Lifestyle activities, mental health and cognitive function in adults aged 50 to 90 years

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By

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Abstract

In a series of studies, lifestyle activities, mental health and aerobic fitness were investigated in relation to mean RT and response time variability (trial-to-trial variability in RT performance) obtained from a battery of cognitive measures in 257 healthy adults aged 50 to 90 years (*M* = 63.60). Cognition was assessed across four domains; psychomotor performance, executive function, visual search and word recognition. Hierarchical multiple regression analyses and structural equation modelling (SEM) were used to explore associations between age and outcome measures in a mediated-moderator analysis. The dedifferentiation of cognition and the dissociation between the outcome measures of mean RT and response time variability was also explored. Additionally, the neural correlates of response time variability were investigated using functional magnetic resonance imaging (fMRI).

The findings indicated that poor mental health was associated with greater within-person (WP) variability and slower mean RTs and that this effect was greater in older adults. Higher lifestyle activity scores and higher aerobic fitness (VO_{2max}) attenuated negative age gradients in WP variability and mean RT. Analyses suggested that the above effects were mediated by executive function. There was no evidence of dedifferentiation across cognitive domains and there was selective dissociation between the measures of mean RT and WP variability. The fMRI results suggested that WP variability was associated with fluctuations in executive control and, relatedly, attentional lapses.

Overall, the findings suggest that executive function mediates a substantial portion of age-related variance in cognition and that this association is influenced by moderators such as an active lifestyle, aerobic fitness and mental health. The findings underline the potential benefits and importance of interventions to help maintain and promote mental health, and active lifestyles, in old age.

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Daddy (1932-1988) and Kirsten (1964-1989). Part of everything I do.

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Bauermeister, S., Williams, A., & Bunce, D. (2010). *Neural correlates of response time variability in healthy older adults.* Poster presented at the Cognitive Aging Conference, Atlanta, USA.

Bunce, D., & Bauermeister, S. (2008). *Age and the factor structure of executive function and associations with wider cognitive performance*. Paper presented at the British Psychological Society (BPS) Cognitive Section Conference, University of Herfordshire.

Main Introduction

Ageing has been defined as a period when an interchange between both normal biological processes and neurodegenerative disease define the rate of cognitive decline (MacDonald, Hultsch, & Dixon, 2011). Cognitive decline is accelerated with increasing years in what has been termed the 'terminal decline hypothesis' where age-related cognitive deficits are an inevitable outcome (Riegel & Riegel, 1972). However, the variability with which this process occurs is diverse, both within and between individuals. This thesis focuses on the variability of normal age-related neurobiological decline and the affect it has on cognition in older age. In addition, it focuses on factors which influence that variability.

The thesis consists of five individual studies that investigate factors that may influence the rate of cognitive and neurobiological ageing. It is noted here that although the term 'studies' is used throughout the thesis, this term refers to different analyses of the same group of participants for the first four studies and a selection of these participants for the fifth study. This Main Introduction initially describes the main age-related neurobiological changes that have direct consequences on cognitive performance in older age, and in particular, focuses on the executive processes underlying them. The age-related neurobiological changes described here are some of the relevant major changes that occur in the process of ageing. For example, reductions in blood flow, changes in structural brain matter and modulation of neurotransmitter function, all of which may influence cognitive performance in older age. Although neurobiological research was not undertaken the relevant neurobiological background is presented in accordance with the themes of the research. Following the section on neurobiology, a brief overview of the main age-related factors associated with both cognitive and neurobiological decline are described and key themes of the research are presented. This Main Introduction is concluded with an overview of the studies to be conducted in this thesis.

Neurobiology and Cognitive Ageing

The first age-related neurobiological factor that is important to consider is cerebral blood flow (CBF) which shows a gradual decline in resting levels throughout the adult lifespan and particularly into older age (Bangen et al., 2009; Bertsch et al., 2009; Devous, Stokely, Chehabi, & Bonte, 1986; Frackowiak, Lenzi, Jones, & Heather, 1980; Hagstadius & Risberg, 1989; Leenders et al., 1990; Marchal et al., 1992; Martin, Friston, Colebatch, & Frackowiak, 1991; Poels et al., 2008; Rodriguez et al., 1991; Sorond, Schnyer, Serrador, Milberg, & Lipsitz, 2008). Due to methodological differences in the measurement of CBF, varying results have been obtained regarding the cognitive effects associated with an age-related decline in CBF and great variation is evident between studies (Bertsch et al., 2009). However, it has been found that reductions in CBF adversely affect major cognitive processes, one of which is executive control, neuroanatomically supported by the frontal lobes (Cabeza, 2001; Farkas & Luiten, 2001; Sorond et al., 2008). Executive control combines several interrelated elements of cognition and includes functions such as inhibition, updating and switching of attentional resources. These underpin many cognitive processes and require a high level of metabolic support (i.e., oxygen and glucose) (Miyake et al., 2000). Any reduction in CBF will adversely affect the efficiency of executive performance and cognition more broadly (Gusnard & Raichle, 2001; Sorond et al., 2008). Rogers et al. (1990) found a gradual decrease in CBF in older participants (62 to 70 years) over four years if they were physically inactive, compared to an active comparison group. At follow-up, they also found that the cognitive scores of the inactive group were lower than those for the active group indicating that physical activity may maintain CBF levels and by extension, cognition in older age (Rogers, Meyer, & Mortel, 1990). A study by Bertsch et al. (2009) found that CBF accounted for up to 36% of the age-related variance in speed. However, research also suggests that CBF is associated with cerebral volume. When cortical atrophy (shrinkage) is controlled for, changes in CBF were less marked, suggesting that the decrease in CBF may be related to neuronal loss and cellular impairment (Marchal et al., 1992). This suggests that the association between CBF and cognitive performance could be mediated by cerebral atrophy, a factor that should be controlled for in studies using CBF as a factor of cognitive decline (Poels et al., 2008).

The second neurobiological factor concerns neuronal loss associated with general and specific regional atrophy of cortical brain matter (Anderton, 2002; Gunning-Dixon & Raz, 2003; Raz, 2000; Raz, Gunning-Dixon, Head, Dupius, & Acker, 1998; Raz & Rodrigue, 2006). More specifically, this volumetric loss concerns the grey matter of the brain, which totals approximately 15% of the entire brain between the ages of 30 and 90 (Weinstein et al., 2011). Significantly, there is a higher loss in areas supporting executive control, particularly the dorsal lateral prefrontal cortex (DLPFC), and this contributes to a decline in executive control (Raz et al., 2005). The loss can be further differentiated by its nature. Namely, the reduction in cortical thickness and a decrease in grey matter density (Burzynska et al., 2012). A positive correlation was found between the thickness of the cortex and executive function but this became non-significant when age was controlled for, indicating that there was little causal relationship between executive function and cortical thickness but that cortical attrition occurred as a natural age related occurrence (Kochunov, Rogers, Mangin, & Lancaster, 2012). However, Hartberg et al. (2010) found thicker cortices (superior, temporal, superior frontal and inferior frontal gyri) were related to fewer errors on the Wisconsin Card Sorting Test (WCST), a measure of executive function requiring inhibition (Grant & Berg, 1948). Gunning-Dixon and Raz (2003) found a higher number of errors on the WCST correlated with smaller right frontal lobe volumes. Burzynska et al. (2012) investigated the association of cortical thickness with executive function in 73 younger (20 to 32 years) and 56 older (60 to 71 years) adults. They used the WCST to assess executive function and T1-weighted magnetic resonance images (MRI) to measure cortical thickness. The regions of focus were the lateral prefrontal and parietal cortices, regions that support executive function. It was found that preservation of cortical thickness was associated with higher levels of executive function and this association was more significant in the older group of participants. They concluded that preservation of cortical integrity underpinned preservation of cognitive function.

In addition to changes in grey matter volume, changes in the cerebral white matter have been found amongst healthy older adults (Au et al., 2006). Specifically, these authors found that the volume of white matter hyperintensities (WMH) was negatively associated with cognitive performance. WMH are subcortical white matter lesions that appear as high signal intensities using T2-weighted MRI scans.

It is suggested that they originate from axon demyelination, axon degeneration and other microscopic structural changes that occur in the white matter connective tracts of the brain as part of the normal ageing process (Kennedy & Raz, 2009). Additionally, increased WMH are also associated with Alzheimer's disease and other dementias, compromised frontal lobe function (Jackson, Balota, Duchek, & Head, 2012). WMH have also been associated with slower processing speed, poorer working memory and general lower cognitive performance (Gunning-Dixon & Raz, 2000). Frontal WMH are related to greater within-person variability (WP variability), a measure of fluctuations in reaction times for a given cognitive task over a short period of time (Bunce et al., 2010; Bunce et al., 2007; Jackson et al., 2012; Kennedy & Raz, 2009). WP variability is discussed in more detail below. However, it is relevant to state here that WP variability is also associated with inefficient neurotransmitter modulation (MacDonald, Li, & Bäckman, 2009), the third significant neurobiological change associated with the ageing process.

The integrity of neurotransmitter modulation (chemical synaptic transmission of signals) declines during ageing, with changes in the dopamine, serotonin and acetylcholine systems (Li, 2012; West, 1996). In particular, the dopamine (DA) system, a regulator of motor function implicated in high-order cognitive functions such as executive control, shows significant decline (Bäckman, Lindenberger, Li, & Nyberg, 2010; Bäckman, Nyberg, Lindenberger, Li, & Farde, 2006; Nyberg & Bäckman, 2004). With loss of striatal and extrastriatal DA gradually occurring throughout adulthood, it can be expected that cognitive functions will consequently be compromised (Kaasinen et al., 2000). This has become such a significant conceptual factor in cognitive ageing theory that a 'correlative triad' has been proposed whereby ageing, DA and cognition are intricately related with one another such that a concomitant decline in DA levels and cognition occur with increasing age (Bäckman et al., 2010; Bäckman et al., 2006). Dysfunction of the DA system has also been associated with increased neural noise which may contribute to greater WP variability and decreased overall cognitive performance (MacDonald, Cervenka, Farde, Nyberg, & Bäckman, 2009). Additionally, MacDonald et al. (2009) proposed that dysfunction of DA neurotransmission may be due to inefficient top-down regulating by the prefrontal regions.

The Prefrontal Cortex

Building on the above, the prefrontal regions of the brain are critical for executive function and it is likely that compromised integrity of the DA system, as well as reductions in CBF and grey matter volume in this region, will adversely affect executive function (Nyberg & Bäckman, 2004; West, 1996). Additionally, performance on some executive tasks has been associated with a larger prefrontal cortex (PFC) volume, (Gunning-Dixon & Raz, 2003; Head, Kennedy, Rodrigue, & Raz, 2009). Also, the integrity of the PFC has been associated with processing speed and inhibition (Rodrigue & Kennedy, 2011), and it has been suggested that age-related impairments in broader cognitive function are related to a weakening of the inhibitory processes (Hasher & Zacks, 1988). The PFC has been defined as the 'central executive of the brain' whereby it supports the organisation of overall cognitive function (Miller & Cohen, 2001; West, 1996). If the PFC is particularly susceptible to age-related neurobiological decline, the ability to control the inhibitory processes of executive function will also be compromised. This will subsequently affect WP variability and reaction times, both of which rely on executive control and any neurobiological compromise to executive control will adversely affect cognitive performance, resulting in slower response times and greater WP variability (Jackson et al., 2012).

Within-Person Variability

Slower response times and increased WP variability are likely consequences of the age-related neurobiological declines described here. WP variability, as mentioned earlier, refers to moment-to-moment fluctuations in RTs over a short period of time. It is also termed 'inconsistency' and is calculated from successive trials of a given cognitive task (Bunce et al., 2007; Bunce, MacDonald, & Hultsch, 2004; Jackson et al., 2012). It represents a rapid, yet stable, characteristic that is a measurement of variability around an individual's average response time, (Burton, Strauss, Hultsch, Moll, & Hunter, 2006; MacDonald, Hultsch, & Dixon, 2003; Salthouse, 2007). It has been suggested that WP variability reflects both neurobiological disturbance and a compromise to central nervous system integrity due to its association with age-related neurobiological changes such as those

discussed here (Bunce et al., 2007; Bunce, Handley, & Gaines, 2008a; Bunce & Murden, 2006; MacDonald, Nyberg, & Bäckman, 2006; Nesselroade & Salthouse, 2004; Stuss, Murphy, Binns, & Alexander, 2003). As older age is associated with neurobiological decline, particularly in the frontal lobe regions responsible for executive control, any compromise to these regions will affect the inhibitory mechanisms resulting in increased WP variability. Furthermore, Bunce et al. (2007, 2010) found that frontal white matter lesioning was associated with greater WP variability. In addition, white matter water diffusion and corpus collosum size was associated with WP variability, supporting the suggestion that the measure is related to neurobiological mechanisms (Anstey et al., 2007; Deary et al., 2006). Greater WP variability was also found in patients with frontal lobe damage (Stuss et al., 2003), Parkinson's disease (Burton et al., 2006), epilepsy (Bruhn & Parsons, 1977), mild cognitive impairment and mild dementia (Hultsch, MacDonald, Hunter, Levy-Bencheton, & Strauss, 2000; Strauss, Bielak, Bunce, Hunter, & Hultsch, 2007), and traumatic brain injury (Bleiberg, Garmoe, Halpern, Reeves, & Nadler, 1997).

Mean Reaction Time

Slower response times, or slower processing speed, is also associated with increasing age (Park & Bischof, 2011; Salthouse, 1992, 1993, 1996). Typically measured as mean reaction time (mean RT), it is considered a measure of central tendency in contrast to WP variability which is more a measure of dispersion. The slowing of mean RT in older age occurs regardless of the nature of the task (McDowd & Shaw, 2000). Salthouse (1996) proposed that processing speed was a major contributor in age-related differences across varied measures of cognition. It has been suggested that the use of mean RT and WP variability should be seen as equally important measures of the representation of the cognitive system as a whole (Schmiedek, Lövden, & Lindenberger, 2009). Both increased mean RT and WP variability have been associated with a failure of top-down processing and of executive control with neurobiological origins (Sonuga-Barke & Castellanos, 2007). However, the origin of slow processing speed can be ambiguous as slowing due to the neurobiological changes in the PFC (reducing inhibitory mechanisms) could lead to attentional lapses and slow responding. Slow responding alternatively could also lead to a decline in attentional focus which could then be associated

with attentional lapses (McDowd & Shaw, 2000). However, WP variability is intricately linked to neurobiological disturbance and compromised central nervous system integrity, particularly of the frontal lobe regions, responsible for executive control. A critical question is whether measure of mean RT and WP variability taken from the same cognitive task are equally sensitive to neurobiological disturbance or whether the latter measure is more sensitive to subtle effects as has been suggested previously (e.g., Bunce et al, 2007, 2008b). Specifically, do the two measures dissociate?

Dissociation of Cognitive Measures

Whether measures of mean RT and WP variability obtained from the same cognitive task dissociate is a key theme throughout this thesis. This is of considerable interest to ascertain whether WP variability shows evidence of being a more sensitive measure of cognitive decline or mild psychopathology. Previous research by Bunce et al. (2008a) investigated the effect of anxiety and depression on cognition, in a population of 300 community-dwelling adults aged 18 to 85 years. They found that measures of mean RT and WP variability dissociated. Age differences in WP variability for visual search was moderated by depression (higher depression and older age were associated with significantly greater variability) and this relationship was mediated by executive function. This was not found for the measure of mean RT, suggesting that WP variability could be a more sensitive measure of subtle mental health effects on cognition. In addition, Bunce et al. (2008b) found a similar effect with poor mental health, as measured with the General Health Questionnaire (GHQ). They found that poorer mental health was associated with increased WP variability, but not mean RT, in older adults for four-choice reaction time and Stroop tasks. Furthermore, Bunce et al. (2007 and 2010) found a similar effect with the presence of white matter hyperintensities (WMH) and cognition but not for mean RT, again indicating a dissociation between two measures. The dissociation between the measures of mean RT and WP variability is a key area of investigation of Studies 1 to 4.

Executive Control

Executive control, as mentioned earlier, has been described as a collection of functions, most notably inhibition (ability to inhibit a prepotent response), updating (monitor incoming information and update the response accordingly) and switching (ability to switch between tasks or mental sets) (Miyake et al., 2000). The three components of executive function are considered as separate but interrelated modalities, but inhibition is seen as the 'unifying measure' most closely associated with the integrity of the PFC (Hasher & Zacks, 1988; Miyake et al., 2000). Hasher and Zacks (1988) suggest that it is because the inhibitory mechanisms (of the PFC) function with working memory and are necessary for maintaining task-related attention within the goal-path of a task such as comprehension. When the integrity of the PFC is compromised by neurobiological changes, the inhibitory component of executive function is challenged, moving focus away from the goal-path, causing deficits in wider cognitive performance (Dempster, 1991; West, 1996). This is also referred to as the 'inhibition deficit hypothesis' by Hasher and Zacks (1991). Executive function is important from the present perspective, as a failure of inhibition results in reduced ability to inhibit irrelevant information, resulting in increased WP variability (Bunce, Warr, & Cochrane, 1993). This has also been associated with age-related neurobiological decline in the PFC, as previously discussed (MacDonald, Nyberg, et al., 2006). This is confirmed in studies of individuals who have sustained damage (traumatic brain injury) to the PFC resulting in increased WP variability (Hetherington, Stuss, & Finlayson, 1996; Stuss et al., 2003). As the mechanism of suppressing irrelevant information declines in older age, lapses in attention involving non-task related thoughts become more prevalent, resulting in both slower response times and increased WP variability (Garrett, MacDonald, & Craik, 2012). It is suggested that fluctuations in executive control are associated with variations in attentional focus. In other words, a failure of top-down processing leads to increased susceptibility to external distractions, resulting in increased response times and WP variability (Sonuga-Barke & Castellanos, 2007).

Attentional Lapses

The failure of top-down processes and consequent intermittent unusually slow RTs have been conceptualised as attentional lapses that will increase as a consequence of an age-related decline in executive control (Bunce et al., 1993; Kane et al., 2007; Unsworth, Redick, Lakey, & Young, 2010). It is proposed that fluctuations in the efficiency of executive control are associated with the maintenance of goal-directed behaviour (West, Murphy, Armilio, Craik, & Stuss, 2002) and executive control has also been defined as the ability to resolve conflicts between thoughts and responses (Hu, He, & Xu, 2012). If there are fluctuations in the control of goal-directed behaviour, there will be conflict between thought processes and behavioural responses. As task demands increase, so will the demand on attentional resources necessary to inhibit inappropriate responses, resulting in increased response inconsistency (Bunce et al., 2004). Increased variability has been associated with the neurobiological changes occurring in the frontal regions that support attention and executive control (Bunce et al., 2008a; Bunce et al., 2004; Weissman, Roberts, Visscher, & Woldorff, 2006). If executive function is compromised due to age-related neurobiological changes, there is a greater likelihood of the occurrence of attentional lapses and an associated increase in behavioural variability and slower responding (Unsworth et al., 2010). The association of attentional lapses and slower responding are explored in Study 5.

Dedifferentiation

One of the theoretical considerations of this thesis is the dedifferentiation of cognitive functions in older age. This is commonly demonstrated empirically by cognitive domains factoring out separately in young adulthood while in old age they converge onto a single factor. Some existing research suggests dedifferentiation is an inevitable process of cognitive decline in older age (Babcock, Laguna, & Roesch, 1997; Baltes & Lindenberger, 1997; Dennis & Cabeza, 2011). Dennis and Cabeza (2011) found that dedifferentiation occurred across memory systems in older age. However, there *are* suggestions that dedifferentiation is more characteristic of pathological ageing (Batterham,

Christensen, & Mackinnon, 2011; Sims, Allaire, Gamaldo, Edwards, & Whitfield, 2009). Recent research by Salthouse (2012) found no evidence of dedifferentiation across a battery of cognitive tasks mapping onto five separate cognitive domains. A particular theme in Studies 1 to 4 here was whether there was evidence of dedifferentiation in this healthy sample of older adults, and whether this varied for measures of mean RT and WP variability.

Key Themes of the Research

The key themes of this research concern variables that moderate cognition in older age and the mediation of those effects by executive function. A moderator variable alters the strength of a relationship between the independent and dependent variable. Here, the moderators considered are mental health, lifestyle activities and aerobic fitness. Research suggests that these factors play a major role in moderating the relationship between older age and cognition. Poor mental health has been associated with poorer cognitive function due to a reduction in the ability to process information, resulting in both slower reaction times, increased variability and poor overall performance (Sliwinski, Almeida, Smyth, & Stawski, 2009; Sliwinski, Smyth, Hofer, & Stawski, 2006; Stawski, Sliwinski, & Smyth, 2006). This could be because attentional resources are directed toward depression or anxiety-related thoughts rather than the task in hand (Bunce et al., 2008a; Hartlage, Alloy, Vazquez, & Dykman, 1993). In other words, mental resources are directed towards emotional rather than cognitive processing resulting in involuntary disruption of cognition (Sapolsky, 1999). One hypothesis is that as there is a high density of corticosteroid receptors in the frontal cortex, any additional stress response caused by anxiety or depression will have an adverse effect on these receptors, increasing activation and may be detrimental to executive function (Bunce & Murden, 2006; Channon & Green, 1999; Raz & Rodrigue, 2006). Sapolsky et al. (1983) found that in rats, older age is associated with an increased production of stress hormones such as glucocorticoid steroids as well as a slower return to normal resting state of hormone levels post-stress (Sapolsky, Krey, & McEwen, 1983). It has also been proposed that increased exposure to these stress hormones has a toxic effect on neurons, resulting in the inability to resist damage by factors such as age (Sapolsky, Krey, & McEwen, 1986). Additional human post-mortem research found that glucocorticoids had a

depressing effect on axonal transport when at high concentrations (Dai, Buijs, & Swaab, 2004). It has also been suggested therefore that glucocorticoids could have a negative effect on regions such as the PFC, specifically on neuronal function and survival (Lupien, McEwen, Gunnar, & Heim, 2009). This raises the possibility that older persons who are experiencing anxiety, depression or poorer mental health generally, are more at risk of cognitive deficits in functions supported by frontal regions such as executive control. Existing research suggests that age and poor mental health are associated with increased WP variability and slower mean RTs across numerous cognitive domains (Bunce, Tzur, Ramchurn, Gain, & Bond, 2008b). This work is extended in Study 2.

Lifestyle activities (Hultsch, Hertzog, Small, & Dixon, 1999) and aerobic fitness (Bunce & Murden, 2006; Kramer, Erickson, & Colcombe, 2006) are considered positive moderators of cognition with evidence suggesting that an active, socially integrated and intellectually challenging lifestyle may slow cognitive decline, delay the early onset of dementia and even mortality in older adults (Bielak, Hughes, Small, & Dixon, 2007; Fratiglioni, Paillard-Borg, & Winblad, 2004; Larson et al., 2006). General social activity has a beneficial effect on general cognition (working memory, perceptual speed and visuospatial ability) and social support is positively associated with problem solving abilities and processing efficiency, but not with storage of information (Krueger et al., 2009). As research suggests, physical, intellectual and social activities are all positively associated with cognitive benefits in older age with the emphasis on participating in activities which are both novel and intellectually challenging. Regionally and functionally, the frontal brain regions supporting the executive control processes (executive function) have been shown to derive the largest positive benefits from physical activities (Kramer et al., 2006). Given this background of positive effects, the benefits of an active lifestyle on age differences in cognition are explored in Studies 3 and 4.

Overview of the Research

Given the foregoing, the aim of this thesis was to investigate how mental health and lifestyle factors affected age differences in cognitive performance in a healthy older population. Various lifestyle factors and mental health were investigated as

moderators and executive function is considered as a potential mediator based on the research which suggests executive function is an indicator of age-related neurobiological decline, as outlined above. Five separate studies were designed and conducted here to investigate these moderating and mediating factors of cognition in older age.

