germine, L. T. (2015). When Does Cognitive Functioning Peak? The Asynchronous Rise and Fall of Different Cognitive Abilities Across the Life Span. https://doi.org/10.1177/0956797614567339

Heuninckx, S., Wenderoth, N., & Swinnen, S. P. (2008). Systems neuroplasticity in the aging brain: recruiting additional neural resources for successful motor performance in elderly persons. *The Journal of Neuroscience : The Official Journal of the Society for Neuroscience*, *28*(1), 91–99. https://doi.org/10.1523/JNEUROSCI.3300-07.2008

Holtgraves, T. M., & Kashima, Y. (2008). Language, Meaning, and Social Cognition. *Personality and Social Psychology Review*, *12*(1), 73–94. https://doi.org/10.1177/1088868307309605

Hofer, S. M., Sliwinski, M. J., & Flaherty, B. P. (2002). Understanding Ageing: Further Commentary on the Limitations of Cross-Sectional Designs for Ageing Research. *Gerontology*, *48*(1), 22–29. https://doi.org/10.1159/000048920

Hox, J. J., & Boeije, H. R. (2004). Data Collection, Primary vs. Secondary. *Encyclopedia of Social Measurement*, 593–599. https://doi.org/10.1016/B0-12-369398-5/00041-4

Krueger, K. R., Wilson, R. S., Kamenetsky, J. M., Barnes, L. L., Bienias, J. L., & Bennett, D. A. (2009). Social engagement and cognitive function in old age. *Experimental Aging Research*, *35*(1), 45–60. https://doi.org/10.1080/03610730802545028

Larson, M. J., Baldwin, S. A., Good, D. A., & Fair, J. E. (2010). Temporal stability of the error-related negativity (ERN) and post-error positivity (Pe): The role of number of trials. *Psychophysiology*, *47*(6), no-no. https://doi.org/10.1111/j.1469-8986.2010.01022.x

Larson, M. J., & Carbine, K. A. (2017). Sample size calculations in human electrophysiology (EEG and ERP) studies: A systematic review and recommendations for increased rigor. *International Journal of Psychophysiology*, *111*, 33–41. https://doi.org/10.1016/j.ijpsycho.2016.06.015

Lipina, S. J., & Posner, M. I. (2012). The impact of poverty on the development of brain networks. *Frontiers in Human Neuroscience*, *6*, 238. https://doi.org/10.3389/fnhum.2012.00238

Meiran, N., & Gotler, A. (2010). Modelling cognitive control in task switching and ageing., *13*(1–2), 165–186. https://doi.org/10.1080/09541440042000269

Mezzacappa, E. (2004). Alerting, Orienting, and Executive Attention: Developmental Properties and Sociodemographic Correlates in an Epidemiological Sample of Young, Urban Children. *Child Development*, *75*(5), 1373–1386. https://doi.org/10.1111/j.1467-8624.2004.00746.x

Nielson, K. A., Langenecker, S. A., & Garavan, H. (2002). Differences in the functional neuroanatomy of inhibitory control across the adult life span. *Psychology and Aging*, *17*(1), 56–71. https://doi.org/10.1037/0882-7974.17.1.56

Shafto, M. A., Tyler, L. K., Dixon, M., Taylor, J. R., Rowe, J. B., Cusack, R., … Matthews, F. E. (2014). The Cambridge Centre for Ageing and Neuroscience (Cam-CAN) study protocol: A cross-sectional, lifespan, multidisciplinary examination of healthy cognitive ageing. *BMC Neurology*, *14*(1).

Shankar, Aparna. ;, Hamer, Mark. ;, McMunn, Anne. ;, And, & Steptoe, Andrew. (2013). Social Isolation and Loneliness: Relationships With Cognitive Function. *Encyclopedia of Mental Health*, *75*, 161–170. https://doi.org/10.1016/B978-0-12-397045-9.00118-X

Lindsay Smith, G., Banting, L., Eime, R., O'Sullivan, G., & van Uffelen, J. G. Z. (2017). The association between social support and physical activity in older adults: A systematic review. *International Journal of Behavioral Nutrition and Physical Activity*, *14*(1), 1–21. https://doi.org/10.1186/S12966-017-0509-8/TABLES/1

Wascher, E., Schneider, D., Hoffmann, S., Beste, C., & Sänger, J. (2012). When compensation fails: Attentional deficits in healthy ageing caused by visual distraction. *Neuropsychologia*, *50*(14), 3185–3192. https://doi.org/10.1016/J.NEUROPSYCHOLOGIA.2012.09.033

Xu, S., Liu, Z., Tian, S., Ma, Z., Jia, C., & Sun, G. (2021). Physical Activity and Resilience among College Students: The Mediating Effects of Basic Psychological Needs. *International Journal of Environmental Research and Public Health*, *18*(7), 3722. https://doi.org/10.3390/ijerph18073722

Zhengid, X., Roelofs, A., Farquhar, J., & Lemhö, K. (2018). *Monitoring of language selection errors in switching: Not all about conflict*. https://doi.org/10.1371/journal.pone.0200397