Study 1 investigates whether executive function mediates age differences in cognitive function across other cognitive domains (psychomotor performance, visual search and recognition), according to the recommendations of Baron and Kenny (1986). They propose a three stage mediation process of analysis: Step one establishes whether the predictor and outcome variables are correlated, step two whether there is a correlation between the mediator and outcome variable, and step three, whether the correlation in step one becomes nonsignificant when the mediator variable is controlled (see Figures 1. and 2. for diagrammatical representations of the mediation and moderation procedures). The mediation method of Baron and Kenny (1986) was chosen to analyse mediation effects as it provides a tight mediation method, whereby full mediation is initially sought and it is a good initial starting point for any mediation analysis (Kenny, 2012). Alternative mediation methods are available, one of which is the Sobel Test, which is a more conservative measure of mediation as it utilises a normal approximation and has lower power; it is suitable for large samples and when there is no access to raw data (Kenny, 2012; Preacher & Hayes, 2004). Bootstrapping is also recommended for large samples with multiple mediators, here, however, with the focus on a single mediator (executive function) it was not chosen, avoiding any misleading results which can accompany bootstrapping (Byrne, 2001). The Baron and Kenny (1986) method is used throughout studies one to four, based on the procedure used by Bunce et al. (2008b).

Further aims of this study were to investigate whether the measures of mean RT and WP variability dissociated, whereby mediation effects are different for each measure, indicating possible differences in the cognitive processes tapped by the respective measures. Also, a final aim was to investigate evidence of dedifferentiation among cognitive variables in this group of healthy and active 50 to 90 year olds.

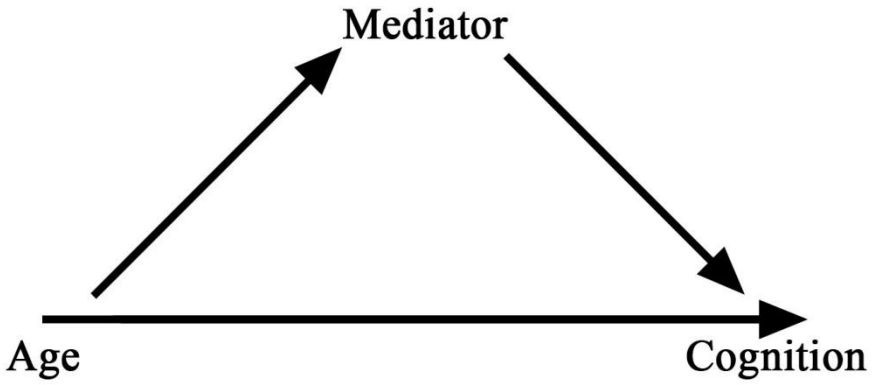

Figure 1. A mediation model where Age is the predictor, Cognition is the outcome and executive function acts as a Mediator.

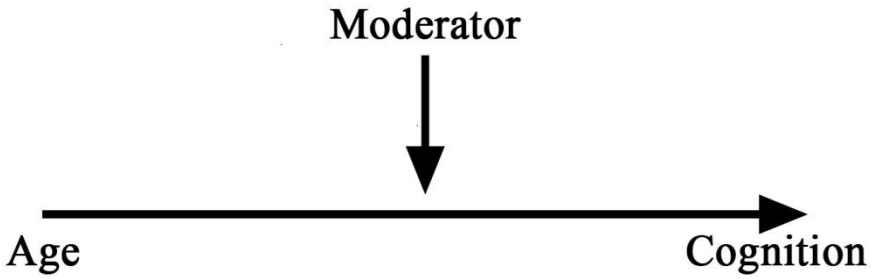

Figure 2. A moderation model where Age is the predictor, Cognition is the outcome and mental health or lifestyle factor is the Moderator.

Study 2 extends the research of Study 1 and examined mental health as a moderator of cognition using the foregoing moderation procedure. The study examined whether mental health, as measured by the General Health Questionnaire (Goldberg, 1978), moderated the relationship between age and cognition and whether this association was mediated by executive function.

Study 3 in contrast to Study 2, examined lifestyle factors as moderators of cognition. Using the Victoria Longitudinal Study self-reported lifestyle questionnaire (Hultsch et al., 1999) the study examined whether social, intellectual and physical activities moderated the relationship between age and cognition. This study arises from research that suggests an active lifestyle is associated with

enhanced cognition and a delay in the onset of dementia (Hultsch et al., 1999; Larson et al., 2006).

Study 4 further explored physical activity as a moderator by investigating the affect of aerobic fitness on cognition, as measured by the objective measure, VO_{2max}. Additionally, the study investigated whether any moderation effects were mediated by executive function in a mediated-moderation relationship. Given the centrality of WP variability to this thesis, Study 5 investigated the neural correlates of intermittent slower responding. The previous studies have explored whether executive function mediated age-related deficits in WP variability in other cognitive domains. An important issue is the association between executive function and WP variability and the common neural mechanisms between them. Therefore, Study 5 uses functional magnetic resonance imaging (fMRI) to examine the neural substrates of intraindividual variability. Specifically, faster behavioural responses were contrasted with slower behavioural responses to investigate whether the neural mechanisms, and by implication, underlying cognitive processes, differ. The aim of the study was to obtain evidence of differences in attentional or executive engagement associated with the two types of responses. This is based on research that suggests that slower responding is associated with attentional lapses (Bunce et al., 1993; Weissman et al., 2006).

To begin though, Study 1 assesses basic processes, and investigates whether executive function mediates age differences in other cognitive domains. It also investigates the dedifferentiation of cognition and whether measures of mean RT and WP variability dissociate.

Study 1

The factor structure of cognitive performance in adults aged 50 to 90 years

Introduction

Cognitive performance can be differentiated into separate domains, which include psychomotor performance, executive function, visual search and recognition. These broadly provide an overall representation of cognition. Specific cognitive tasks are designed to measure these domains and a statistical procedure well-suited to investigation of relations between these domains is structural equation modelling (SEM). This study uses SEM to investigate the factor structure of cognition in older age. Importantly, the study also explores executive function which supports a range of mental abilities and is multidimensional in itself (Ardila, 2008; Banich, 2009; Batterham et al., 2011; Hedden & Gabrieli, 2010; Miyake et al., 2000), with the main measurable components represented by the three interrelated constructs - shifting, updating and inhibition (Friedman & Miyake, 2004; Miyake et al., 2000).

Older age is associated with a decline in a wide range of cognitive abilities, some of which relate to the encoding of new memories, speed of processing and the operation of working memory (Hedden & Gabrieli, 2004). In addition, variability in learning rate, asymptotic performance, interference susceptibility and increased intraindividual and interindividual variability occur due to age-related effects on cognition (Bunce et al., 2008a; Bunce et al., 2008b; Li, Lindenberger, & Sikström, 2001; Miyake et al., 2000). Cognitive decline and performance in old age has been described as a process of dedifferentiation, where the separate cognitive domains start to lose their differentiating functional features, and exhibit stronger correlations with increasing age and functional decline (Babcock et al., 1997; Baltes & Lindenberger, 1997). In other words, dedifferentiation accompanies age-

related decline in cognitive ability as it becomes more difficult to recruit specialized neural mechanisms in support of specific cognitive domains (Batterham et al., 2011; Cabeza, Anderson, Locantore, & McIntosh, 2002; Sims et al., 2009). Recent fMRI research suggests that there is evidence of some dedifferentiation occurring across the memory systems in older age (Dennis & Cabeza, 2011). However, other research suggests that general dedifferentiation of cognition does not take place but instead, is only evident in cases of dementia and other neuropathologies (Batterham et al., 2011; Sims et al., 2009). A key question, therefore, that provides the focus for the present work is how far dedifferentiation occurs in normal, non-pathological ageing. Is dedifferentiation a characteristic of neurodegenerative decline or does it occur ubiquitously with increasing age? The present study will consider this question in relation to a comprehensive battery of cognitive measures covering psychomotor performance, executive function, visual search and recognition domains.

Central to this formulation is the role of executive function which is held to provide support for a wide range of other cognitive functions. According to Miyake (2000), executive function is represented by three distinct but overlapping constructs, shifting, updating and inhibition (Miyake et al., 2000). First, *shifting* is the ability to shift between mental sets such that the focus of attention can be readily switched between tasks. In order to perform this function, a person has to disengage a now irrelevant task set and engage the now relevant one. Second, *updating* is a process that is closely linked to working memory and requires the monitoring and coding of incoming information for the present task by continually revising information held in working memory and replacing where relevant. Finally, *inhibition* is the ability to inhibit a dominant, automatic or prepotent response with deliberate intention. It has been proposed that executive function regulates the dynamics of overall cognitive performance (Miyake et al., 2000) leading to the expectation of a strong association between executive function and other cognitive domains. Additionally, it is suggested that within-person variability (WP variability) in executive control is strongly associated with WP variability in other domains (Bunce et al., 2008a).

As noted, there is general consensus that executive function plays a key supporting role for other cognitive domains. For example, executive function is also referred

to as a mediator of general cognition, described as a group of regulatory control mechanisms and processes (Miyake et al., 2000) that monitor, inhibit and update pre-learned responses in order to modify behaviour (Friedman et al., 2006). Further to this, executive function has been described as the control process responsible for planning, assembling, coordinating, sequencing and monitoring of other cognitive functions (Salthouse, Atkinson, & Berish, 2003). It has been defined as a capacity that allows a person to successfully engage in independent, purposeful and self preservation behaviour (Lezak, 1995), and as a multidimensional construct of related higher-order cognitive processes that include initiation, planning, hypothesis generation, cognitive flexibility, decision making, feedback and self-perception (Spreen & Strauss, 1998). As it has the ability to filter interfering information and engage goal-directed behaviour (Ardila, 2008), it is suggested that any disruption to executive functioning could detrimentally affect the execution of other cognitive tasks. Research also suggests that executive function is influenced by an inherited common factor which is found at the latent variable level. A latent variable is an unobserved variable which is inferred by observed variables that are directly measured. The three widely recognised components of executive function are shifting of mental set, updating information and inhibition of prepotent responses (Miyake et al., 2000).

In this study, the focus is on testing the inhibition and interference components of executive function, seen as integral frontal lobe functions and susceptible to age-related neurodegeneration. Friedman and Miyake (2004) refer to these collectively as *interference-related functions.* Inhibition in older adults has been shown to be inefficient with the ability to prevent irrelevant information from interfering with the focus of attention, which in turn, disrupts performance (Lustig, Hasher, & Zacks, 2007). Lustig et al. (2007) described three functions of inhibition as controlling access to attentional focus, deleting irrelevant information from attention and suppressing inappropriate responses. When these mechanisms perform inefficiently then inhibition will be detrimentally affected, and in turn, overall executive function will be adversely affected with a consequent deleterious impact on cognitive performance. Inhibition of irrelevant information is the major contributor to poor cognitive performance (Lustig et al., 2007), therefore, three tasks were chosen to measure this inhibitory aspect of executive function; flanker arrows, Stroop arrow and Stroop word tasks (see Method section).

At the neurobiological level, executive function, as discussed in the Main Introduction, is considered a frontal lobe function as it is primarily supported by the prefrontal cortex (PFC), although the inferior parietal lobe and the basal ganglia are also implicated (Hedden & Gabrieli, 2010). The area most commonly associated area with inhibition is the ventral lateral PFC (Aron, Robbins, & Poldrack, 2004; Hedden & Gabrieli, 2010). As the prefrontal cortex is susceptible to early neurobiological changes with age, decline in this region will have a detrimental effect on executive function (Miyake et al., 2000; Raz, 2000) . Given the age-related neuroanatomical changes occurring in the frontal cortex, WP variability is of some interest as it has been shown to be sensitive to early neuroanatomical change and decline (Hultsch, Strauss, Hunter, & MacDonald, 2008). Indeed, the role of the frontal cortex in WP variability is suggested by work showing variability to be greatest in tasks placing the highest demands on executive processes (Bunce et al., 2004; Hultsch, MacDonald, & Dixon, 2002; Nesselroade & Salthouse, 2004; West et al., 2002).

The first aim of this study was to assess whether dedifferentiation of cognitive processes was evident in a group of healthy adults aged 50 to 90 years living in the community. Given suggestions that dedifferentiation in old age may be a characteristic of pathological ageing (Batterham et al., 2011), it was of interest to explore the extent of dedifferentiation in this healthy group. The second aim arose from work suggesting WP variability and executive function are susceptible to neurobiological changes in the frontal regions and that executive function is widely held to support general cognition. Specifically, using SEM and following the recommendations of Baron and Kenny (1986), this study used a three step process to examine evidence that executive function mediated age differences in several other domains, psychomotor performance, visual search and word recognition. Of particular interest was to contrast measures of mean RT obtained from the cognitive variables with measures of WP variability. Essentially, this contrasts a measure of central tendency with a measure of dispersion across the RT distribution. Although both measures are based on the same underlying component of processing speed, research suggests WP variability is able to capture a wider scope of variance and therefore provides a greater power of prediction (Hultsch et al., 2008). Furthermore, the two measures do correlate highly on the amount of overlapping variance that they share, as indicated in a partial set

correlation analysis conducted by Hultsch et al. (2002). Their analysis examined the two measures across two groups of reaction time tasks which included perceptual speed and episodic memory. However, they found that the individual ISD measures predicted variance in other cognitive measures above that of the mean measurement. Further research suggests that the relationship between the measurements of mean RT and WP variability is both linear and invariant over time and within person (Wagenmakers & Brown, 2007). It has also been suggested that by applying a diffusion model to data, focusing on the worst performance rule whereby slowest RTs could be more variable, it can be seen that the two measures do vary across individuals (Ratcliff, Schmiedek, & McKoon, 2008; Schmiedek et al., 2009). Of particular interest here was whether the factor structures across variables for the two measures dissociated given that WP variability is held to be sensitive to the early or subtle neurobiological changes associated with ageing.

Method

Participants

Two hundred and fifty seven (154 women, 103 men) cognitively intact, community-dwelling persons aged 50 to 90 years (M = 63.60, SD = 7.82) participated in the study. Participants were recruited from local health clubs, sport clubs, community groups and the general local community through printed advertisements and oral presentations about the study (See Appendix I for an example of an advertisement). Potential participants were excluded from the study if they could not walk a distance of 1 mile (required for Study 4), and if they had experienced any neurological or cardiovascular disorder (e.g., heart attacks, strokes, traumatic brain injury). This information was collected via a comprehensive biographical and health history questionnaire (See Appendix II for a copy of the Biographical questionnaire). Participants were also screened for cognitive impairment using the Mini-Mental State Examination (MMSE) (Folstein, Folstein, & McHugh, 1975). All participants scored >24 on this measure (M = 29.20, SD = .88). None were excluded due to scores below this value (See Appendix

III for a copy of the MMSE). The ethnic profile of the sample reflected that of the local community. That is, 94% Caucasian with the remainder made up of various ethnicities. The sample was selected such that there was an approximate even distribution across the age range of 50 to 90 years.

Participants rated their general perceived health in comparison to others their age on a scale of 1 – 10, with 1 representing "poor" and 10 "excellent" health (*M* = 8.33, *SD* = 1.32). Years of full time education was also recorded (*M* = 14.07, *SD* = 2.72) as well as the amount of physical activity completed each week (hours). Descriptive variables according to age are presented in Table 1.1. For descriptive purposes, data are presented for "young-old" participants (50 to 62 years) and "old-old" participants (63 to 90 years), as well as for the whole sample. Analyses reported below, however, used the entire continuous age range. Verbal intelligence was assessed using the National Adult Reading Test (NART) (Nelson, 1982) and estimates of full-scale IQ were computed according to standard guidelines (*M* = 120.33, *SD* = 7.39) (See Appendix IV for copy of NART).

Table 1.1. Descriptive Variables According to Age

Range	Age	Gender	Education	NART
Young-Old				
50-62				
M	57.58	45:91	14.59	120.95
SD	4.24		2.70	6.70
(N)	136			
Old-Old				
63-90				
M	70.37	58:63	13.48	119.64
SD	5.03		2.62	8.07
(N)	121			
Whole Group				
50-90				
M	63.60	103:154	14.07	120.33
SD	7.89		2.72	7.39
(N)	257			

Notes. Age, Education = years; Gender = Male -1, Female - 2; NART = National Adult Reading Test - estimate of full-scale IQ; *M* = mean; *SD* = standard deviation.

Cognitive Tasks

The cognitive tasks were administered on a laptop using E-Prime version 1.2 (Psychology Software Tools, 2006). Participants were asked to complete 11 tasks counter-balanced across the sample. This was to reduce any order effects and any bias caused by familiarity with completing computer-based tasks. The only tasks not randomised in this way were immediate and delayed recognition. Accuracy, and mean reaction time (mean RT) were recorded for all cognitive tasks, and data for correct responses only used to compute the metrics subjected to statistical analyses. Where appropriate, trials were pseudorandomized across condition. The selection of cognitive tasks was chosen to measure four cognitive domains, psychomotor performance, executive function, visual search and recognition. It is acknowledged here that these tasks do not represent each domain in its entirety. The tasks were chosen as select measures of these domains, recognising that in particular, the visual search tasks and recognition tasks selectively represent single measures of the visual and recognition domains and do not represent a total representation of visual perception or recognition. The tasks were also chosen based on their ability to reflect mean RT and WP variability effectively and there was a limit to the amount of tasks that a participant could realistically complete within a reasonable amount of testing time (two hours) and before fatigue became a mitigating factor. Therefore, throughout this thesis, the word 'domain' is used but it is a 'representational' measure thereof as used in existing research (Bunce et al., 2008a; Bunce et al., 2008b). For all tasks, participants completed a series of practice trials which did not form part of the analyses and were discarded. Instructions to all tasks emphasised speed and accuracy of responding.

Psychomotor Tasks

Three psychomotor tasks were chosen to measure psychomotor performance over three levels of increasing difficulty.

Simple Reaction Time (SRT)

For this task, there were eight practice trials and 48 test trials, during which the letter X was presented in the centre of the screen. The participant was required to

press the space bar whenever the X was presented. The X was presented in randomly spaced intervals between 300 and 1,000 milliseconds (ms). The data collected was the time taken to press the space bar after the X was presented.

Two-Choice Reaction Time (2-CRT)

In this task, a black circle of 25 mm diameter was displayed either on the right or the left of the screen. The circle was presented with an inter-trial interval of 500 ms. There were 12 practice trials and 48 test trials, during which the participant was required to press either the X (left) or M (right) key of the keyboard, depending on which side the stimulus was presented. A correct response was recorded when the corresponding correct key pressed matched the side of the stimulus presented.

Four-Choice Reaction Time (4-CRT)

This task was a more complex version of the 2-CRT task where the black circle appeared in any of the four corners of the screen, top, bottom, left and right. The participant therefore had four choices to respond to. For this task, the S and X keys were used to respond to top left and bottom left respectively, and the K and M keys were used to respond to top right and bottom right respectively. A correct response was recorded when the correct key pressed matched the side and position of the stimulus presented. The intertrial interval was 500 ms.

Executive Function Tasks

Three tasks were used to assess this construct. As the primary interest was in the inhibition of distractor stimuli, the mean RT and within-person variability (WP variability) data for correct responses in the incongruent condition only were used in statistical analyses.

Flanker Arrows

In this version of the Eriksen flanker task (Eriksen & Schultz, 1979), five arrows appeared next to each other in the middle of the screen. The arrows were either all facing the same direction (congruent) or the middle one was in an opposite direction (incongruent), (see Figure 1.1.)

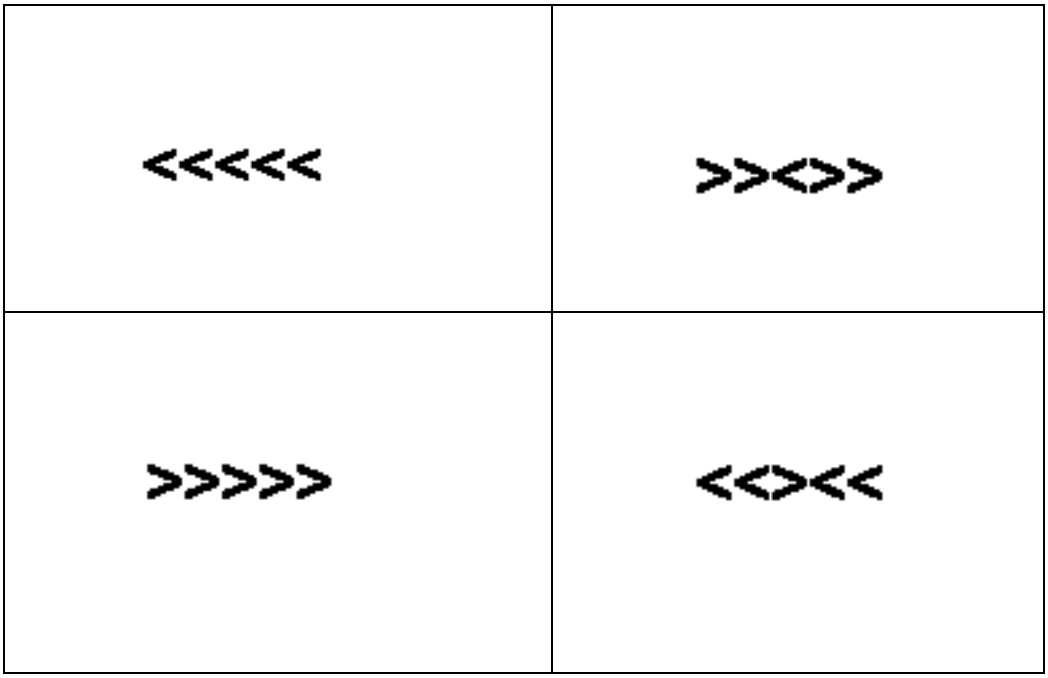

Figure 1.1. Flanker arrows task stimuli: Top row - left arrows; congruent (left) and incongruent (right); bottom row - right arrows; congruent (left) and incongruent (right).

The task involved focussing only on the middle target arrow and indicating whether the arrow pointed left or right by using the X and M keys on the keyboard. There were 64 trials, half of which were congruent and the other half incongruent. The intertrial interval was 500 ms. A correct response was recorded when the central target arrow matched the direction of the key pressed.

Stroop Arrow

In this spatial Stroop task (Salthouse et al., 1997) participants were required to respond to the direction of an arrow presented to the left, right or middle of the screen. There were 100 trials and of which 40 were congruent (arrow pointed in

the same direction as its position on the screen), 40 were incongruent (arrow pointed in the opposite direction to its position on the screen) and 20 were neutral (arrow was in the middle of the screen but could point either direction, left or right). For a correct response, the participant was required to press the key that corresponded spatially to the direction the arrow pointed in. That is, to press the "X" key if the arrow pointed left and the "M" key if the arrow pointed right (see Figure 1.2.). The intertrial interval was 500 ms.

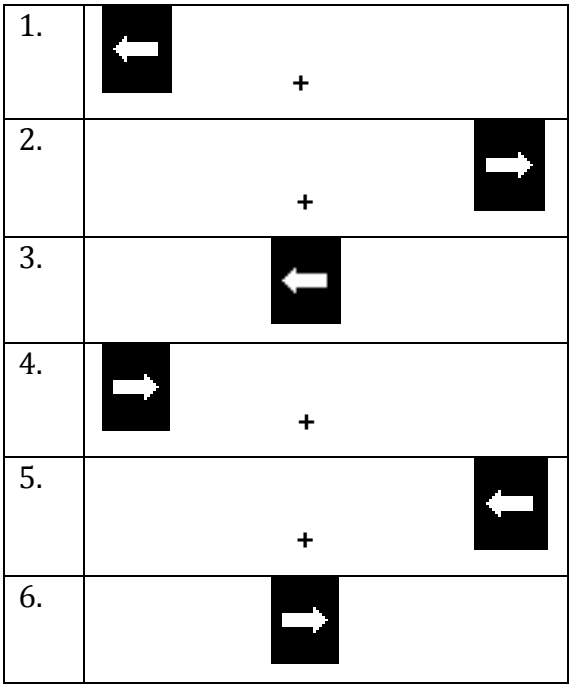

Figure 1.2. Stroop arrow task stimuli: 1. Left pointing arrow congruent, 2. Right pointing arrow congruent, 3. Left pointing arrow neutral, 4. Right pointing arrow incongruent, 5. Left pointing arrow incongruent, 6. Right pointing arrow neutral. + = Fixation cross.

Stroop Word

Here, participants were presented with one of the words 'red, yellow, blue or green'. These words were presented in the middle of the screen and were written in either red, yellow, blue or green ink. Responses were required to the ink colour rather than the colour described by the written word (see Figure 1.3.). There were

16 practice trials followed by 96 test trials, half of which were congruent (word-colour matched) and half incongruent (word-colour not matched). Responses were recorded via the C, V, B and N keys, which were colour-coded red, yellow, blue and green, respectively. The intertrial interval was 500 ms.

Key	Congruent	Incongruent	Key
C	Red	Red	B
V	Yellow	Blue	N
B	Blue	Yellow	C
N	Green	Green	V

Figure 1.3. Stroop word task stimuli with response keys

Visual Search Tasks

These tasks serve to measure both simple visual perception and conjunctive (complex) visual perception and were used successfully in previous research (Bunce et al., 2008a). Mean RT and within-person variability (WP variability) were computed for correct responses. The intertrial interval was 500 ms.

Simple Visual Search

For this task, a block of 6 x 6 green letter Os appeared in the centre of the screen during each trial. Half of the trials had a green letter Q embedded randomly within the block (see Figure 1.4.).

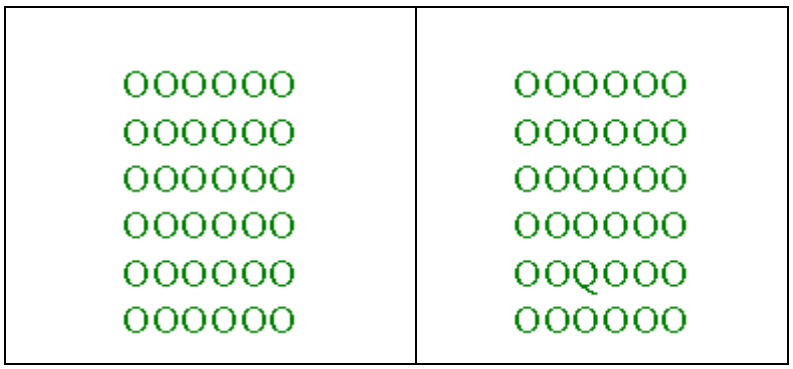

Figure 1.4. Simple visual search task stimuli (left column: control with only 'O's; right column: target 'Q' embedded in 'Os').

There were 16 practice trials and 64 test trials for the participant to respond to. If a target letter green Q was present, the X key was pressed to say 'yes' and if the Q was not present, the M key was pressed to respond 'no'. The target trials were pseudorandomised amongst the non-target 'O' trials. As correct data from the target and non-target conditions were highly intercorrelated for mean RT (0.78, $p < .01$) and for WP variability (0.71, $p < .01$), the mean for the two conditions was used in statistical analyses. The intertrial interval was 500 ms.

Complex Visual Search

This task was the same as the simple visual search task except the stimulus consisted of both green and red letter Os and Qs (see Figure 1.5.).

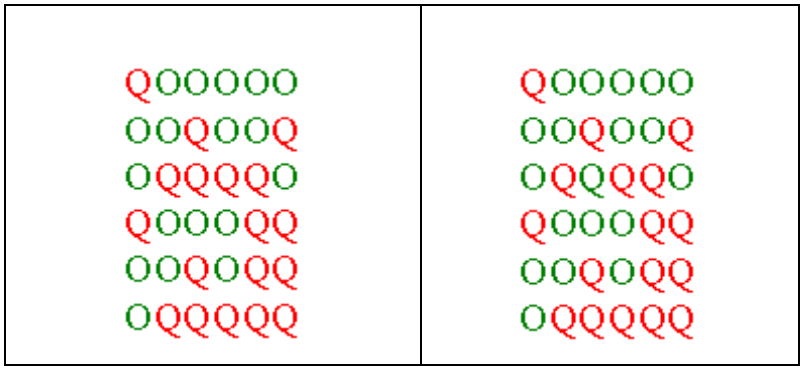

Figure 1.5. Complex visual search task stimuli (left column: control with only green 'O's and red 'Qs'; right column: target green 'Q' embedded in red 'Qs' and green 'Os').

Target responses therefore had to take both colour and letter shape into consideration before responding. There were 16 practice trials and 64 test trials for the participant to respond to. If a target letter green Q was present, the X key was pressed to say 'yes' and if the Q was not present, the M key was pressed to respond 'no'. The green 'Q' trials were pseudorandomised amongst the non-target 'O' trials. Target trials consisted of 18 green O letters intermixed with 17 red Q letters and one green Q. Non-target trials consisted of 18 green O letters and 18 red Q letters. A correct response would, for example, identify a green Q amongst red Qs and green Os. As with the simple version of the visual search task, the mean RT and WP variability data were collapsed across target and non-target conditions as the conditions correlated highly for mean RT (0.80, $p < 0.01$) but for WP variability it was low (0.15, $p < .05$) but to keep the method consistent across all four conditions, the mean was chosen throughout as the majority correlated highly. The intertrial interval was 500 ms.

Recognition Tasks

The recognition tasks were designed to measure immediate and delayed episodic memory. For computation of mean RT and within-person variability metrics (see below), RTs for hits and correct rejections were combined to increase the range of available data. This was due to the nature of the task (episodic memory) where inaccuracy for both recognition tasks was between 30 and 40 percent, and as inaccurate trials were removed, this left only 60-70 percent of the trials on which to calculate mean RT and WP variability.

Immediate Recognition

For the immediate recognition, at study, 16 target nouns were randomly presented on the screen with an inter-word interval of 500ms. Each word was presented for two seconds, during which the participant was required to read the word. No response was required. After the completion of a brief distractor task (either the 2-CRT or Stroop arrow task depending on counterbalance order), at test, the

participant was again presented with the list of words. On this occasion though, the 16 target nouns were presented with 16 randomly intermixed foil (distractor) nouns. Participants were required to respond "yes" if they thought the word was a target, or "no" if they thought the word was a distractor.

Delayed Recognition

The delayed recognition task was the final task that participants completed and was 30 minutes after stimulus presentation at the beginning of the session. The procedure was the same as for the test part of the immediate recognition version of the task where targets and distractor were randomly intermixed. The intertrial interval was 500 ms,

National Adult Reading Test (NART)

Verbal intelligence was assessed using the National Adult Reading Test (NART; Nelson, 1982). An estimate of full-scale IQ was obtained using standard procedures.

Data Processing

The RT data for the cognitive tasks collected in E-Prime were exported into SPSS (PASW 18, SPSS Inc., 2009) for processing of mean RT from the raw response latencies. Systat (SYSTAT Software, 2004) was used to produce the WP variability measures, computed as the Intraindividual Standard Deviation (ISD).

Trimming

Error responses and unusually fast responses below 150 ms caused by accidental key presses and premature responses, were eliminated. Likewise, extremely slow latencies beyond the individual mean RT + 3 *SDs* were eliminated. As this top and bottom trimming has the effect of reducing RT variability, it represents a conservative approach to the investigation of response variability. This approach

was applied to all cognitive tasks, except for the recognition tasks, as discussed previously. The eliminated trials were replaced with the individual mean which was calculated on an individual level for each participant. After trial replacement, mean RT and ISDs were calculated for each participant. The trimming procedure resulted in the loss of less than 5% of total trials for most tasks, which was comparable with work elsewhere (e.g., Bunce et al., 2008a, 2008b; Hultsch et al., 2002).

Accuracy

Mean error rates for the psychomotor performance and inhibition tasks were below 5.8%, which is comparable to Bunce et al. (2008a). For the visual search tasks, mean target hit and miss rate and, mean non-target correct rejections and error rate (false alarms) were recorded out of 32 trials each (target and non-target). The mean hit rate out of 32 trials for simple visual search was 31.42 (*SD* = 1.98), and the mean false alarm rate out of 32 trials was 0.25 (*SD* = 1.97). The mean hit rate for complex visual search was 25.93 (*SD* = 5.34), and the mean false alarm rate was 0.51 (*SD* = 2.19). These results compared similarly with Bunce et al., (2008b). For the word recognition tasks, mean target hit and miss rate and mean distractor correct rejections and error rate (false alarms) were recorded out of 16 trials each (target and distractor). The mean hit rate out of 16 trials for immediate recognition was 12.01 (*SD* = 2.82), and the mean false alarm rate out of 16 trials was 5.08 (*SD* = 4.44). The mean hit rate out of 16 trials for delayed recognition was 11.24 (*SD* = 2.69), and the mean false alarm rate out of 16 trials was 7.20 (*SD* = 4.14). Immediate recognition accuracy compared similarly to Bunce et al. (2008b), who did not test delayed recognition. Table 1.2. shows the percentage errors for all tasks with the figure for the visual search and recognition tasks combining target misses and false alarms.

Table 1.2. Cognitive Task Accuracy

Variable	*M (SD)*
	Percentage Incorrect
SRT	0.00 (0.00)
2-CRT	0.90 (2.61)
4-CRT	5.75 (14.56)
Flanker Arrow	3.26 (8.90)
Stroop Arrow	3.78 (6.16)
Stroop Word	4.45 (16.49)
Simple Visual Search	0.81 (6.20)
Complex Visual Search	1.78 (6.87)
Immediate Recognition	32.07 (28.00)
Delayed Recognition	45.46 (26.13)

Notes: SRT = simple reaction time; 2-CRT or 4-CRT = two or four-choice reaction time.

Mean RT and Within-Person Variability Computations

For each of the cognitive tasks, the intraindividual mean RT was computed from the raw correct response latencies, after trimming and replacing the individual mean RT, as explained above. Within-person variability (WP variability) was calculated using the ISD (individual standard deviation). Because time-on-task effects (e.g., practice and fatigue) tend to inflate WP variability, they were partialled from the ISDs together with their higher-order interactions with age. Following Hultsch et al. (2002), a regression procedure was used to achieve this. Individual RTs were regressed on chronological age and trial number to produce residuals that were statistically independent of age or trial number and their higher-order interactions. These residual scores were then standardised and converted to t scores (M = 50, SD = 10) to facilitate comparisons across the different tasks.

Missing Data

At the sample level across all 257 participants, there was a small amount of missing data. This was minimal and was replaced using the EM algorithm in SPSS that took into account all of the variables in this study, as recommended elsewhere

(Shafer & Graham, 2002). This procedure helps counter statistical problems (e.g., failure to converge) in the modelling that followed. The percentages of data replaced in this way for the respective tasks varied between (0% and 1.6%). These figures were comparable with those reported by Bunce et al. (2008b).

Centring Data

All variables underwent centring before the main statistical analyses and structural equation modelling proceeded. Centring transforms the variables into deviations around a fixed point. One way of doing this is through converting data to *z*-scores (Field, 2009) which have a mean of 0 and a standard deviation of 1. Centring is useful in countering multi-collinearity and when a predictor variable does not have a meaningful zero point (Field, 2009; Kraemer & Blasey, 2004). Centring also increases the precision of parameters estimates and also helps the power of statistical testing (Kraemer & Blasey, 2004).

Procedure

Participants arrived at a designated testing location at a mutually convenient time. The study and testing procedure were explained to the participant. Participants were then provided with a brief summary about the study before signing an informed consent form (See Appendix V and VI for the Information sheet and Consent form). The Biographical questionnaire was then completed by participants (See Appendix II for Biographical questionnaire) and the MMSE (Folstein, Folstein & McHugh, 1975), followed by the NART (Nelson, 1982), were administered before commencing the cognitive tasks. Participants were then given an overview of the testing procedure and instructions about the cognitive tasks to be completed on the laptop. Each task had full instructions written on the screen and the participant was asked if they fully understood the task before commencing. If not, an additional verbal explanation was given. The participant then completed all of the counterbalanced computerized tasks. The word presentation for the recognition tasks was always presented first with immediate

recognition third and delayed recognition last. After completion of the computer tasks, the participant completed two questionnaires used in the other studies contributing to the broader investigation: General Hospital Questionnaire-12 (GHQ) (Goldberg, 1978), and the Victoria Longitudinal Study (VLS Lifestyle) (Hultsch et al., 1999) (See Appendices V and VI for the GHQ and VLS lifestyle questionnaires respectively). Finally, participants completed a one-mile treadmill walk for Study 4. Once finished, participants were thanked, provided a contact card and a written debrief together with a reminder of the aims of the study (See Appendix VII for the Debrief document). Each testing session took from one hour and forty minutes to two hours and thirty minutes. Participants were allowed breaks if they requested. No financial or material rewards were provided.

Research ethics

All aspects of this research were carried out in accordance with Brunel University's ethical guidelines and procedures for research involving human participants. Ethical approval for the study (See Appendix VIII for Ethical approval) was granted by the Research Ethics Committee of the School of Social Sciences prior to recruitment of participants.

Results

Bivariate correlations, together with means and standard deviations for the cognitive variables, are presented in Table 1.3. for both mean RT and WP variability. In addition to the initial bivariate correlation analysis, structural equation modelling was used to explore the factor structure of the cognitive variables. This procedure was also used to explore the mediating role of executive function in age-cognitive performance associations. This was achieved by investigating the relationship between age and the latent constructs formed by the cognitive domains of psychomotor performance, executive function, visual search and recognition for both mean RT and WP variability. Of particular interest here was whether factor structures varied according to whether mean RT or intraindividual variability were used to quantify the cognitive variables.

Table 1.3. Bivariate Correlations Between Age and The Cognitive Variables

	Variable	*M (SD)*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	Age	63.60 (7.89)	—																						
2	Gender-women	154 (*n* = 257)	-.18 **	—																					
3	NART	120.33 (7.39)	-.04	-.12	—																				
4	SRT (ms)	309.61 (75.05)	.35 **	.05	-.19 **	—																			
5	SRT isd	6.87 (3.37)	.21 **	.03	-.16 **	.72 **	—																		
6	2-CRT (ms)	363.82 (77.49)	.34 **	-.13 *	-.08	.55 **	.38 **	—																	
7	2-CRT isd	6.71 (3.00)	.28 **	-.04	-.07	.35 **	.36 **	.51 **	—																
8	4-CRT (ms)	553.35 (116.63)	.41 **	-.22 **	-.16 *	.48 **	.34 **	.67 **	.43 **	—															
9	4-CRT isd	7.02 (2.81)	.29 **	-.10	-.17 **	.30 **	.25 **	.41 **	.40 **	.73 **	—														
10	Flanker Arrow (ms)	685.28 (204.41)	.46 **	.07	-.20 **	.52 **	.31 **	.41 **	.38 **	.51 **	.45 **	—													
11	Flanker Arrow isd	6.34 (6.06)	.35 **	.06	-.18 **	.44 **	.28 **	.28 **	.34 **	.40 **	.44 **	.92 **	—												
12	Stroop Arrow (ms)	766.01 (117.41)	.52 **	-.03	-.23 **	.48 **	.34 **	.56 **	.45 **	.65 **	.50 **	.55 **	.44 **	—											
13	Stroop Arrow isd	7.97 (3.20)	.28 **	.06	-.29 **	.36 **	.31 **	.40 **	.36 **	.49 **	.47 **	.40 **	.35 **	.76 **	—										
14	Stroop Word (ms)	1079.39 (263.69)	.52 **	-.12	-.06	.38 **	.26 **	.36 **	.32 **	.48 **	.40 **	.49 **	.43 **	.54 **	.37 **	—									
15	Stroop Word isd	8.19 (4.52)	.43 **	-.06	-.08	.30 **	.23 **	.26 **	.29 **	.36 **	.35 **	.45 **	.43 **	.43 **	.35 **	.85 **	—								
16	Visual Search S. (ms)	827.18 (230.35)	.49 **	-.22 **	-.10	.30 **	.22 **	.31 **	.27 **	.43 **	.31 **	.49 **	.42 **	.52 **	.35 **	.55 **	.43 **	—							
17	Visual Search S. isd	6.73 (4.54)	.31 **	-.16 *	-.08	.14 *	.10	.11	.14 *	.28 **	.23 **	.28 **	.23 **	.35 **	.29 **	.39 **	.31 **	.88 **	—						
18	Visual Search C. (ms)	1998.14 (671.32)	.30 **	-.13 *	-.09	.20 **	.11	.21 **	.10	.30 **	.18 **	.29 **	.21 **	.38 **	.30 **	.49 **	.43 **	.55 **	.48 **	—					
19	Visual Search C. isd	7.09 (3.41)	.18 **	-.07	-.04	.08	.00	.09	.00	.22 **	.14 *	.17 **	.12	.27 **	.25 **	.34 **	.32 **	.49 **	.51 **	.89 **	—				
20	Recognition Imm. (ms)	1149.50 (297.41)	.39 **	-.04	-.03	.26 **	.19 **	.33 **	.27 **	.34 **	.30 **	.43 **	.37 **	.40 **	.31 **	.43 **	.34 **	.42 **	.31 **	.34 **	.25 **	—			
21	Recognition Imm. isd	8.34 (5.00)	.22 **	.02	.03	.17 **	.12 *	.15 *	.22 **	.17 **	.16 *	.29 **	.30 **	.20 **	.16 *	.27 **	.23 **	.31 **	.24 **	.27 **	.24 **	.82 **	—		
22	Recognition Del. (ms)	1086.76 (279.67)	.42 **	-.01	-.03	.23 **	.08	.27 **	.29 **	.28 **	.22 **	.27 **	.20 **	.38 **	.27 **	.38 **	.34 **	.33 **	.21 **	.26 **	.21 **	.51 **	.39 **	—	
23	Recognition Del. isd	7.97 (4.54)	.24 **	.05	.02	.09	.00	.14 *	.21 **	.13 *	.19 **	.18 **	.18 **	.21 **	.15 *	.23 **	.24 **	.18 **	.13 *	.14 *	.16 *	.33 **	.32 **	.81 **	—

Notes: NART = National Adult Reading Test; (ms) = milliseconds for mean reaction time; isd = intraindividual standard deviation; SRT = simple reaction time; 2-CRT or 4-CRT = two or four-choice reaction time; Visual Search S. Or C. = visual search simple or complex; Recognition Imm. or Del. = recognition immediate or delayed; *Gender = Male - 1, Female - 2*

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

Consideration of Table 1.3. indicates that correlations between age and the cognitive variables were all highly significant (*ps* < .01) with older age associated with slower responding (mean RT) and greater WP variability across all tasks. Gender differences in performance were apparent for most of the cognitive tasks for both mean RT and WP variability. NART scores were significantly associated with six of the cognitive variables (mean RT and WP variability for 4-CRT, flanker arrows and Stroop arrow), all *p*s < .01, except mean RT for 4-CRT, which was *p* < .05. NART scores, as previously mentioned, were used in this study as an adjusted IQ estimate. Given this finding therefore, the possibility that age differences in IQ underlie age differences in performance in the cognitive tasks was addressed in the structural equation models (SEMs) by controlling for this variable.

A confirmatory model was created using SEM that explored the factor structure of the cognitive variables and whether there was evidence of a dissociation between mean RT and WP variability. The advantage of using SEM is that the cognitive domains of psychomotor performance, executive function, visual search and recognition can be pre-determined as latent constructs and the model can then explain if and how the cognitive tasks factor onto the specific domains simultaneously. Therefore, a first-order model was constructed using AMOS version 18 (Arbuckle, 2009) whereby the ten cognitive tasks (observed constructs) loaded onto the unobserved latent constructs of the cognitive domains (see Figure 1.6.). Provisional models found that allowing two error terms to covary between SRT and 4-CRT (e1 and e4), and between Stroop word and complex visual search (e6 and e8), increased model fit. This suggested that there were elements in each variable which overlapped and allowing them to covarying made the model more parsimonious. Any two variables within the same latent construct could theoretically be covaried, as with SRT and 4-CRT. Stroop word and complex visual search, though, load onto different latent constructs, executive function and visual search, respectively. However, both are inhibitory tasks requiring colour processing and an inhibitory response. It was found that by covarying both of these, all models gained increased fit and converged successfully.

The output from the SEM is presented in Table 1.6. for both mean RT and WP variability. As is required in the procedure, the regression weights for the first variable in each latent construct were fixed at 1 (SRT, simple visual search,

immediate recognition and Stroop Arrow), and therefore, path coefficients were not estimated for these variables.

Structural Equation Modelling

Structural equation modelling (SEM) is a confirmatory analytical procedure that enables causal relationships to be made between variables (Blunch, 2008; Byrne, 2004; Kline, 2005). SEM uses models to explain and confirm relationships amongst observed variables (dependent and independent variables) with the aim of creating a quantitative test of a theoretical model which is based on a proposed hypothesis (Schumacker & Lomax, 2004). The hypothesis is based on existing research and present research aims, and the model is then designed around the hypothesis to be tested. The model is then tested against the data and estimates of the fit computed. If the model does not prove to be a good fit then it can be adjusted whilst maintaining theoretical associations, or a new model can be designed which takes into account the limitations and deficiencies of the initial model. The structural equation model is based on a regression model but combines both path and confirmatory factor models, testing multiple variables simultaneously. In this study, the dependent variables are the cognitive tasks, the independent variables are, age and IQ (measured by the National Adult Reading Test – NART score). By controlling for NART (adjusted IQ score), the possibility that age differences in IQ confound with age differences in performance on the cognitive tasks is addressed. The cognitive domains, onto which they all load, are the unobserved or latent variables (see the ellipses in Figure 1.6.). Variables are also specified as being exogenous or endogenous. An exogenous variable is one that is synonymous with an independent variable in multiple regression and predicts variation in the other latent variables whereas an endogenous variable is akin to the dependent variable. In summary, SEM has the ability of describing the latent structure underpinning a set of observed variables and explaining how they are related to each other (Byrne, 2001). The following sections briefly consider issues related to model estimation and fit.

Model estimation

After the model is specified, a method has to be chosen which estimates the actual covariance in the data in relation to that model. At this stage, there has to be enough data points for the model to be estimated or the model will be unidentified. A model is identified if it is theoretically possible to derive a unique estimate of each parameter (Kline, 2005). This involves the estimation of presumed causal relationships between the observed variables. This model was identified because all parameters were freely estimated except for e1 with e3 (SRT and 2-CRT), and e6 with e8 (Stroop word and complex visual search) which were constrained due to high covariance between the respective variables. The maximum likelihood (ML) estimation method was chosen over the generalised least squares (GLS) as this method selects parameters that maximises the likelihood that the data are normally distributed. Using this method, SEM will continue to run the data through repeated iterations to find the best fit, whereas GLS is less stringent, resulting in larger standard errors, more suitable for a less normally distributed dataset. The ML method requires the sample to be large (> 200) (Kline, 2005) because the method is a more stringent method of estimation. The advantage of using the ML method also is that it is scale free and means that the value of the ML fitting function remains the same, regardless of the scale of the observed variables (Blunch, 2008; Kline, 2005).

Model fit

Goodness-of-fit measures are used in SEM which ensure the data and the model are a good fit suggesting, therefore, that the hypothesis is based on conceptually sound rationale, as discussed previously. Chi-square (χ^2) indicates if the observed and hypothesised variance-covariance matrices differ or not. While a significant χ^2 indicates that they differ and the difference could be due to sample variation or a misspecified model, a non-significant χ^2 indicates they are similar and that the model closely reproduces the sample variance-covariance relationship within the matrix (Schumacker & Lomax, 2004). However, χ^2 is sensitive to sample size and a large sample (> 200) tends to produce a significant χ^2 (i.e., a difference between model and data), whilst a smaller sample size is more likely to produce a non-

significant χ^2 (p = .05). This process is the opposite of the usual method of rejection of a null hypothesis if the critical statistic is significant. In other words, if χ^2 is significant, the model is 'rejected' as not fitting the data and if χ^2 is non-significant, the model is accepted as having a good fit. However, due to the sensitivity to sample size, as mentioned above, χ^2 should not be used alone as a measure of model fit.

Another goodness-of-fit measure that counters sample size is based on χ^2 and is χ^2/df. This produces a lower value chi-square, known as a normed chi-square (Kline, 2005) and the ideal value of this has been put at < 2.0 (Byrne, 2001; Schumacker & Lomax, 2004). The comparative fit index and normative fit index (CFI and NFI respectively) provide two further fit indices which are derived from the comparison of the hypothesized model with the independence model. They are also dependent on the *df* and provide measures of covariation with the data (Byrne, 2001). In ideal situations, good values for these are considered to be > .90 (Kline, 2005; Schumacker & Lomax, 2004), but > .95 would be preferable (Byrne, 2001).

The final measure is the root mean square error of approximation (RMSEA), which is a measure of the model which takes into account the error of approximation in the population (Byrne, 2001). It does not assume the model to be a perfect fit and estimates the amount of error per degree of freedom (and is therefore sensitive to sample size) with zero indicating a perfect fit (Kline, 2005). A close approximation of fit is suggested when RMSEA < .05 with lower values suggesting better fit and higher becoming increasingly poor (Byrne, 2001; Kline, 2005). As can be seen, with different goodness-of-fit measures, the test of a model fitting data does not depend on one measurement alone but on a range of statistics.

In relation to the present study, data for the model presented in Figure 1.6. are detailed in Table 1.4. Chi-square for both mean RT and WP Variability was significant (X^2 = 41.02, p < .05 and X^2 = 47.18, p < .01, respectively), with the other goodness-of-fit statistics suggesting acceptable fit (mean RT: X^2/df = 1.52, CFI = .99, NFI = .96, RMSEA = .05, WP variability, X^2/df = 1.75, CFI = .96, NFI = .91, RMSEA = .05). Consideration of path coefficients in Table 1.4. show that all the cognitive tasks were significantly (p < .01) associated with their respective cognitive domains.

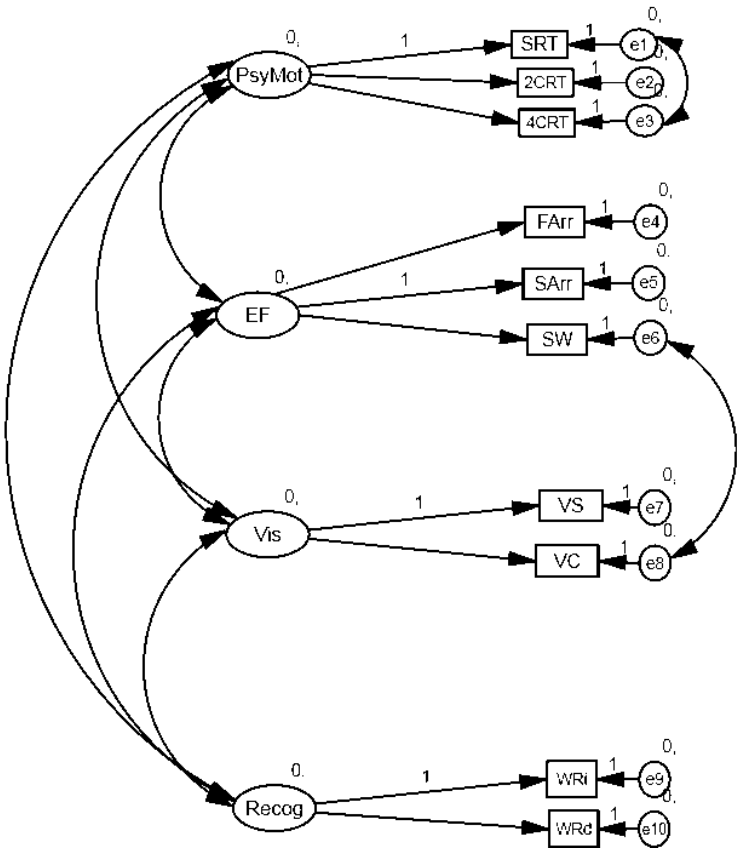

Figure 1.6. First-order Structural Equation Model, for the cognitive variables.

e1-e10 = error terms 1-10; PsyMot = psychomotor performance; EF = executive function; Vis = visual search; Recog = recognition; SRT = simple reaction time; 2CRT = two-choice reaction time; 4CRT = four-choice reaction time; FArr = flanker arrows; SArr = Stroop arrow; SW = Stroop word; VS = simple visual search; VC = complex visual search; WRi = immediate recognition; WRd = delayed recognition.

Table 1.4. Goodness-of-Fit Measures and Standardized Regression Weights For Mean RT and WP Variability First-Order Structural Equation Model

		Mean RT	ISD
Goodness-of-fit			
Chi-squared		41.02	47.18
p value		.041	.009
CMIN/DF		1.52	1.75
CFI		.99	.96
NFI		.96	.91
RMSEA		.05	.05
Path Coefficients			
SRT	<-- Psychomotor	.74	.52
2-CRT	<-- Psychomotor	.74 **	.60 **
4-CRT	<-- Psychomotor	.90 **	.72 **
Flanker Arrow	<-- Executive Function	.70 **	.80 **
Stroop Arrow	<-- Executive Function	.79	.63
Stroop Word	<-- Executive Function	.70 **	.67 **
Simple Visual Search	<-- Visual Search	.88	.49
Complex Visual Search	<-- Visual Search	.61 **	.63 **
Immediate Recognition	<-- Recognition	.79	.59
Delayed Recognition	<-- Recognition	.65 **	.63 **

Notes: CMIN/DF = chi-squared/degrees of freedom; CFI = comparitive fit index; NFI = normative fit index; RMSEA = root mean square error of approximation; SRT = simple reaction time;
2-CRT or 4-CRT = two or four-choice reaction time.
*p < .05; **p < .01

Given that this initial analysis suggested that the hypothesised model provided good fit to the data, a further aim of this study was to investigate whether executive function mediated the association between age and performance in the other cognitive domains. It was also of interest to see whether the relationship dissociated between mean RT and WP variability. Again an SEM procedure was used to explore this association in a three step modelling process following Baron and Kenny (Baron & Kenny, 1986), as described in the Main Introduction. The aims of these structural equation models were two-fold. First, to investigate whether WP variability and mean RT varied as a function of age, and second to

examine whether executive function mediated the association between age and the other cognitive variable.

In Model 1, NART and age formed the exogenous variables whilst psychomotor performance, executive function, visual search, and recognition domains served as the endogenous latent variables (see Figure 1.7.). The important aspect of this model was to confirm that the cognitive domains attained significance in relation to age after intelligence (NART score) had been taken into account. This procedure controls for the possibility that age differences in IQ may underlie differences in the cognitive variables and therefore acts to confound associations. In Model 2, all of the paths from the exogenous to the endogenous variables were eliminated except for those to executive function. Additional paths were introduced, however, from executive function to the endogenous variables of psychomotor performance, visual search and recognition (see Figure 1.8.). The focus of interest in this model was whether the Age to executive function path was significant and also whether the paths between executive function and the other endogenous variables were significant. If these associations are evident, it provides provisional indication that the effects of age on the other cognitive variables are mediated by executive function. Finally, Model 3 combined Models 1 and 2, but with the additional direct paths from executive function to the latent variables of psychomotor performance, visual search and recognition (see Figure 1.9.). The aim of this step was to see if any of the direct paths from age to the endogenous cognitive variables identified in Model 1 became non-significant after executive function was taken into account in the model. In order to completely meet the requirements of Baron and Kenny for full mediation, in this model the age to executive function path, and also significant executive function to cognitive domain paths identified in Model 2, have to remain significant.

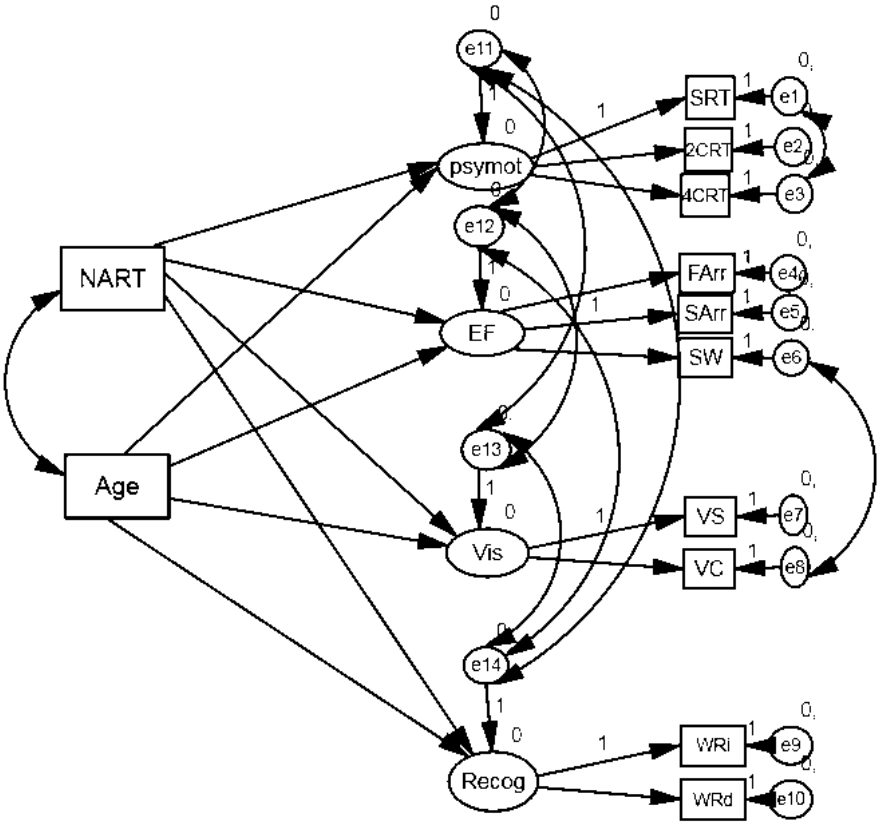

Figure 1.7. Structural Equation Model 1, for Age and cognitive variables.

e1-e14 = error terms 1-14, PsyMot = psychomotor performance, EF = executive function, Vis = visual search, Recog = recognition, SRT = simple reaction time, 2CRT = two-choice reaction time, 4CRT = four-choice reaction time, FArr = flanker arrows, SArr = Stroop arrow, SW = Stroop word, VS = simple visual search, VC = complex visual search, WRi = immediate recognition, WRd = delayed recognition, NART = National Adult Reading Test.

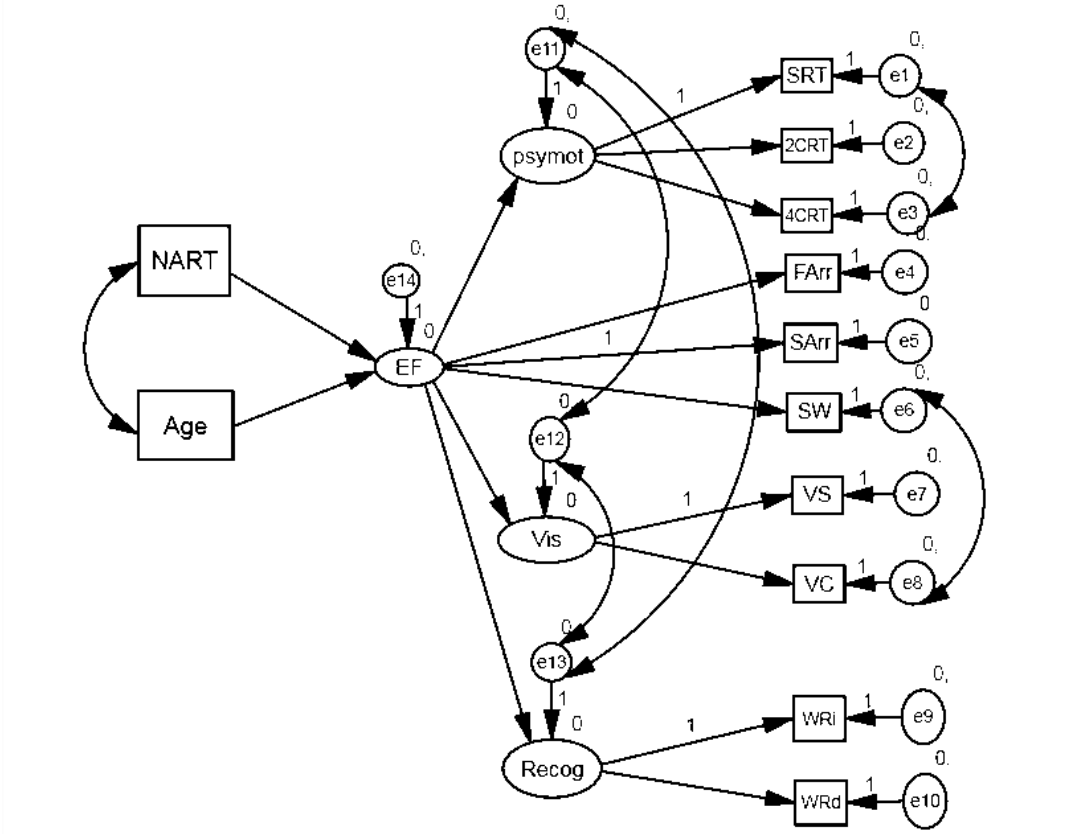

Figure 1.8. Structural Equation Model 2, for Age and cognitive variables.

e1-e14 = error terms 1-14, PsyMot = psychomotor performance, EF = executive function, Vis = visual search, Recog = recognition, SRT = simple reaction time, 2CRT = two-choice reaction time, 4CRT = four-choice reaction time, FArr = flanker arrows, SArr = Stroop arrow, SW = Stroop word, VS = simple visual search, VC = complex visual search, WRi = immediate recognition, WRd = delayed recognition, NART = National Adult Reading Test.

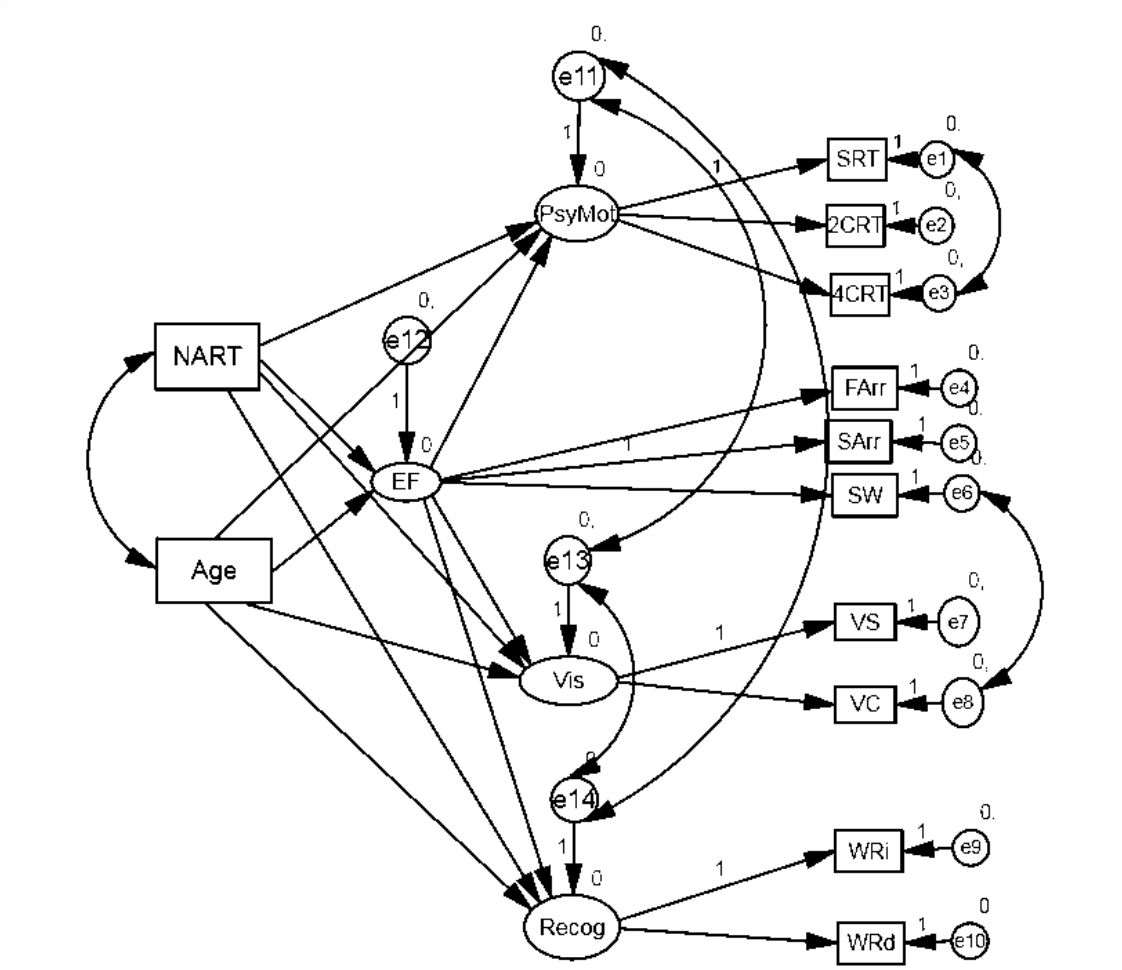

Figure 1.9. Structural Equation Model 3, for Age and cognitive variables.

e1-e14 = error terms 1-14, PsyMot = psychomotor performance, EF = executive function, Vis = visual search, Recog = recognition, SRT = simple reaction time, 2CRT = two-choice reaction time, 4CRT = four-choice reaction time, FArr = flanker arrows, SArr = Stroop arrow, SW = Stroop word, VS = simple visual search, VC = complex visual search, WRi = immediate recognition, WRd = delayed recognition, NART = National Adult Reading Test.

Regarding model fit, in Model 1 although chi-square for both mean RT and WP Variability was significant ($X^2 = 58.59$, $p < .05$ and $X^2 = 65.85$, $p < .01$, respectively), the other goodness-of-fit statistics suggested acceptable fit (mean RT: $X^2/df = 1.50$, CFI = .98, NFI = .95, RMSEA = .04. WP variability, $X^2/df = 1.69$, CFI = .96, NFI = .90, RMSEA = .05). Consideration of Table 1.5. shows that older age was significantly ($p < .01$) associated with greater WP variability and slower mean RT, with all paths between age and the latent variables (psychomotor performance, executive function, visual search and recognition) highly significant, in agreement with the bivariate correlations (see Table 1.3.).

In Model 2, paths were directed to and from executive function to see whether it was the possible mechanism by which age influenced mean RT and WP variability in the other cognitive domains (latent variables). If executive function was the mechanism, it is expected that the paths between these latent variables and executive function are significant. Age and executive function were positively associated ($p < .01$), as they were in Model 1. Importantly though, executive function and the cognitive domains psychomotor performance, visual search and recognition variability were all positively associated ($p < .01$) for both mean RT and WP. This indicates covariation between mean RT and WP variability in executive function, and mean RT and WP variability in the other cognitive domains, and fulfils the second step criteria for mediation, according to Baron and Kenny (1986).

To examine mediation fully, Model 3 combined Models 1 and 2 with additional direct paths drawn from executive function to psychomotor performance, visual search and recognition. If executive function accounted for the age associations with the three other cognitive domains (psychomotor performance, visual search and recognition) for mean RT and WP variability, then the regression paths should become non-significant. Importantly, consideration of Step 3 in Table 1.5., indicates that for mean RT, the age to visual search and recognition paths do indeed become non-significant ($p = .76$ and $p = .45$ respectively). This suggests that executive function attenuated the age effects for both of these domains and full mediation was taking place, according to the criteria set out by Baron and Kenny (1986).

Table 1.5. Goodness-of-Fit Measures and Standardized Regression Weights for Mean RT and WP Variability

		Mean RT			ISD		
Goodness-of-fit		**Step 1**	**Step 2**	**Step 3**	**Step 1**	**Step 2**	**Step 3**
Chi-squared		58.59	74.04	58.59	65.85	77.71	65.85
p value		.023	.004	.023	.005	.002	.005
CMIN/DF		1.50	1.65	1.50	1.69	1.73	1.69
CFI		.98	.98	.98	.96	.95	.96
NFI		.95	.94	.95	.90	.88	.90
RMSEA		.04	.05	.04	.05	.05	.05
Path Coefficients							
Psychomotor	<--Age	.45 **		-.24 **	.41 **		-.19
Executive Function	<--Age	.68 **	.65 **	.68 **	.56 **	.54 **	.56 **
Visual Search	<--Age	.53 **		-.03	.34 **		.06
Recognition	<--Age	.55 **		.08	.39 **		.03
Psychomotor	<--EF		.81 **	1.02 **		.88 **	1.06 **
Visual Search	<--EF		.79 **	.83 **		.54 **	.51 **
Recognition	<--EF		.73 **	.70 **		.57 **	.64 **

Notes: CFQ = comparitive fit index; NFI = normative fit index; RMSEA = root mean square error of approximation; CMIN/DF = chi-squared/degrees of freedom; EF = executive function

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

For WP variability, full mediation took place for the psychomotor performance, visual search and recognition domains with the paths from age all becoming non-significant (p = .08, p = .57 and p = .80 respectively). In sum then, evidence was produced that executive function mediated associations between age and the other cognitive constructs for both mean RT and to a slightly greater degree, WP variability.

Interestingly, there was no suggestion of age-related dedifferentiation for either mean RT or WP variability, as the respective models fitted the data well.. In the case of dedifferentiation, with increasing age, cognitive variables do not factor onto their respective cognitive domains but converge onto a single factor. In order to confirm the lack of dedifferentiation, an alternative single factor model was tested where all of the cognitive tasks were required to load directly onto a single factor while controlling for age (see Figure 1.10.).

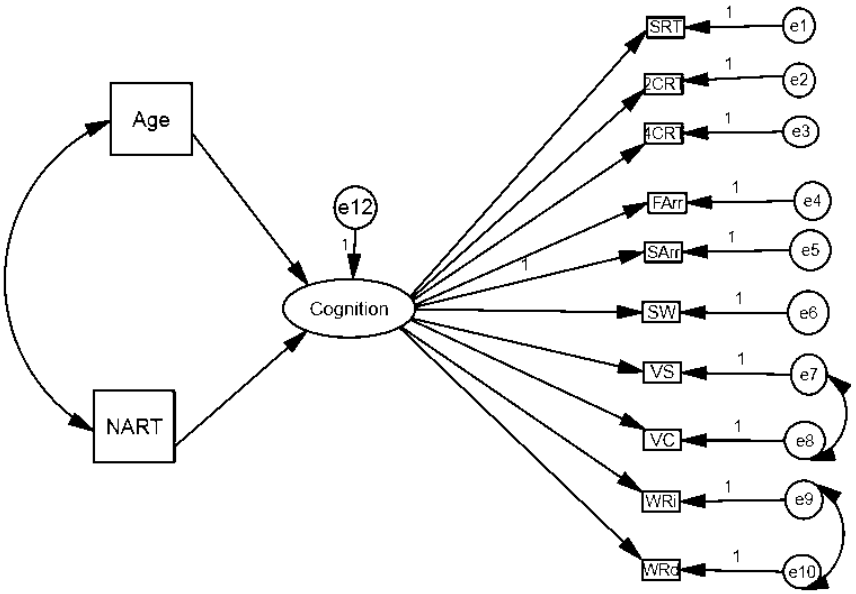

Figure 1.10. Structural Equation dedifferentiation model.

e1-e10 = error terms 1-10, PsyMot = psychomotor performance, EF = executive function, Vis = visual search, Recog = recognition, SRT = simple reaction time, 2CRT = two-choice reaction time, 4CRT = four-choice reaction time, FArr = flanker arrows, SArr = Stroop arrow, SW = Stroop word, VS = simple visual search, VC = complex visual search, WRi = immediate recognition, WRd = delayed recognition.

Even though some of the parameters were allowed to covary (see Figure 1.10.), none of the goodness-of-fit measures were within acceptable ranges. Therefore, this single factor model was rejected for both mean RT and WP variability in favour of the multi-domain model described in Figure 1.6. that provided the more parsimonious fit to the data.

Discussion

This study initially investigated the factor structure of cognition across a comprehensive battery of cognitive tasks in a cross-sectional community-dwelling population of adults aged 50-90. Of interest was whether the cognitive variables factored onto the psychomotor performance, executive function, visual search and recognition domains as hypothesised and tested using SEM. A further aim was to ascertain if executive function mediated age differences in performance in other cognitive domains. Importantly, analyses sought evidence that fluctuations in executive control was the mechanism underlying WP variability and whether this differed for mean RT. This followed from earlier research that suggests WP variability and executive function have a common underlying neurobiological mechanism (Bunce et al., 2008a; Bunce et al., 2004; Lustig et al., 2007; West et al., 2002).

Two features of the findings are of particular note. First, there was little evidence in support of the dedifferentiation hypothesis and data analyses indicated that the factor structure of cognition in this group of community-dwelling adults aged 50-90 was still distinct and had not converged onto a single factor as suggested by the dedifferentiation hypothesis. The findings are therefore contrary to evidence that dedifferentiation ubiquitously occurs in older age (Babcock et al., 1997; Baltes & Lindenberger, 1997; Dennis & Cabeza, 2011) and may suggest that dedifferentiation is more characteristic of pathological ageing (Batterham et al., 2011; Salthouse, 2012; Sims et al., 2009). These findings could be due to this sample group being very healthy as they were recruited in fitness centres due to the requirements for Study 4 that follows. The participants recruited for the other research citing evidence of dedifferentiation were healthy, community-dwelling

individuals but were not assessed for physical fitness, neither was it a requirement for participation. These were also cross-sectional studies on sample groups of 249, 687 and 24 (fMRI study) participants, whereas Salthouse (2012) conducted a longitudinal study of 3416 healthy adults with a follow-up sample group of 1490 participants and found no evidence of dedifferentiation. Batterham et al. (2011) found that amongst 687 participants, across a longitudinal study, evidence of dedifferentiation was present but disappeared once all participants with cognitive impairments were excluded from the analysis. In this present study, the lack of dedifferentiation was further confirmed by running a single factor model whereby the cognitive tasks were factored directly onto a single cognitive factor, controlling for age and NART (see Figure 1.10.). As none of the goodness-of-fit measures were within acceptable ranges, this model was rejected for both mean RT and WP variability.

The second finding of interest was that no evidence of a dissociation between the factor structures of mean RT and WP variability was obtained. The difference in association between the various cognitive domains was minimal for the respective measures. Again, this finding may be related to the healthy sample population and that there was little or no early neurobiological decline. It has been noted elsewhere (Bunce et al., 2007; MacDonald, Li, et al., 2009) that WP variability may be particularly sensitive to the subtle cognitive effects that accompany early neurobiological decline. However, there was no evidence of that here.

The further aim of this study was to examine the mechanism behind cognitive performance for both mean RT and WP variability and to see how far executive function accounted for age associations with other cognitive domains. The rationale behind these analyses was that WP variability is associated with age-related neurobiological changes in the frontal regions, and executive control is supported by these regions, so the possibility was explored that the two could be interrelated. Therefore, following the guidelines of Baron and Kenny (1986), the study set out to formally assess if executive function mediated age associations with cognition in other domains. In the first model, age was highly significantly ($p < .01$) associated with all cognitive domains (psychomotor performance, executive function, visual search and recognition) for both mean RT and WP variability (see Table 1.7., Step 1 and Figure 1.7.). The paths between age and all the cognitive

variables were highly significant for both mean RT and WP variability. This indicates that older age was associated with slower mean RT and greater WP variability across all cognitive tasks. In Model 2 of the SEM three stage process, direct paths from the exogenous variables (age and NART) to the latent constructs (psychomotor performance, executive function, visual search and recognition) were omitted and direct paths from executive function to the latent constructs were introduced (see Figure 1.8.). The important aspect of this model was that the direct path from executive function to age retained significance ($p < .01$). Also, the paths introduced between the cognitive domains (psychomotor performance, visual search and recognition) and executive function were all significant ($p < .01$) for both mean RT and WP variability. Model 3 combined both Models 1 and 2, reintroducing the direct paths between the exogenous and endogenous variables (see Figure 1.9.). The key part of this final stage of the modelling was whether the significant paths obtained in Model 1 were rendered nonsignificant having controlled for executive function. Importantly, this is exactly what happened for all the significant paths. According to Baron and Kenny (1986) this indicates that executive function was mediating the effect of age on both mean RT and WP variability in visual search and recognition and additionally, WP variability in psychomotor performance. Other existing research has indicated that older adults experience greater WP variability in psychomotor tasks (Bunce et al., 2004; MacDonald, Hultsch, & Bunce, 2006). Of interest here is that executive function mediated the effect of age for WP variability in psychomotor performance but not mean RT.

Executive function is significantly affected by ageing with increased susceptibility to fluctuations in its efficiency (Banich, 2009; Treitz, Heyder, & Daum, 2007; West et al., 2002). The present findings confirm that cognitive performance in older age is associated with the efficiency of executive control. Inhibition, an integral component of executive control, functions early in the cognitive processing preventing irrelevant information from gaining access to attentional focus (Lustig et al., 2007). Any disruption in this early process will have a detrimental effect on cognitive performance, causing both slower mean RTs and increased WP variability. This disruption is more prevalent in older age because the prefrontal cortex (PFC) is vulnerable to neurobiological decline. As the PFC supports executive control (Aron et al., 2004; Raz et al., 2005), executive functions will be

adversely affected by ageing and, therefore, cognition more broadly. In this study, it was found that executive function, as measured by the inhibitory tasks of flanker arrows, Stroop arrow and Stroop word, predicted performance in varying cognitive domains for both mean RT and WP variability. It should also be noted that the executive function to psychomotor performance path coefficient for mean RT was 1.01, $p < .01$ and the executive function to psychomotor performance path coefficient for the ISD measure was 1.05, $p < .01$. In structural equation modelling, it is acceptable that a standardised path coefficient is + > 1, which often occurs when variables share a high degree of multi-collinearity (Jöreskog, 1999; Kline, 2005). In this case, the cognitive domains of executive function and psychomotor performance correlated highly to produce coefficient pathways of + > 1. This happened in Model 3 for both mean RT and WP variability. This could be due to the nature of the tasks within each domain which may have overlapped considerably in the cognitive processes they captured. It is also suggested that coefficient pathways of + > 1 can also be due to common method variance whereby each of the cognitive variables were obtained from the same measurements (mean RT and WP variability) throughout and this may inflate multi-collinearity between variables (Johnson, Rosen, & Djurdjevic, 2011).

This study does possess some limitations that should be acknowledged. Firstly, this was a cross-sectional study and therefore causality cannot be inferred. Second, the practical constraints of the investigation meant that additional cognitive domains (e.g., linguistic reasoning, spatial abilities) could not be tested. It is possible that had additional cognitive abilities been tested, greater evidence of dedifferentiation and dissociation between mean RT and WP variability, would have been evident. In addition, although not a limitation, the population taking part may have been above average fitness as they were predominantly recruited from local gymnasiums and physical fitness facilities. Higher physical activity level and fitness are positively correlated with cognitive performance (Erickson & Kramer, 2009; Kramer & Erickson, 2007b). This will be further explored in Study 4 of this thesis. Additionally, despite these limitations, this study provides important theoretical insights into WP variability. In addition, the study reveals that executive function mediates cognition in older age for both mean RT and WP variability in the visual search and recognition domains and also WP variability in the psychomotor performance domain. To conclude, in this sample of 257

community-dwelling, healthy older adults aged 50-90 years, there was little evidence that mean RT or intraindividual variability measures of cognitive performance dedifferentiate onto a single cognitive factor. Rather, the factor structure for both measures was maintained in this population, at least for executive function, psychomotor performance, visual search and recognition. Moreover, the findings suggest that executive function plays a mediating role in associations between age and cognition. It is possible that in a different sample population with a lower level of physical fitness, a dissociation between mean RT and WP variability may have been more evident and that also, the factor structure of cognition may differed with more evidence of dedifferentiation.

Study 2 builds upon the present investigation by assessing how far mental health acts as a moderator of cognition in older age. Existing research suggests that poor mental health can have a detrimental effect on cognitive function (Bunce et al., 2008a; Elderkin-Thompson, Mintz, Haroon, Lavretsky, & Kumar, 2007; Sheline et al., 2006; Sliwinski et al., 2006). In addition, the study also investigates if executive function mediates the effects of mental health using a similar three step process to that conducted in the present study.

Study 2

Mental health and cognitive function in older adults

Introduction

It is not unusual for older people to experience occasional mild anxiety, depression or just a feeling of being mentally 'low'. This may be related generally to growing old or to specific day-to-day circumstances. Although these episodes are often not enough to debilitate or adversely affect everyday functioning in an otherwise normal, healthy population, they can have a detrimental effect on cognitive function (Bunce et al., 2008a; Bunce et al., 2008b; Elderkin-Thompson et al., 2007; Isaacowitz, Charles, & Carstensen, 2000; Salthouse, 1991; Sheline et al., 2006; Sliwinski et al., 2006). In the Main Introduction, a general background was presented discussing how mental health may affect cognitive function in older age. Here, a summary of the main points is presented, in accordance with the aim of this study.

A possible reason for poor mental health having a detrimental effect on cognitive function is that depression and anxiety are associated with a reduction in the ability to process information, resulting in both slower reaction times, increased variability and general poor overall performance (Sliwinski et al., 2009; Sliwinski et al., 2006; Stawski et al., 2006). This is because attentional resources are directed toward depression or anxiety-related thoughts rather than on the task in hand (Bunce et al., 2008b; Hartlage et al., 1993). In other words, mental resources are directed towards emotional rather than cognitive processing. Biological perspectives suggest that just as environmental stress will trigger the release of glucocorticoids (adrenal steroids secreted in response to a stressful situation, diverting energy to muscle and cardiovascular, rather than metabolic and cognitive processes), mental stress related to anxiety and depression may have a similar effect which may result in involuntary disruption of cognition (Sapolsky, 1999). As there is a high density of corticosteroid receptors in the frontal cortex, any

additional stress response caused by anxiety or depression will have an effect on these receptors and may be detrimental to executive function which is supported by frontal regions (Bunce et al., 2008b; Channon & Green, 1999; Raz & Rodrigues, 2006). Age-related neural changes in these brain areas have been shown to adversely affect executive function in a variety of ways including changes in white matter integrity (Anstey et al., 2007; Bunce et al., 2010; Bunce et al., 2007; Deary et al., 2006), deficient neuromodulation associated with increased neural noise (Li et al., 2001) and decreased regional brain volume (Elderkin-Thompson, Hellemann, Pham, & Kumar, 2009; Raz, 2000; Raz et al., 1998). These changes are likely to contribute to cognitive decline and disruption. Therefore, any additional frontal changes taking place due to poor mental health may impact upon executive processes and disrupt cognition further.

This raises the possibility that older people who are experiencing anxiety, depression or poorer mental health generally, are more at risk of increased cognitive deficits in functions supported by frontal regions, for example, executive control. With the age-related decrease in processing resources, the additional demands created by mental health problems may further reduce the capacity available for cognitive processing. This suggests that the detriment to cognitive function, especially executive function, will be substantially greater in older people.

Existing research suggests that age and poor mental health are associated with increased within-person variability (WP variability) and slower mean reaction times (mean RTs) across numerous cognitive domains (Bunce et al., 2008a). Considering the age-related neuroanatomical changes occurring in the frontal cortex, WP variability has been shown to be a sensitive measure of early neuroanatomical change and decline (Hultsch et al., 2008). For example, research has shown that greater WP variability occurs in patients with frontal lobe lesions (Stuss et al., 2003), and age-related neurobiological decline. Other research suggests that an increase in WP variability occurs in more demanding executive control tasks (Bunce et al., 2004; Hultsch et al., 2002; Nesselroade & Salthouse, 2004; West et al., 2002).

Given that WP variability is a possible indicator of early cognitive decline and that people with poor mental health are more variable in their response times, one

main focus in this study was to investigate whether measures of mean RT and WP variability dissociate. As described in the Main Introduction to this thesis, it is not clear if measures of mean RT and WP variability derived from the same cognitive task capture similar or distinct cognitive processes. One way of addressing this issue is to assess if their respective associations with age and mental health dissociate. An important aspect of this study was therefore to contrast measures of mean RT and WP variability in relation to age and mental health. In this analysis, it was of particular interest whether mental health moderated the association between age and cognitive performance. An additional aim was to examine if any associations were mediated by executive function. Therefore, the recommendations of Baron and Kenny (Baron & Kenny, 1986) guided the analyses reported below.

In order to measure mental health, this study used the General Health Questionnaire-12 (GHQ), (Goldberg, 1978). The GHQ is a self-report instrument designed to measure mental health problems and contains items which relate to both psychiatric and somatic problems. The scale possesses good psychometric properties with a previous factor structure indicating that the GHQ measures constructs relating to anxiety, depression, social dysfunction, and loss of confidence (Werneke, Goldberg, Yalcin, & Ustun, 2000). It is effective in identifying individuals who would be classified as suffering from minor psychiatric disorders (Goldberg et al., 1997).

This study set out to explore the association of age and mental health on cognitive performance by means of a two-stage analysis which assessed moderator-mediator relations. Initially, it investigated whether mental health, as measured by the GHQ score, was associated with age and cognitive function. Specifically, in an initial moderator analysis using hierarchical multiple regression, the cognitive variables were regressed onto the Age x GHQ cross-product interaction term. In effect, this procedure assessed whether the association between age and the cognitive variable varied according to the level of GHQ score (the moderator variable). If the Age x GHQ interaction achieved significance over and above the primary effects for age and GHQ, it suggests that moderation has occurred. In a second analysis using structural equation modelling, executive function was controlled to see if any significant Age x GHQ interactions in the initial analysis

were attenuated or became non-significant. If such a finding was produced, it suggests that the association of age and mental health in respect to cognition is mediated by executive function. The cognitive domains examined included psychomotor performance, executive function, visual search and recognition. The decision to run both hierarchical regression analyses and structural equation modelling builds upon the work by Bunce and colleagues (2008a; 2008b) who used both of these procedures in separate studies investigating mental health, cognition and ageing. Additionally, the present study contrasted the pattern of results for mean RT and WP variability. Importantly, by focusing on an age range of 50 to 90 years, the study provides valuable insights into age, mental health and cognitive relations in this older age group.

Method, Data Analysis and Procedure

See Study 1 for these sections.

Measurement

Mental health

As noted earlier, the 12-item version of the General Health Questionnaire (GHQ) was used to measure general mental health (Goldberg, 1978), see Appendix IX for a copy of the GHQ questionnaire used. The GHQ assesses different aspects of mental health (e.g., Have you recently ... "been able to enjoy your normal day-to-day activities?", "been able to face up to your problems", "been feeling unhappy and depressed?"). The participant is required to answer by selecting a score that reflects how they have been feeling over the previous few weeks. The Likert method of scoring was used, in which each item was scored '0' (not at all) to '3' (much more than usual). The scale mean is reported here in which higher scores indicate poorer mental health. A Cronbach alpha of .87 suggested that internal consistency was good for this scale.

Results

Bivariate correlations, together with means and standard deviations for both the GHQ and the cognitive variables, are presented in Table 2.1. The correlations between age and the cognitive variables have already been described in Study 1. Here, the focus is on the correlations between the GHQ, age and the cognitive variables and are highlighted in bold in the table. In addition to the initial bivariate correlation analysis, a series of hierarchical regression models were used to provisionally explore the relationship between age, mental health, and the individual cognitive variables, using both mean RT and the WP variability measure as dependent variables. WP variability was measured by calculating the intraindividual standard deviation (ISD), as described in the Method section of Study 1. Additionally, structural equation modelling was used to further explore the extent to which executive function mediated the association between mental health and age in respect to cognitive performance. This was achieved by investigating the relationship between age and the latent constructs formed by the cognitive domains of psychomotor performance, executive function, visual search and recognition for both mean RT and WP variability.

Consideration of Table 2.1. indicates that correlations between GHQ scores and the cognitive variables were predominantly non-significant with the only exception being the correlation between GHQ score and WP variability in the simple reaction time (SRT) task (0.14, $p < .05$). This indicates that higher GHQ (poorer mental health) scores were associated with greater WP variability in the SRT task. A series of hierarchical multiple regression models were then used to explore the relationship between age, mental health (GHQ) and the cognitive variables. A mean score of 0.82, $SD = 0.36$ was obtained across all participants for the GHQ. This was comparable to Bunce et al. (2008), $M = 0.93$, $SD = 0.49$, with a higher level of good mental health recorded here.

Table 2.1. Bivariate Correlations Between Biographical, GHQ and Cognitive Variables

	Variable	*M (SD)*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	Age	63.60 (7.89)	—																							
2	Gender-women	154 (*n* = 257)	-.18 **	—																						
3	NART	120.33 (7.39)	-.04	-.12	—																					
4	**GHQ**	**0.82 (0.36)**	**-.05**	**.04**	**.09**	**—**																				
5	SRT (ms)	309.61 (75.05)	.35 **	.05	-.19 **	**.06**	—																			
6	SRT isd	6.87 (3.37)	.21 **	.03	-.16 **	**.14 ***	.72 **	—																		
7	2-CRT (ms)	363.82 (77.49)	.34 **	-.13 *	-.08	**-.03**	.55 **	.38 **	—																	
8	2-CRT isd	6.71 (3.00)	.28 **	-.04	-.07	**.04**	.35 **	.36 **	.51 **	—																
9	4-CRT (ms)	553.35 (116.63)	.41 **	-.22 **	-.16 *	**-.01**	.48 **	.34 **	.67 **	.43 **	—															
10	4-CRT isd	7.02 (2.81)	.29 **	-.10	-.17 **	**.10**	.30 **	.25 **	.41 **	.40 **	.73 **	—														
11	Flanker Arrow (ms)	685.28 (204.41)	.46 **	.07	-.20 **	**.05**	.52 **	.31 **	.41 **	.38 **	.51 **	.45 **	—													
12	Flanker Arrow isd	6.34 (6.06)	.35 **	.06	-.18 **	**.09**	.44 **	.28 **	.28 **	.34 **	.40 **	.44 **	.92 **	—												
13	Stroop Arrow (ms)	766.01 (117.41)	.52 **	-.03	-.23 **	**-.04**	.48 **	.34 **	.56 **	.45 **	.65 **	.50 **	.55 **	.44 **	—											
14	Stroop Arrow isd	7.97 (3.20)	.28 **	.06	-.29 **	**-.01**	.36 **	.31 **	.40 **	.36 **	.49 **	.47 **	.40 **	.35 **	.76 **	—										
15	Stroop Word (ms)	1079.39 (263.69)	.52 **	-.12	-.06	**-.03**	.38 **	.26 **	.36 **	.32 **	.48 **	.40 **	.49 **	.43 **	.54 **	.37 **	—									
16	Stroop Word isd	8.19 (4.52)	.43 **	-.06	-.08	**.03**	.30 **	.23 **	.26 **	.29 **	.36 **	.35 **	.45 **	.43 **	.43 **	.35 **	.85 **	—								
17	Visual Search S. (ms)	827.18 (230.35)	.49 **	-.22 **	-.10	**.02**	.30 **	.22 **	.31 **	.27 **	.43 **	.31 **	.49 **	.42 **	.52 **	.35 **	.55 **	.43 **	—							
18	Visual Search S. isd	6.73 (4.54)	.31 **	-.16 *	-.08	**.05**	.14 *	.10	.11	.14 *	.28 **	.23 **	.28 **	.23 **	.35 **	.29 **	.39 **	.31 **	.88 **	—						
19	Visual Search C. (ms)	1998.14 (671.32)	.30 **	-.13 *	-.09	**-.01**	.20 **	.11	.21 **	.10	.30 **	.18 **	.29 **	.21 **	.38 **	.30 **	.49 **	.43 **	.55 **	.48 **	—					
20	Visual Search C. isd	7.09 (3.41)	.18 **	-.07	-.04	**.01**	.08	.00	.09	.00	.22 **	.14 *	.17 **	.12	.27 **	.25 **	.34 **	.32 **	.49 **	.51 **	.89 **	—				
21	Recognition Imm. (ms)	1149.50 (297.41)	.39 **	-.04	-.03	**.09**	.26 **	.19 **	.33 **	.27 **	.34 **	.30 **	.43 **	.37 **	.40 **	.31 **	.43 **	.34 **	.42 **	.31 **	.34 **	.25 **	—			
22	Recognition Imm. isd	8.34 (5.00)	.22 **	.02	.03	**.08**	.17 **	.12 *	.15 *	.22 **	.17 **	.16 *	.29 **	.30 **	.20 **	.16 *	.27 **	.23 **	.31 **	.24 **	.27 **	.24 **	.82 **	—		
23	Recognition Del. (ms)	1086.76 (279.67)	.42 **	-.01	-.03	**-.05**	.23 **	.08	.27 **	.29 **	.28 **	.22 **	.27 **	.20 **	.38 **	.27 **	.38 **	.34 **	.33 **	.21 **	.26 **	.21 **	.51 **	.39 **	—	
24	Recognition Del. isd	7.97 (4.54)	.24 **	.05	.02	**-.02**	.09	.00	.14 *	.21 **	.13 *	.19 **	.18 **	.18 **	.21 **	.15 *	.23 **	.24 **	.18 **	.13 *	.14 *	.16 *	.33 **	.32 **	.81 **	—

Notes: NART = National Adult Reading Test; (ms) = milliseconds for mean reaction time; isd = intraindividual standard deviation; GHQ = 12 item General Health Questionnaire; SRT = simple reaction time; 2-CRT or 4-CRT = two or four-choice reactior Recognition Imm. or Del. = recognition immediate or delayed.
*p < .05; **p < .01

As National Adult Reading Test (NART) scores were significantly associated with both the mean RT and WP variability of the 4-CRT, flanker arrows and Stroop arrow tasks, this variable was controlled for at Step 1 of all of the regression models. By controlling for NART (adjusted IQ score), the possibility that age differences in IQ confound with age differences in performance on the cognitive tasks is addressed. At Step 2, the primary effects for chronological age and GHQ scores were entered. At Step 3, the Age x GHQ cross-product interaction term was entered. Importantly, if Step 3 added significantly to the variance (R^2) explained in the cognitive variable after taking age and GHQ score into account, then it would suggest that the strength of the association between age and cognitive performance varied according to GHQ score. The results of the hierarchical regression models are presented in Table 2.2. All predictor variables were centred and resulting *z* scores used throughout the analyses (see Study 1 for additional information on centring). Consideration of the beta weights obtained at Step 2 suggests that having controlled for NART scores, the associations between age and GHQ scores and the cognitive variables corresponded to the results obtained in the bivariate correlations reported in Table 2.1. Age and GHQ scores varied in their contribution to the shared variance with the outcome variables, with between 9% and 27% for mean RT and between 3% and 18% for WP variability. Of particular interest, however, was whether entry of the Age x GHQ cross-product interaction term added to the variance explained in the various cognitive measures.

As can be seen in Table 2.2., for the majority of measures, the entry of this term did not add significantly to the variance.

Table 2.2. Hierarchical Regression Analysis: Cognitive Variables Regressed on Age, GHQ, and the Age x GHQ Cross-Product Interaction Term for Mean Reaction Time and Intraindividual Standard Deviation (ISD)

	SRT		2-CRT		4-CRT		Flanker Arrow		Stroop Arrow		Stroop Word		Visual Search S.		Visual Search C.		Recognition Imm.		Recognition Del.	
	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2
mean RT																				
Step 1:																				
NART	-.18 **	.04 **	-.07	.01	-.14 *	.02 *	-.19 **	.04 **	-.21 **	.05 **	-.04	.00	-.08	.01	-.08	.01	-.02	.00	-.01	.00
Step 2:																				
Age	.36 **		.34 **		.42 **		.45 **		.52 **		.53 **		.47 **		.29 **		.37 **		.42 **	
GHQ	.08	.12 **	-.02	.11 **	.01	.16 **	.10	.21 **	.00	.27 **	.00	.27 **	.06	.24 **	.02	.09 **	.13 *	.16 **	-.02	.18 **
Step 3:																				
Age x GHQ	-.11	.01	-.09	.01	-.08	.01	.06	.00	-.03	.00	-.01	.00	.09	.01	.02	.00	.13 *	.02 *	.02	.00
ISD																				
Step 1:																				
NART	-.17 **	.03 **	-.06	.01	-.17 **	.03 **	-.18 **	.03 **	-.28 **	.08 **	-.07	.01	-.08	.01	-.04	.00	.03	.00	.03	.00
Step 2:																				
Age	.23 **		.29 **		.29 **		.35 **		.27 **		.42 **		.29 **		.17 **		.21 **		.23 **	
GHQ	.15 *	.07 **	.06	.08 **	.12 *	.10 **	.14 *	.14 **	.03	.07 **	.06	.18 **	.10	.10 **	.03	.03 *	.11	.06 **	.00	.06 **
Step 3:																				
Age x GHQ	-.16 **	.02 **	-.06	.00	-.02	.00	.07	.01	.01	.00	.03	.00	.14 *	.02 *	.04	.00	.15 *	.02 *	.06	.00

Notes: NART = National Adult Reading Test; GHQ = 12 item General Health Questionnaire; SRT = simple reaction time; 2-CRT or 4-CRT = two or four-choice reaction time; Visual Search S. or C. = visual search simple or complex; | Recognition Imm. or Del. = recognition immediate or delayed.
Step 1, $df = 1, 255$; Step 2, $df = 2, 253$; Step 3, $df = 1, 252$.
*$p < .05$; **$p < .01$

However, for mean RT, the Age x GHQ interaction for immediate recognition task was significant ($\Delta R^2 = .02$, $p < .05$) and for WP variability in the SRT, simple visual search and immediate recognition tasks, the interaction terms were significant (SRT, $\Delta R^2 = .02$, $p < .01$, simple visual search, $\Delta R^2 = .02$, $p < .05$ and immediate recognition, $\Delta R^2 = .02$, $p < .05$). The regression lines for the significant interaction terms are presented in Figures 2.1. to 2.4. These graphs were constructed using a median split on age and GHQ mean score (Age median = 63, $M = 63.60$, $SD = 7.89$; GHQ score median = 0.75, $M = 0.82$, $SD = 0.36$). For mean RT in immediate recognition, for low GHQ, greater age was not associated with increased mean RT. However, for higher GHQ (poorer mental health), mean RT increased with age. In other words, poorer mental health GHQ had a greater negative impact on mean RT in older age. For the significant interaction terms for WP variability in simple visual search and immediate recognition, a similar trend was apparent with poorer mental health (high GHQ) having a greater impact on WP variability (increased) in older age. However, for WP variability in SRT, people with lower GHQ scores become more variable with age, so that although a high GHQ score was associated with greater WP variability in younger old age, there is diminishing return towards older old age. In older age, a high GHQ score had no greater impact than a low GHQ on WP variability in the SRT task.

Figure 2.1. The significant Age x GHQ interaction in respect to mean RT in immediate recognition (GHQ = General Health Questionnaire, High GHQ = poorer mental health).

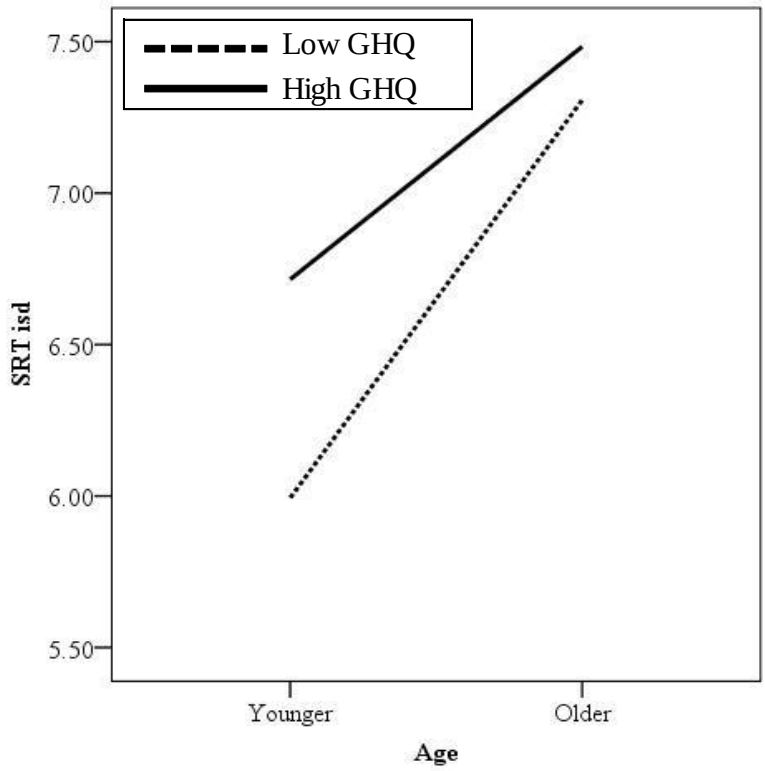

Figure 2.2. The significant Age x GHQ interaction in respect to WP variability in SRT (GHQ = General Health Questionnaire, High GHQ = poorer mental health).

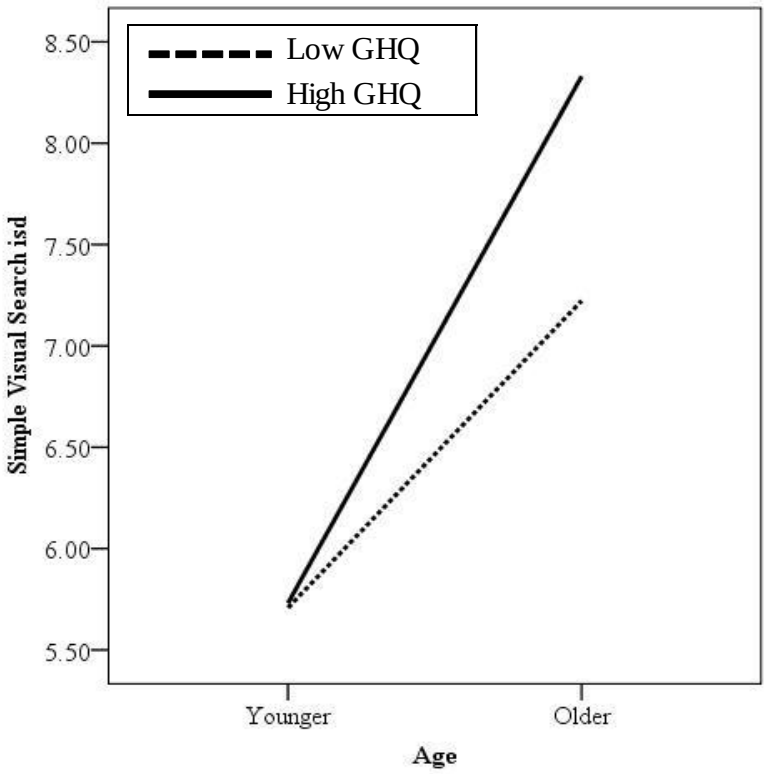

Figure 2.3. The significant Age x GHQ interaction in respect to WP variability in simple visual search (GHQ = General Health Questionnaire, High GHQ = poorer mental health).

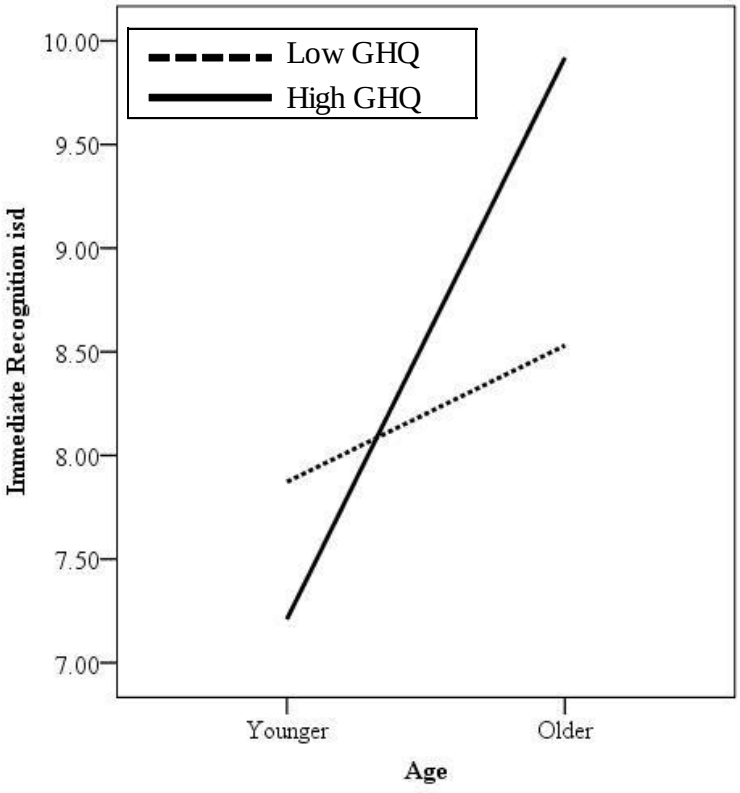

Figure 2.4. The significant Age x GHQ interaction in respect to WP variability in immediate recognition (GHQ = General Health Questionnaire, High GHQ = poorer mental health).

This was of particular interest given that there was a dissociation between mean RT and WP variability, indicated by more significant interactions for the ISD measures than for mean RT measures. These additional exploratory analyses stemmed from the theoretical rationale that WP variability reflects fluctuations in executive control. Therefore, a further series of hierarchical regression models were run for the four significant interactions, namely WP variability in SRT, simple visual search and immediate recognition, and mean RT in SRT. Here, the hierarchical regression analysis also controlled for a composite measure of executive function combining the flanker arrows, Stroop arrow and Stroop word data for both congruent and incongruent conditions for respective mean RT or WP variability analyses. These composite measures were obtained from principal component analysis where a single factor was requested and the factor scores saved. The resulting composite measure of executive function was entered into repeat regression analyses at Step 1 to ascertain if the effect sizes of the significant interactions obtained in the original equations were attenuated. Such attenuation of the shared variance associated with the significant Age x GHQ interaction terms would indicate that executive function mediated associations between age, GHQ and cognition. However, the results from these analyses did not indicate that executive function mediated any of the significant Age x GHQ interaction terms, with only marginal changes found in R^2. This suggests that although the GHQ moderates the association between age and mean RT for immediate recognition, and WP variability in SRT, simple visual search and immediate recognition, executive function was not the mechanism mediating GHQ those associations.

Structural equation modelling (SEM) was used to further explore how far interactions between age and mental health were mediated by executive function. Hierarchical regression analysis is able to explain how well variables are able to predict an outcome and whether a predictor variable is still able to predict this outcome when the effects of another variable are controlled for. Structural equation modelling (SEM), however, is a more sophisticated approach that allows simultaneous analyses of multiple variables and constructs (Schumacker & Lomax, 2004). Additional information regarding SEM is outlined in Study 1. Here, age, NART, GHQ and Age x GHQ formed the exogenous variables, and psychomotor performance, executive function, visual search and recognition served as the endogenous variables. The aims of the structural equation models were two-fold.

First, to investigate whether WP variability and mean RT varied as a function of age and mental health (GHQ), and second to investigate if executive function mediated the Age x GHQ interactions. For this reason, a three-step model process (see below) was used that followed the recommendations of Baron and Kenny (Baron & Kenny, 1986). Various established goodness-of-fit measures were used to evaluate the models, as previously discussed in Study 1.

In Model 1, NART, age, GHQ score and the Age x GHQ cross-product interaction term formed the exogenous variables whilst psychomotor performance, executive function, visual search, and recognition latent constructs formed the endogenous variables (see Figure 2.5.). The important aspect of this model was whether the Age x GHQ interaction paths attained significance after the primary effects of intelligence (NART score), age and the GHQ score had been taken into account. This procedure controls for the possibility that age differences in IQ may underlie differences in the cognitive variables and therefore act as a confounder. In Model 2, all of the paths from the exogenous to the endogenous variables were eliminated except for those to executive function. Additional paths were introduced, however, from executive function to the endogenous variables of psychomotor performance, visual search and recognition (see Figure 2.6.). The focus of interest in this model was whether the Age x GHQ path to executive function was significant and whether the paths between executive function and the endogenous variables became significant. Finally, Model 3 combined Models 1 and 2, but with the additional direct paths from executive function to the latent variables of psychomotor performance, visual search and recognition (see Figure 2.7.). The aim of this step was to see if any of the significant Age x GHQ paths identified in Model 1 became non-significant after executive function was taken into account. Following Baron & Kenny (1986), this final model formally confirms whether executive function mediates the association between exogenous and endogenous variables in the earlier models. The goodness-of-fit statistics and standardized path coefficients for WP variability and mean RT for the three models are presented in Table 2.3. The advantage of using both mean RT and WP variability is discussed both previously, and in the Main Introduction, where the theoretical background of these measures is presented.

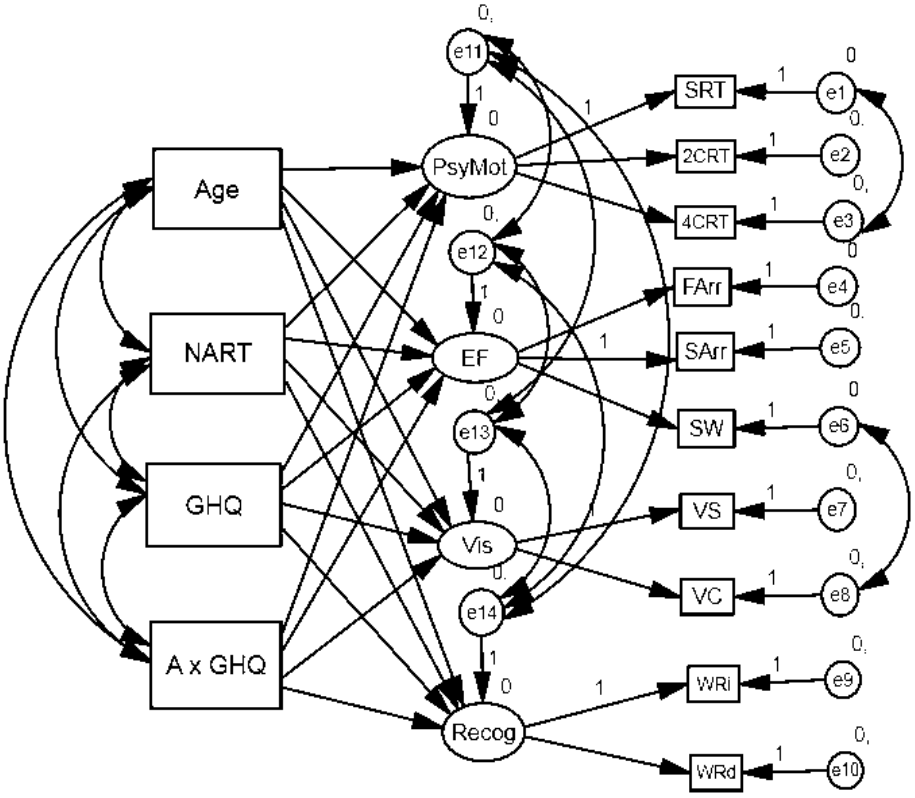

Figure 2.5. Structural Equation Model 1, for Age, GHQ, Age x GHQ interaction terms, and Cognitive Variables.

e1-e14 = error terms 1-14, PsyMot = psychomotor performance, EF = executive function, Vis = visual search, Recog = recognition, SRT = simple reaction time, 2CRT = two-choice reaction time, 4CRT = four-choice reaction time, FArr = flanker arrows, SArr = Stroop arrow, SW = Stroop word, VS = simple visual search, VC = complex visual search, WRi = immediate recognition, WRd = delayed recognition, GHQ = General Health Questionnaire-12, A x GHQ = age x General Health Questionnaire-12 interaction term, NART = National Adult Reading Test.

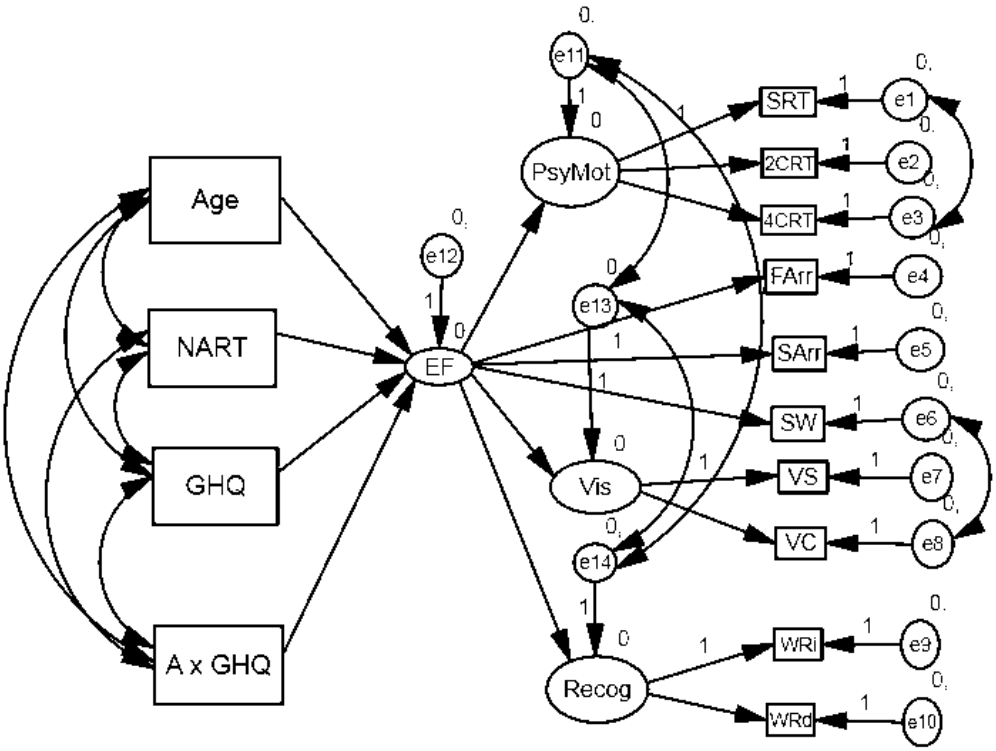

Figure 2.6. Structural Equation Model 2, for Age, GHQ, Age x GHQ interaction terms, and Cognitive Variables.

e1-e14 = error terms 1-14, PsyMot = psychomotor performance, EF = executive function, Vis = visual search, Recog = recognition, SRT = simple reaction time, 2CRT = two-choice reaction time, 4CRT = four-choice reaction time, FArr = flanker arrows, SArr = Stroop arrow, SW = Stroop word, VS = simple visual search, VC = complex visual search, WRi = immediate recognition, WRd = delayed recognition, GHQ = General Health Questionnaire-12, A x GHQ = age x General Health Questionnaire-12 interaction term, NART = National Adult Reading Test.

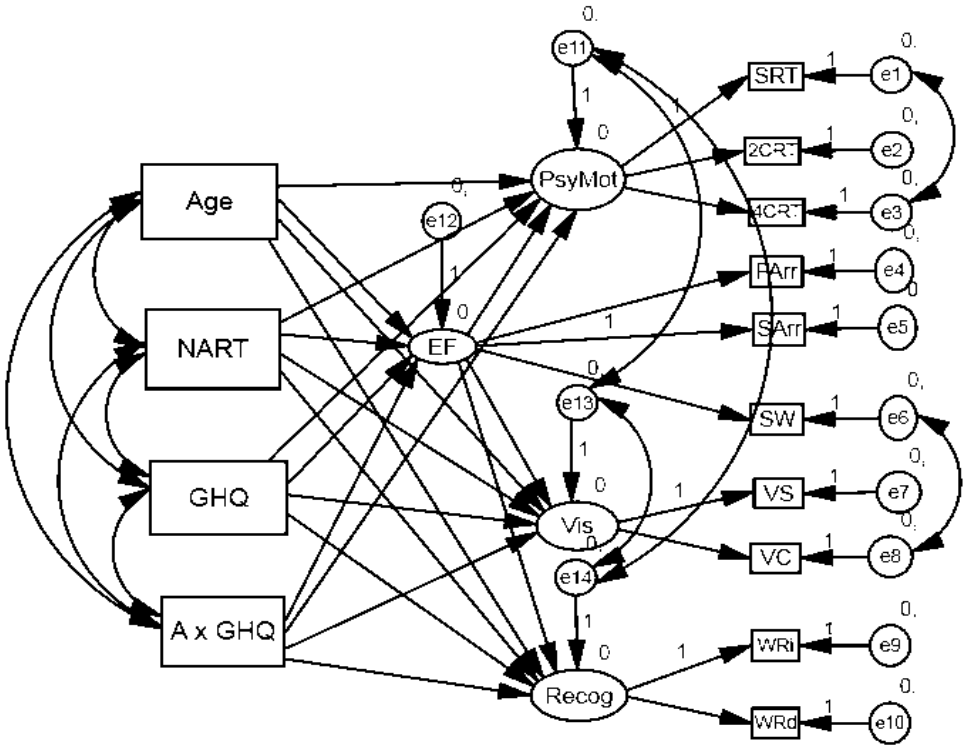

Figure 2.7. Structural Equation Model 3, for Age, GHQ, Age x GHQ interaction terms, and Cognitive Variables.

e1-e14 = error terms 1-14, PsyMot = psychomotor performance, EF = executive function, Vis = visual search, Recog = recognition, SRT = simple reaction time, 2CRT = two-choice reaction time, 4CRT = four-choice reaction time, FArr = flanker arrows, SArr = Stroop arrow, SW = Stroop word, VS = simple visual search, VC = complex visual search, WRi = immediate recognition, WRd = delayed recognition, GHQ = General Health Questionnaire-12, A x GHQ = age x General Health Questionnaire-12 interaction term, NART = National Adult Reading Test.

In Model 1, although chi-square for both mean RT and WP Variability was significant (X^2 = 73.46, p < .05 and X^2 = 78.78, p < .01, respectively), the other goodness-of-fit statistics suggested acceptable fit (mean RT: X^2/df = 1.44, CFI = .98, NFI = .94, RMSEA = .04, WP variability, X^2/df = 1.55, CFI = .96, NFI = .89, RMSEA = .05). Considering Table 2.3., it can be seen that older age is significantly (p < .01) associated with greater WP variability and slower mean RT with all paths to the latent variables (psychomotor performance, executive function, visual search and recognition) significant, as was established in Study 1. The important outcomes of this model were the significant coefficient pathways between visual search and the Age x GHQ interaction (p < .05), and recognition and the Age x GHQ interaction (p < .05) for WP variability (ISDs). This suggests that older age and higher GHQ scores (poorer mental health) were associated with greater variability in both visual search and recognition. It is of note that for mean RT, although in the hierarchical regression analysis there was a significant Age x GHQ interaction for immediate recognition, it was not repeated in Model 1 of this structural equation model procedure having simultaneously taken the other variables into account. As the main objective of this part of the analyses was to establish whether significant Age x GHQ interactions were mediated by executive function, mean RT was not considered further with this procedure.

In Model 2 for WP variability, paths were directed to and from executive function to see whether it was the possible mechanism by which the Age x GHQ interaction influenced WP variability in visual search and recognition. If executive function was the mechanism, it would be expected that the paths between these latent variables and executive function would be significant. Age and executive function were positively associated (p < .01), as they were in Step 1.

Table 2.3. Goodness-of-Fit Measures and Standardized Regression Weights for Mental Health (GHQ) For both Mean RT and WP Variability

		Mean RT	ISD		
Goodness-of-fit		**Step 1**	**Step 1**	**Step 2**	**Step 3**
Chi-squared		73.46	78.78	107.61	78.78
p value		.021	.008	.000	.008
CMIN/DF		1.44	1.55	1.71	1.55
CFI		.98	.96	.93	.96
NFI		.94	.89	.85	.89
RMSEA		.04	.05	.05	.05
Path Coefficients					
Psychomotor	<--Age	.47 **	.43 **		-.16
Executive Function	<--Age	.68 **	.56 **	.54 **	.56 **
Visual Search	<--Age	.52 **	.32 **		.06
Recognition	<--Age	.53 **	.36 **		.02
Psychomotor	<--GHQ	.04	.18 *		.04
Executive Function	<--GHQ	.04	.13	.17 **	.13
Visual Search	<--GHQ	.06	.10		.04
Recognition	<--GHQ	.10	.12		.04
Psychomotor	<--Age X GHQ	-.11	-.11		-.18 **
Executive Function	<--Age X GHQ	.00	.07	.04	.07
Visual Search	<--Age X GHQ	.09	.15 *		.12
Recognition	<--Age X GHQ	.12	.20 *		.16
Psychomotor	<--EF			.88 **	1.05 **
Visual Search	<--EF			.54 **	.47 **
Recognition	<--EF			.57 **	.61 **

Notes: CFI = comparitive fit index; NFI = normative fit index; RMSEA = root mean square error of approximation; CMIN/DF = chi-squared/degrees of freedom; GHQ = General Health Questionnaire-12.
*$p < .05$; **$p < .01$

Executive function and the cognitive domains, psychomotor performance, visual search and recognition were also positively associated ($p < .01$). This indicates co-variation between WP variability in executive function, and WP variability in other cognitive domains. The path between executive function and GHQ also attained significance ($p < .01$) suggesting that mental health was associated with variability in executive functioning. Importantly though, the Age x GHQ path to executive function was non-significant ($p = .54$) which does not completely fulfil the criteria for mediation, according to Baron and Kenny (1986). This indicated that WP variability in executive function was not the mechanism by which the Age x GHQ association influenced WP variability in visual search and recognition.

To test this further, Model 3 combined both Models 1 and 2 with additional direct paths drawn from executive function to psychomotor performance, visual search and recognition. If executive function was accounting for the Age x GHQ interaction

with visual search and recognition for WP variability, then the regression paths should become non-significant. Importantly, consideration of Step 3 in Table 2.3. indicates the Age x GHQ to visual search path and the Age x GHQ to recognition paths became non-significant (p = .07 and p = .05 respectively). This suggests that executive function attenuated the Age x GHQ effects for both visual search and recognition, even though the criteria for full mediation according to Baron and Kenny (1986) had not been met. The significant GHQ to psychomotor performance path from Model 1 also became non-significant (p = .53), indicating that executive function was fulfilling a mediation role in the effect of mental health and age on psychomotor performance.

Discussion

This study investigated the association between mental health and cognition in older adults, in relation to both mean RT and WP variability across a comprehensive battery of cognitive tasks. The aim of the study was to extend existing research (Bunce et al., 2008a; 2008b) that investigated age, mental health and WP variability in cross-sectional community-dwelling adults aged 18-90. This study similarly used a cross-sectional design but focused on the older age ranges of 50 to 90 years. An important aspect of the study was to understand how mental health interacted with cognition in older age and to see whether this interaction was mediated by executive function. The main findings of this study indicated that there were significant Mental health x Cognitive interactions for both mean RT and WP variability, but that these interactions were not directly mediated by executive function. An additional finding was that mean RT and WP variability dissociated for both the moderation and mediation of age, mental health and cognition, suggesting that WP variability may capture a different aspect of cognitive performance relative to mean RT. This will be discussed further in light of the findings of this study.

Considering the evidence that mild mental health problems are associated with slower mean RTs and greater WP variability in old age, an objective of this study was to build on the previous work of Bunce et al. (2008a; 2008b) in the area. In

addition, this study was based on the evidence that greater WP variability may be an early marker of neurobiological disturbance (Bunce et al., 2004; Hultsch et al., 2002; Hultsch et al., 2008; MacDonald, Hultsch, et al., 2006). The additional focus of this study was to investigate the mechanism behind the significant Age x GHQ effects using a mediator analysis (Baron and Kenny, 1986) and to consider the role of executive function as previous research implicates fluctuations in executive function as underlying WP variability. Therefore, executive function was investigated as a possible mediator in both hierarchical multiple regression analysis and structural equation modelling.

The GHQ is widely used as a screening instrument in research studies and surveys and although it is the shortest version of the questionnaire, validity coefficients have been reported as being similar to those from the longer versions of the scale (Goldberg et al., 1997; Piccinelli et al., 1993). Furthermore, participants in this study recorded GHQ scores in line with, and indeed, slightly lower (better mental health) than those participants in the study of Bunce et al. (2008a). This indicated that participants were representative of the general population and were not experiencing major mental health problems with mean and standard deviation, *M (SD)* = 0.82 (0.36) compared to Bunce et al. (2008a), 0.93 (0.49).

According to the bivariate correlation, there was only one significant association between mental health and cognition, namely the association between the GHQ score and WP variability in simple reaction time (SRT, $p < .05$), see Table 2.1. There were no significant associations between GHQ score and mean RT of any of the cognitive variables, suggesting an initial weak dissociation between the two measures. This indicates that WP variability in SRT was sensitive to mental health effects, with higher WP variability associated with poorer mental health. The hierarchical regression analyses for both mean RT and WP variability yielded several significant Age x GHQ interactions. For mean RT, the interaction in respect to immediate recognition suggested that poorer mental health was associated with slower responding in older adults (see Figure 2.1.). For WP variability, significant Age x GHQ interactions were found for SRT, simple visual search and immediate recognition. Of interest here also was the dissociation between mean RT and WP variability, indicating a difference in how the respective measures captured associations between age, mental health and cognition. The dissociation suggests

that WP variability may be more sensitive than mean RT to the subtle effects of mild mental health problems on cognition in older age, a finding that is consistent with existing research (Bunce et al., 2008a; Bunce et al., 2008b). The Age x GHQ interaction for WP variability in SRT ($p < .01$), notably, was different to the other interactions. This interaction indicated that a higher GHQ score was associated with increased WP variability in the SRT task. However, this was primarily apparent for younger persons and thereafter with increasing age this effect diminished such that there was only a minimal difference between high and low GHQ (see Figure 2.2.). One reason for this occurring in SRT could be that WP variability increases with task demands and cognitively demanding tasks are associated with higher WP variability scores (Bielak, Hultsch, Strauss, MacDonald, & Hunter, 2010; Bunce et al., 2008a). As SRT is a simple psychomotor performance task, it is possible that the task demands were not sufficiently great to produce the expected finding. For simple visual search and immediate recognition (both more demanding tasks), higher GHQ scores (poorer mental health) were significantly associated with greater WP variability ($p < .05$), see Figures 2.3. and 2.4. It has been suggested that an increase in WP variability could also be related to a greater proportion of slower responses occurring in the slow end (tail) of an individual's mean RT distribution. Such intermittent slow responding may represent fluctuations in executive control associated with the older age (Bunce et al., 2004; West et al., 2002).

Considering the initial results of the hierarchical regression and the dissociation between mean RT and WP variability, it is possible that poorer mental health in older individuals contributes to an increase in momentary fluctuations in information processing which manifests in measures of WP variability, but not mean RT. Moreover, the findings suggest that WP variability, measured in the form of intraindividual standard deviations (ISDs), is more sensitive to subtle mental-health effects, and is consistent with work elsewhere (Bunce et al., 2008b). Another possible age-related mechanism contributing to the dissociation is impaired neural connectivity which arises from neurotransmitter deficiencies and compromised white matter tracts, and is exacerbated by poor mental health in older age (Harrison, 2002). Although white matter lesioning and evidence of neurobiological disturbance is outside the scope of this study, increased WP variability is an indicator for these disturbances and could be considered as a

possible contributing factor in older age WP variability (Bunce et al., 2007). One way to explore the dissociation between mean RT and WP variability in cognitive performance, whilst considering mental health as a potential moderator, is to investigate if executive function mediates the significant interactions between age, mental health, and cognition.

The second aim of this study was to examine the mechanism behind the Age x Mental health interaction in respect to cognition and to examine how far how executive function explained these interactions. The rationale behind these analyses was that WP variability is associated with age-related neurobiological changes in the frontal regions of the brain which support executive control. In order to explore this, structural equation modelling was used. If the previously significant Age x GHQ interactions became non-significant having controlled for executive control, it would indicate that executive function was mediating the association. Following initial exploratory analyses involving hierarchical multiple regression, structural equation models were run following the theoretical guidelines of Baron and Kenny (1986) to formally assess if executive function accounted for any significant interaction effects of Age x GHQ. In the first model (see Figure 2.5.), significant interactions of Age x GHQ for WP variability in visual search and recognition were identified. For mean RT, none of the interactions were significant. Also, for WP variability, the path between GHQ and psychomotor performance was significant ($p < .05$), indicating that poorer mental health was associated with greater WP variability. The paths from age to the latent constructs psychomotor performance, executive function, visual search and recognition were all highly significant ($p < .01$) for both mean RT and WP variability, as was established in Study 1.

As Model 1 of the SEMs for mean RT did not yield any significant Age x GHQ interactions, no further analyses were undertaken for this variable. For WP variability, In Model 2 of the SEM three stage process, direct paths from the exogenous variables (Age, NART, GHQ, Age x GHQ) to the latent constructs (psychomotor performance, executive function, visual search and recognition) were omitted and direct paths from executive function to the latent constructs were introduced (see Figure 2.6.). The important aspect of this model was that the path from executive function to GHQ (mental health) was significant ($p < .01$),

indicating a significant association between executive function and mental health. Paths from executive function to psychomotor performance, visual search and recognition were also highly significant (all *ps* < .01), suggesting that WP variability in executive control was positively associated with WP variability in the psychomotor performance, visual search and recognition domains. Importantly though, the executive function to Age x GHQ interaction path failed to achieve significance. Thus, one of the prerequisites for mediation according to Baron and Kenny (1986) was not fulfilled. Model 3 combined both Models 1 and 2, reintroducing the direct paths between the exogenous and endogenous variables (see Figure 2.7.). Additionally, the coefficient paths between executive function and psychomotor performance, visual search and recognition latent variables were retained. The key part of this final stage of the modelling was whether the significant Age x GHQ interactions obtained in Model 1 were rendered nonsignificant having controlled for executive function. For both visual search and recognition, the originally significant paths did indeed became nonsignificant. This finding is consistent with the view that executive function was mediating the Age x Mental health associations with visual search and recognition. However, following the recommendations of Baron and Kenny (1986), this conclusion is limited as the requirements for full mediation were not met as the Age x GHQ path to executive control in Model 2 failed to achieve statistical significance. Therefore, these results were in partial agreement with research which has shown that executive function plays a significant role in mental health-related cognitive deficits in older age (Bunce et al., 2008b; Elderkin-Thompson et al., 2007; Sheline et al., 2006; Sheline et al., 2009).

Deficits in cognition in older age have also been associated with attentional lapses, and neuroimaging research has found that poor mental health also leads to an inability to suppress attentional lapses, causing an inward focus of attention towards the emotional state of the individual rather than on the task in-hand (Sheline et al., 2009). This, in turn, is also related to the suggestion that attentional lapses have been described as fluctuations in executive control and could also be the mechanism underlying WP variability (Bunce et al., 2004; Bunce et al., 1993). This is a subject of investigation in a later study but is of some relevance to be mentioned here. Furthermore, it has been shown that attentional resources may be reduced in depression and that task-irrelevant thoughts related to depression

may contribute to cognitive deficits. This is particularly evident when tasks are more cognitively demanding (Hartlage et al., 1993).

This study does possess some limitations that should be acknowledged. Firstly, it was a cross-sectional study and therefore causality cannot be inferred. In addition, the population taking part may have been of above average fitness and health for this age group as they were predominantly recruited from local gymnasiums and physical fitness facilities. Higher physical activity level and fitness are correlated with a higher level of cognitive performance (Erickson & Kramer, 2009; Kramer et al., 2006), and it is also likely that more physical activity is positively associated with mental health (Benedetti, Borges, Petroski, & Goncalves, 2008; Cao et al., 2011; Holley, 2011). Had there been a higher level of psychopathology in the sample, the associations between age, mental health and cognition may have been stronger, and the mediating effect of executive function more apparent. It should also be noted that the executive function to psychomotor performance path coefficient for mean RT was 1.01, $p < .01$ and the executive function to psychomotor performance path coefficient for the ISD measure was 1.05, $p < .01$. In structural equation modelling, it is possible that a standardised path coefficient is + >1, which often occurs when variables share a high degree of multi-collinearity (Jöreskog, 1999; Kline, 2005). In this case, the cognitive domains of executive function and psychomotor performance correlated highly to produce coefficient pathways of + >1. This happened in Model 3 for both mean RT and WP variability. This could be due to the nature of the tasks within each domain which may have overlapped considerably in the cognitive processes they captured. This was discussed further in Study 1.

Despite these limitations, this study provides important theoretical insights into WP variability and how it may reveal subtle effects relative to measures of mean RT obtained from the same task. In addition, the study reveals that mental health is associated with cognitive function in older age, and evidence suggesting effects were mediated by executive control in certain cognitive domains was obtained. From a clinical point of view, the study also highlights the importance of how mental health affects cognition in older age and how psychological wellbeing may appropriately provide the focus of intervention in primary health care provision for older people.

To conclude, in this sample of 257 community-dwelling, healthy older adults aged 50-90 years, there was evidence that mental health, as measured by the GHQ, moderated the association between age and cognition. However, although the results were consistent with the view that executive control mediated this association, the full requirements for mediation were not met following the recommendations of Baron and Kenny (1986). There was also evidence of co-variation between WP variability in executive function and other cognitive domains (psychomotor performance, visual search and recognition). This was not apparent for measures of mean RT. The present findings indicate that mental health can have a subtle effect on older persons' cognitive performance, when they are otherwise in good health and active. They, therefore, extend the work of Bunce et al. (2008a, 2008b), confirming that WP variability is sensitive to subtle variation in cognition when mean RT is not. Further exploration of this concept would be of interest, using a different sample population with a lower level of physical fitness.

The present findings suggest that the theoretical insights gained about how mental health moderates the relationship between age and cognition can be applied to other moderators of cognition in older age. The following study (Study 3) investigates how the level of participation in social, mental and physical activities (lifestyle activities) can act as additional moderators of cognition in older age. Existing research suggests that regular participation in such activities or having an 'engaged lifestyle' is associated with a higher level of cognitive performance in older adults (Bielak, Anstey, Christensen, & Windsor, 2012; Fratiglioni et al., 2004; Hultsch et al., 1999; Krueger et al., 2009; Lee, Kim, & Back, 2009; Lövden, Ghisletta, & Lindenberger, 2005; Strawbridge, Cohen, Shema, & Kaplan, 1996; Wang, Karp, Winblad, & Fratiglioni, 2002). Study 3 investigates the association between participation in lifestyle activities, as measured by the Victoria Longitudinal Study Lifestyle Questionnaire (Hultsch et al., 1999) and cognition in older age through the same moderation and mediation process that has been conducted in this study.

Study 3

Lifestyle activities and cognition in later life

Introduction

There is evidence suggesting that an active, socially integrated and intellectually challenging lifestyle may slow cognitive decline, delay the early onset of dementia and even mortality, in older adults (Bassuk, Glass, & Berkman, 1999; Bielak et al., 2007; Fabrigoule et al., 1995; Fratiglioni et al., 2004; Hultsch et al., 1999; Karp et al., 2006; Lövden et al., 2005; Newson & Kemps, 2005; Scarmeas, Levy, Tang, Manly, & Stern, 2001; Schooler & Mulatu, 2001; Seeman, Lusignolo, Albert, & Berkman, 2001; Small, Dixon, McArdle, & Grimm, 2012; Thomas, 2011, 2012; Wang et al., 2002; Wang et al., 2006; Weuve et al., 2004; Wilson, Barnes, & Bennett, 2003; Wilson et al., 2002). However, research also suggests that poor cognitive performance and lower intellect may be associated with a subsequent decline in lifestyle activities (Small et al., 2012). In the Main Introduction, a general background was presented discussing how an active lifestyle affects cognitive function in older age. Here, a summary of the main points is presented, in accordance with the aims of this study.

Activities in which a person regularly participates that contribute to an 'active lifestyle', hereafter termed 'lifestyle activities', are broadly grouped into three main categories; physical, intellectual and social activities (Bielak, 2010; Bielak et al., 2012; Hultsch et al., 1999). An active lifestyle has also been termed an 'engaged' lifestyle, one in which a person is regularly engaged in these three types of activity. *Physical activities* are defined as those requiring physical movement of a kind that is beyond everyday motor activities, *intellectual activities* are those cognitive activities that provide a challenge, enrichment or mental stimulation, and *social activities* require social engagement beyond that of a person's own company. Existing research suggests that maintaining a lifestyle that is active in all three of these areas is associated with a higher level of cognition in older age (Bielak et al., 2012). A considerable amount of research in this area has focussed on cross-

sectional data, as outlined in Chapter 1, however, recent longitudinal evidence from the Victoria Longitudinal Study (Hultsch et al., 1999) does suggest that lifestyle engagement may buffer against the cognitive changes associated in older age (Small et al., 2012).

Considering physical activity, research suggests that regular physical activity is associated with higher cognitive function, slowing of cognitive decline and delay of the onset of dementia (Arcoverde et al., 2008; Bunce & Murden, 2006; Carlson et al., 2008; Cotman & Berchtold, 2007; Flicker, Liu-Ambrose, & Kramer, 2011; Kramer & Erickson, 2007a, 2007b; Larson et al., 2006; Spirduso, 1980; van Praag, 2009). Assessing physical activity generally occurs by means of self-reported questionnaires and also using physical fitness measures such as maximal oxygen uptake (VO_{2max}). The advantage of using an empirical measure such as VO_{2max} is that it avoids subjective bias. Larson et al. (2006) defined regular physical activity as being almost any movement activity, such as walking, hiking, bicycling, aerobics, swimming, weight training (Larson et al., 2006). This had to take place at least three times a week for a minimum of 15 minutes each session and in their study, this was measured over a period of a single year. This methodology is similar to many other studies. Larson et al. (2006) found that physical activity was associated with a delay in the onset of dementia. Yaffe et al. (2001) found that women who regularly walked around the most city blocks experienced a lower rate of cognitive decline compared to those who did not (17% decline compared to 24%, respectively). Research by Weuve et al. (2004) found that higher levels of physical activity were associated with higher cognitive performance and less cognitive decline in a longitudinal study of 766 women. Self-reported questionnaires were completed twice with a two year period between measurements to correlate physical activity with telephone assessments of cognitive measurements (general cognition, verbal memory, category fluency, and attention). Women within the highest quintile of physical activity were found to be at 20% lower risk of cognitive impairment than those in the lower quintile.

Colcombe and Kramer (2003) conducted a meta-analysis examining 18 physical fitness intervention studies published between 1966 and 2001. It was found that overall, physical fitness training had a significant benefit on cognition in older age, with the most influential benefit occurring in executive control. Executive control

is a frontal lobe function and the positive benefits are due to the neurobiological benefits afforded by physical fitness (Colcombe & Kramer, 2003). The benefits associated with physical fitness, are increased blood flow and increased cerebral grey matter, particularly in the frontal lobe regions responsible for executive control (Vogiatzis et al., 2011; Weinstein et al., 2011).

In addition to the significant benefit that physical fitness affords cognition, the benefit of maintaining an intellectual and engaged lifestyle has also been significantly associated with increased cognition. Activities requiring demanding executive processing, such as video games and those involving task switching have a cognitive transfer function, whereby the skills involved, benefit general cognition, and can enhance cognitive reserve (Hertzog, Kramer, Wilson, & Lindenberger, 2008). Furthermore, participation in intellectual activities requiring practice or engagement in an enrichment process has been associated with cognitive maintenance in older age (Stine-Morrow, Parisi, Morrow, & Park, 2008). Research suggests that continued engagement in a range of mentally stimulating activities has self-enhancing effects on both the mind and the body (Salthouse, 2006). Just placing oneself in a novel situation is cognitively stimulating and it was found that new connections are formed among neurons as a consequence (van Praag, Kempermann, & Gage, 2000). In the Victoria Longitudinal Study (VLS), it was found that non-participation in mentally stimulating activities predicted cognitive decline in older adults (Hultsch et al., 1999). Another concept that has been proposed is the cognitive-enrichment hypothesis, which suggests that certain cognitive activities serve as an enrichment function for cognition in older age and continued participation in these preserves cognitive functioning. These, however, are also associated with a person's own self-belief, attitudes and aspirations (Hertzog et al., 2008). Research investigating lifestyle has shown that maintaining an intellectually engaged lifestyle promotes successful cognitive ageing (Kramer & Erickson, 2007a). Defining or measuring intellectually stimulating activities is not a straightforward process, as found by Hertzog et al. (2008) who present a review of current definitions of 'mentally stimulating activities'. Most studies define cognitive activities by the nature and frequency of participation in specific activities. The VLS questionnaire (Hultsch et al., 1999), for example, was divided into six separate scales, three of which were associated with intellectual activities in varying formats (hobbies and home maintenance, novel information processing

and passive information processing). Consideration of the VLS questionnaire suggested new scales to expand measurement aspects of leisure time activity but found, overall, the existing scales provided a valid measurement of the constructs they proposed to measure (Jopp & Hertzog, 2010).

There is some scepticism about the intellectual activity hypothesis because of the self-reporting nature of the existing studies and because findings appear related to educational attainment. Those adults of lower educational level seemed to benefit more cognitively from intellectual intervention studies, scoring higher on post-intervention cognitive tests (Salthouse, 2006). In this study, therefore, in order to counteract this potential confounding factor, intelligence was controlled for in all statistical analyses by controlling the NART score (crystallized intelligence). This was chosen over years of education as older individuals commonly have fewer years of formal education, as discussed in Study 1.

Considering the third component of an active lifestyle, social activity, existing research suggests that social isolation accelerates cognitive decline during older age and maintaining a socially active lifestyle may preserve cognition and delay the onset of dementia (Fratiglioni et al., 2004; Lee et al., 2009; Seeman et al., 2001; Wang et al., 2002). Lövden et al. (2005) defined social participation as an investment of physical and psychological resources into social activities, which involve sharing, or instrumentation of some sort. Additionally, social activities should be those in which involvement is beyond personal care. In one study, it was found that mortality was higher in a particular group of men (aged 42-60) who were less socially active than those who were not (Kaplan et al., 1994). Older adults who become socially isolated ('social disengagement') experience increased cognitive impairment and dementia (Wang et al., 2002). An active social lifestyle contributes towards maintaining healthy cognitive function well into old age (Bassuk et al., 1999; Wang et al., 2002). Bassuk et al. (1999) and Wang et al. (2002) suggest that a socially active lifestyle provides a dynamic interchanging environment, as well as fostering a feeling of purpose and community. This is also enhanced by the increased availability of emotional support that accompanies a higher level of socialization, or even any level of socialization. They found that the level of social disengagement correlated with cognitive decline and that the

chances of experiencing decline were twice as high in disengaged respondents (Bassuk et al., 1999).

It was also found that individuals who participate in fewer social activities and are more socially isolated have a two to four times higher risk of mortality. This is associated with physical illness, particularly coronary heart disease (Fratiglioni et al., 2004). An older adult who is socially integrated maintains a relationship with society. This relationship provides a mental support network which, in turn, has benefits which may reduce the risk of mental illness such as anxiety or depression (Schulz & Salthouse, 1999). This, in itself may preserve cognitive function as depression, anxiety and, poor mental health has been shown to adversely affect cognitive function in older age, as discussed in Study 2. It is also suggested that social networking and maintaining a healthy social life seems to enhance overall 'feeling' of health, even when physical ailments are present. This feeling of well-being consequently contributes towards maintaining an overall active lifestyle and subsequently increased cognition (Stuart-Hamilton, 2006). Lövden et al. (2005) investigated the contribution that social participation plays in cognitive performance in research involved in The Berlin Aging Study. This study investigated older people aged 70 to over 100 years. They assessed whether an active social life alleviated cognitive decline in old age, or whether higher cognitive function was the factor contributing to maintaining a socially integrated lifestyle, or whether it was an interaction of both (Lövden et al., 2005). Interaction of social engagement and cognition is both multi-dimensional and multi-directional, and embedded in an integrated system. A lower level cognitive function could lead to social withdrawal and neurobiological changes associated with older age could lead to social incapacity and withdrawal from society, which then would be associated with more rapid cognitive decline.

The cognitive benefits of social engagement could also be domain specific. Research suggests that when social engagement is differentiated into social support and social activity, there is a difference in the effect it has on cognitive performance and domain specificity. General social activity has a beneficial effect on general cognition (working memory, perceptual speed and visuospatial ability) and social support has a higher positive association with problem solving abilities

and processing efficiency, but not with storage of information (Krueger et al., 2009). As research suggests, physical, intellectual and social activities are all positively associated with cognitive benefits in older age. Regionally and functionally, the frontal brain regions supporting the executive control processes (executive function) have been shown to derive the largest positive benefits from physical activities (Kramer et al., 2006). Cognitive activities are positively associated with increased perceptual speed, visuospatial ability and semantic memory (Wilson et al., 2003). A diminished participation in social activities, relationships and social support are associated with a decrease in cognitive decline and incident dementia (Bassuk et al., 1999; Seeman et al., 2001).

In the present study, active lifestyle was assessed using the VLS lifestyle questionnaire (Hultsch et al., 1999) which was adapted for this study. Six lifestyle scales were extracted from the questionnaire, which measured physical, self-maintenance, hobbies and home-maintenance, social, novel information processing and passive information processing activities regularly undertaken over the past year. Additional details about this questionnaire and the specific scales are described in the Methods section. This study set out to explore the association of age and lifestyle activities on cognitive performance by means of a two-stage analysis which assessed moderator-mediator relations as in Study 2 with mental health. Here too, the interest was whether executive function mediated Age x VLS scale relations, based on existing research which suggests that an engaged lifestyle (intellectually, socially and physically) has a beneficial effect on maintaining cognition in older age (Bielak et al., 2012). If, as research suggests, executive control processes show early age-related decline, there is considerable rationale for investigating executive function as a mediator in the Age x VLS scale association. Initially, it investigated whether an active lifestyle, as measured by the VLS questionnaire, was associated with age and cognitive function. Specifically, in an initial moderator analysis using hierarchical multiple regression, the cognitive variables were regressed onto the Age x VLS scale cross-product interaction term. In effect, this procedure assessed whether the association between age and the cognitive variable varied according to the level of VLS scale (the moderator variable), as measured by the VLS questionnaire. If the Age x VLS scale interaction achieved significance over and above the primary effects for age and VLS scale, it suggests that moderation has occurred. In a second analysis using structural

equation modelling, executive function was taken into account in the analyses to see if any of the significant Age x VLS scale interactions in the initial analysis were attenuated or became non-significant. If such a finding was produced, it suggests that the association of age and VLS scale in respect to cognition is mediated by executive function. This finding would be consistent with the view that executive control, supported by the frontal lobes, is a key beneficiary of lifestyle activity, as measured by the various VLS scales. The cognitive domains examined included psychomotor performance, executive function, visual search and recognition. Importantly, as with previous work reported in this thesis, the present study contrasted the pattern of results for mean RT and WP variability. By focusing on an age range of 50 to 90 years, the study provides valuable insights into age, lifestyle activities and cognitive relations in this older age group.

Method, Data Analysis and Procedure

See Study 1 for these sections.

Measurement

Lifestyle Activities

As noted earlier, the Victoria Longitudinal Study Lifestyle Questionnaire (VLS) questionnaire (Hultsch et al., 1999) was modified for a UK-population (see Appendix X for a copy of the modified VLS questionnaire). The questions asked about the typical frequency of engagement over the past year in 70 everyday cognitive, social and physical activities. Level of engagement was measured on a 9-point scale ("never", "less than once a year", "about once a year", "2 or 3 times a year", "about once a month", "2 or 3 times a month", "about once a week", "2 or 3 times a week", "daily"). Sixty-four of the items were arranged into six subscales. The subscales were chosen to reflect basic categories of lifestyle involvement which a normal community-dwelling population would typically participate in. Six items were dropped altogether as the authors of the questionnaire found difficulty in classifying them into the six subscales (Hultsch et al., 1999). All variables were

scaled so that high scores were associated with a greater level of activity (0 = no activity in that area). Items within each of the six subscales were summed to give a composite activity score for that category. The entire VLS questionnaire had high internal consistency with a Cronbach alpha of .76.

The six subscales and their respective Cronbach alphas were as follows:

1. Physical activities such as jogging or walking (*items* = 4);

e.g., 'I engage in exercises such as jog/swim/cycle/run'

Cronbach alpha = .32

2. Self-maintenance activities such as cooking or shopping *(items* = 6);

e.g., 'I do housework (dishes, laundry, vacuuming etc.)'

Cronbach alpha = .46

3. Social activities such as visiting friends and partying *(items* = 7);

e.g., 'I visit relatives, friends or neighbours'

Cronbach alpha = .51

4. Hobbies and home maintenance activities such as playing a musical instrument or repairing mechanical items (*items* = 12);

e.g., 'I purchase a new item requiring set-up or assembly'

Cronbach alpha = .58

5. Passive information processing such as listening to the radio or watching a sporting event (*items* = 8);

e.g., 'I watch news programs on TV (television)'

Cronbach alpha = .51

6. Novel information processing activities such as learning a language or playing bridge (*items* = 27);

e.g., 'I study or practice a foreign language'

Cronbach alpha = .70

Results

Bivariate correlations, together with means and standard deviations for both the VLS questionnaire scales and the cognitive variables, are presented in Table 3.1. The correlations between age and the cognitive variables have already been described in Study 1. Here, the focus is on the correlations between the VLS scales, age and the cognitive variables and are highlighted in bold in the table. In addition to the initial bivariate correlation analysis, a series of hierarchical regression models were used to provisionally explore the relationship between age, lifestyle activities, and the individual cognitive variables, using both mean RT and the WP variability measure as dependent variables. WP variability was measured by calculating the intraindividual standard deviation (ISD), as described in the Method section of Study 1. Additionally, structural equation modelling was used to further explore the extent to which executive function mediated the association between lifestyle activities and age in respect to cognitive performance.

Table 3.1. Bivariate Correlations Between Biographical, VLS Scales and Cognitive Variables

	Variable	*M (SD)*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
1	Age	63.60 (7.89)	—																												
2	Gender-women	154 (*n* = 257)	-.18 **	—																											
3	NART	120.33 (7.39)	-.04	-.12	—																										
4	**VLS-physical activity**	**16.03 (5.64)**	**.07**	**-.12 ***	**-.01**	—																									
5	**VLS-self maintenance**	**30.87 (7.01)**	**-.21 ****	**.40 ****	**-.16 ****	**-.08**	—																								
6	**VLS-social activity**	**20.02 (6.77)**	**.08**	**.12 ***	**-.05**	**.15 ***	**.07**	—																							
7	**VLS-hobbies and home**	**24.26 (9.38)**	**.03**	**-.21 ****	**.11**	**.27 ****	**-.09**	**.16 ****	—																						
8	**VLS-passive processing**	**36.46 (7.47)**	**.05**	**.04**	**-.15 ***	**-.04**	**.06**	**.22 ****	**.19 ****	—																					
9	**VLS-novel processing**	**81.03 (18.04)**	**-.13 ***	**-.12**	**.22 ****	**.18 ****	**-.03**	**.25 ****	**.40 ****	**.30 ****	—																				
10	SRT (ms)	309.61 (75.05)	.35 **	.05	-.19 **	**-.06**	**.09**	**-.05**	**-.16 ***	**-.03**	**-.11**	—																			
11	SRT isd	6.87 (3.37)	.21 **	.03	-.16 **	**-.05**	**-.02**	**-.01**	**-.12**	**-.01**	**-.05**	.72 **	—																		
12	2-CRT (ms)	363.82 (77.49)	.34 **	-.13 *	-.08	**-.05**	**-.04**	**.05**	**-.02**	**.00**	**-.11**	.55 **	.38 **	—																	
13	2-CRT isd	6.71 (3.00)	.28 **	-.04	-.07	**-.08**	**.03**	**.09**	**-.06**	**.01**	**-.07**	.35 **	.36 **	.51 **	—																
14	4-CRT (ms)	553.35 (116.63)	.41 **	-.22 **	-.16 *	**.02**	**-.12**	**.00**	**-.04**	**-.02**	**-.11**	.48 **	.34 **	.67 **	.43 **	—															
15	4-CRT isd	7.02 (2.81)	.29 **	-.10	-.17 **	**.00**	**-.09**	**.00**	**-.13 ***	**-.04**	**-.04**	.30 **	.25 **	.41 **	.40 **	.73 **	—														
16	Flanker Arrows (ms)	685.28 (204.41)	.46 **	.07	-.20 **	**-.10**	**.04**	**.06**	**-.21 ****	**.06**	**-.12**	.52 **	.31 **	.41 **	.38 **	.51 **	.45 **	—													
17	Flanker Arrows isd	6.34 (6.06)	.35 **	.06	-.18 **	**-.14 ***	**.07**	**-.01**	**-.25 ****	**.03**	**-.09**	.44 **	.28 **	.28 **	.34 **	.40 **	.44 **	.92 **	—												
18	Stroop Arrow (ms)	766.01 (117.41)	.52 **	-.03	-.23 **	**-.07**	**-.04**	**.04**	**-.11**	**.02**	**-.15 ***	.48 **	.34 **	.56 **	.45 **	.65 **	.50 **	.55 **	.44 **	—											
19	Stroop Arrow isd	7.97 (3.20)	.28 **	.06	-.29 **	**-.13 ***	**.05**	**.01**	**-.12**	**.09**	**-.09**	.36 **	.31 **	.40 **	.36 **	.49 **	.47 **	.40 **	.35 **	.76 **	—										
20	Stroop Word (ms)	1079.39 (263.69)	.52 **	-.12	-.06	**-.05**	**-.06**	**.05**	**-.04**	**.00**	**-.13 ***	.38 **	.26 **	.36 **	.32 **	.48 **	.40 **	.49 **	.43 **	.54 **	.37 **	—									
21	Stroop Word isd	8.19 (4.52)	.43 **	-.06	-.08	**-.04**	**-.02**	**.07**	**-.01**	**.06**	**-.11**	.30 **	.23 **	.26 **	.29 **	.36 **	.35 **	.45 **	.43 **	.43 **	.35 **	.85 **	—								
22	Visual Search S. (ms)	827.18 (230.35)	.49 **	-.22 **	-.10	**-.03**	**-.14 ***	**.11**	**-.15 ***	**.05**	**-.11**	.30 **	.22 **	.31 **	.27 **	.43 **	.31 **	.49 **	.42 **	.52 **	.35 **	.55 **	.43 **	—							
23	Visual Search S. isd	6.73 (4.54)	.31 **	-.16 *	-.08	**.05**	**-.12**	**.15 ***	**-.12**	**.09**	**-.03**	.14 *	.10	.11	.14 *	.28 **	.23 **	.28 **	.23 **	.35 **	.29 **	.39 **	.31 **	.88 **	—						
24	Visual Search C. (ms)	1998.14 (671.32)	.30 **	-.13 *	-.09	**.02**	**-.05**	**.04**	**.02**	**.07**	**-.09**	.20 **	.11	.21 **	.10	.30 **	.18 **	.29 **	.21 **	.38 **	.30 **	.49 **	.43 **	.55 **	.48 **	—					
25	Visual Search C. isd	7.09 (3.41)	.18 **	-.07	-.04	**.07**	**.00**	**.03**	**-.01**	**.06**	**-.08**	.08	.00	.09	.00	.22 **	.14 *	.17 **	.12	.27 **	.25 **	.34 **	.32 **	.49 **	.51 **	.89 **	—				
26	Recognition Imm. (ms)	1149.50 (297.41)	.39 **	-.04	-.03	**-.15 ***	**.05**	**.04**	**-.12**	**-.04**	**-.10**	.26 **	.19 **	.33 **	.27 **	.34 **	.30 **	.43 **	.37 **	.40 **	.31 **	.43 **	.34 **	.42 **	.31 **	.34 **	.25 **	—			
27	Recognition Imm. isd	8.34 (5.00)	.22 **	.02	.03	**-.14 ***	**.14 ***	**.01**	**-.08**	**-.09**	**.00**	.17 **	.12 *	.15 *	.22 **	.17 **	.16 *	.29 **	.30 **	.20 **	.16 *	.27 **	.23 **	.31 **	.24 **	.27 **	.24 **	.82 **	—		
28	Recognition Del. (ms)	1086.76 (279.67)	.42 **	-.01	-.03	**-.07**	**-.04**	**.03**	**-.05**	**.03**	**-.15 ***	.23 **	.08	.27 **	.29 **	.28 **	.22 **	.27 **	.20 **	.38 **	.27 **	.38 **	.34 **	.33 **	.21 **	.26 **	.21 **	.51 **	.39 **	—	
29	Recognition Del. isd	7.97 (4.54)	.24 **	.05	.02	**-.12 ***	**.03**	**.02**	**-.07**	**-.02**	**-.06**	.09	.00	.14 *	.21 **	.13 *	.19 **	.18 **	.18 **	.21 **	.15 *	.23 **	.24 **	.18 **	.13 *	.14 *	.16 *	.33 **	.32 **	.81 **	—

Notes: NART = National Adult Reading Test; (ms) = milliseconds for reaction time; isd = intraindividual standard deviation; VO_2 Max = maximal oxygen consumption; VLS = Victoria Longitudinal Study Questionnaire; SRT = simple reaction time; 2-CRT or 4-CRT = two or four-choice reaction time; Visual Search S. Or C. = visual search simple or complex; Recognition Imm. or Del. = recognition immediate or delayed. Gender = 1, male and 2, female.

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

This was achieved by investigating the relationship between age and the latent constructs formed by the cognitive domains of psychomotor performance, executive function, visual search and recognition for both mean RT and WP variability.

Consideration of Table 3.1. indicates that correlations between the VLS scale scores and age were significant for the self-maintenance scale ($p < .01$) and novel-processing ($p < .05$). Correlations between the VLS scale scores and gender was also significant for the physical activity and social activity scales ($p < .05$) and the self maintenance and hobbies and home maintenance scale ($p < .01$). The correlations between the VLS scale scores and the cognitive variables were predominantly non-significant with the following exceptions which were all negative: Physical activity; mean RT in the immediate recognition task and WP variability in the flanker arrows, Stroop arrow, immediate recognition and delayed recognition tasks, (all *ps* < .05). Self-maintenance; mean RT in simple visual search ($p < .05$) and WP variability in immediate recognition ($p < .05$). Social activity; WP variability in simple visual search ($p < .05$). Hobbies and home maintenance; mean RT in the SRT ($p < .05$), flanker arrows ($p < .01$) and simple visual search tasks ($p < .05$) and WP variability in the simple flanker arrows ($p < .01$) and 4-CRT tasks ($p < .05$). Novel-processing; mean RT in Stroop arrow, Stroop word and delayed recognition (all *ps* < .05). For passive-processing there were no significant correlations between any cognitive variables for either mean RT or WP Variability.

In the main, the correlations indicate that a higher level of participation in these activities was associated with lower WP variability and faster mean RT for all the cognitive variables mentioned here. The scale mean scores were comparable to Hultsch et al. (1999), across all six scores. With Hultsch et al. (1999) listed as the second score in each case, they were as follows:

Physical activity: $M = 16.02$, $SD = 5.64$; $M = 16.02$, $SD = 4.81$

Self maintenance: $M = 30.87$, $SD = 7.01$; $M = 28.94$, $SD = 5.67$

Social activity: $M = 20.02$, $SD = 6.77$; $M = 24.79$, $SD = 6.77$

Hobbies and home: $M = 24.16$, $SD = 9.38$; $M = 20.64$, $SD = 8.83$

Passive-processing: M = 36.46, SD = 7.47; M = 33.95, SD = 7.21

Novel-processing: M = 81.03, SD = 18.04; M = 71.96, SD = 16.11

To be noted is that the Hultsch et al. (1999) longitudinal study had 487 participants at the initial measurement stage which is reported here for comparison.

A series of hierarchical multiple regression models were then used to explore the relationship between age, lifestyle activities and the cognitive variables together. As National Adult Reading Test (NART) scores were significantly associated with both the mean RT and WP variability of the 4-CRT, flanker arrows and Stroop arrow tasks, this variable was controlled for at Step 1 in all of the regression models. By controlling for NART (adjusted IQ score), the possibility that age differences in IQ confound age differences in performance on the cognitive tasks is addressed. At Step 2 of the regressions, the primary effects for chronological age and individual VLS scale were entered.

At Step 3, the Age x VLS scale cross-product interaction term was entered. Importantly, if Step 3 added significantly to the variance (R^2) explained in the cognitive variable after taking the primary effects for age and VLS scale into account, it would suggest that the strength of the association between age and cognitive performance varied according to the VLS scale. All predictor variables were centred and resulting z scores used throughout the analyses (see Study 1 for additional information on centring). The results of the hierarchical regression models are presented in Tables 3.2. to 3.7. for all the VLS scales.

Table 3.2. Hierarchical Regression Analysis: Cognitive Variables Regressed on Age, VLS Physical Activity Scale, and the Age x Physical Activity Cross-Product Interaction Term for Mean Reaction Time (Mean RT) and Intraindividual Standard Deviation (ISD)

	SRT		2-CRT		4-CRT		Flanker Arrows		Stroop Arrow		Stroop Word		Visual Search S.		Visual Search C.		Recognition Imm.		Recognition Del.	
	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2
mean RT																				
Step 1:																				
NART	-.17 **	.04 **	-.07	.01	-.14 *	.02 *	-.18 **	.04 **	-.21 **	.05 **	-.03	.00	-.07	.01	-.07	.01	.00	.00	-.01	.00
Step 2:																				
Age	.34 **		.34 **		.40 **		.45 **		.53 **		.52 **		.48 **		.29 **		.38 **		.42 **	
Physical Activity	-.09	.12 **	-.07	.12 **	.00	.16 **	-.12 *	.22 **	-.12 *	.28 **	-.07	.28 **	-.06	.24 **	.01	.09 **	-.15 **	.18 **	-.09	.19 **
Step 3:																				
Age x Physical Activity	-.03	.00	.00	.00	-.05	.00	-.18 **	.03 **	.05	.00	-.12 *	.01 *	-.06	.00	-.06	.00	-.20 **	.04 **	-.08	.01
ISD																				
Step 1:																				
NART	-.15 *	.03 **	-.06	.01	-.15 *	.03 **	-.15 **	.03 **	-.28 **	.08 **	-.06	.01	-.08	.01	-.03	.00	.05	.00	.04	.00
Step 2:																				
Age	.21 **		.29 **		.28 **		.35 **		.28 **		.42 **		.31 **		.17 **		.22 **		.24 **	
Physical Activity	.07	.05 **	-.11	.09 **	.00	.08 **	-.14	.15 **	-.15 **	.01 **	-.05	.19 **	.02	.09 **	.05	.03 *	-.13 *	.07 **	-.13 *	.08 **
Step 3:																				
Age x Physical Activity	-.01	.00	.00	.00	-.12 *	.01 *	-.19 **	.04 **	-.02	.00	-.12 *	.01 *	.04	.00	.01	.00	-.17 **	.03 **	-.13 *	.02 *

Notes: NART = National Adult Reading Test; VLS = Victoria Longitudinal Study Questionnaire; SRT = simple reaction time; 2-CRT or 4-CRT = two or four-choice reaction time; Visual Search S. or C. = visual search simple or complex; Recognition Imm. or Del. = recognition immediate or delayed.

Step 1, $df = 1, 255$; Step 2, $df = 2, 253$; Step 3, $df = 1, 252$.

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

Table 3.3. Hierarchical Regression Analysis: Cognitive Variables Regressed on Age, VLS Self-Maintenance Scale, and the Age x Self-Maintenance Cross-Product Interaction Term for Mean Reaction Time (Mean RT) and Intraindividual Standard Deviation (ISD)

	SRT		2-CRT		4-CRT		Flanker Arrows		Stroop Arrow		Stroop Word		Visual Search S.		Visual Search C.		Recognition Imm.		Recognition Del.	
	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2
mean RT																				
Step 1:																				
NART	-.15 *	.04 **	-.07	.01	-.15 *	.02 *	-.16 **	.04 **	-.20 **	.05 **	-.03	.00	-.09	.01	-.07	.01	-.01	.00	.00	.00
Step 2:																				
Age	.37 **		.34 **		.39 **		.48 **		.53 **		.54 **		.47 **		.30 **		.42 **		.44 **	
Self Maintenance	.12	.13 **	.01	.11 **	-.08	.17 **	.08	.22 **	.05	.27 **	.05	.28 **	-.08	.24 **	-.01	.09 **	.11	.17 **	.03	.18 **
Step 3:																				
Age x Self Maintenance	.08	.01	.07	.00	.05	.00	.12 *	.01 *	.00	.00	.01	.00	.07	.00	.03	.00	.10	.01	.08	.01
ISD																				
Step 1:																				
NART	-.16 **	.03 **	-.05	.01	-.17 **	.03 **	-.15 *	.03 **	-.27 **	.08 **	-.05	.01	-.08	.01	-.03	.00	.08	.00	.05	.00
Step 2:																				
Age	.20 **		.30 **		.27 **		.38 **		.28 **		.44 **		.29 **		.18 **		.27 **		.26 **	
Self Maintenance	.00	.04 **	.08	.09 **	-.05	.08 **	.10	.14 **	.05	.08 **	.07	.18 **	-.08	.10 **	.04	.03 *	.18 **	.09 **	.11	.07 **
Step 3:																				
Age x Self Maintenance	.01	.00	.01	.00	-.04	.00	.09	.01	.06	.00	-.01	.00	.02	.00	-.01	.00	.09	.01	-.04	.00

Notes: NART = National Adult Reading Test; VLS = Victoria Longitudinal Study Questionnaire; SRT = simple reaction time; 2-CRT or 4-CRT = two or four-choice reaction time; Visual Search S. or C. = visual search simple or complex; Recognition Imm. or Del. = recognition immediate or delayed.

Step 1, $df = 1, 255$; Step 2, $df = 2, 253$; Step 3, $df = 1, 252$.

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

Table 3.4. Hierarchical Regression Analysis: Cognitive Variables Regressed on Age, VLS Social Activity Scale, and the Age x Social Activity Cross-Product Interaction Term for Mean Reaction Time (Mean RT) and Intraindividual Standard Deviation (ISD)

	SRT		2-CRT		4-CRT		Flanker Arrows		Stroop Arrow		Stroop Word		Visual Search S.		Visual Search C.		Recognition Imm.		Recognition Del.	
	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2
mean RT																				
Step 1:																				
NART	-.17 **	.04 **	-.08	.01	-.15 *	.02 *	-.18 **	.04 **	-.22 **	.05 **	-.06	.00	-.10	.01	-.08	.01	-.02	.00	-.02	.00
Step 2:																				
Age	.35 **		.33 **		.41 **		.45 **		.51 **		.52 **		.47 **		.29 **		.38 **		.42 **	
Social Activity	-.09	.12 **	.03	.11 **	-.04	.17 **	.02	.20 **	-.01	.27 **	.01	.27 **	.07	.24 **	.02	.09 **	.01	.15 **	-.01	.18 **
Step 3:																				
Age x Social Activity	-.07	.01	.06	.00	.04	.00	.01	.00	.11 *	.01 *	.12 *	.01 *	.20 **	.04 **	.09	.01	.10	.01	.06	.00
ISD																				
Step 1:																				
NART	-.16 *	.03 **	-.06	.01	-.17 **	.03 **	-.16 **	.03 **	-.30 **	.08 **	-.08	.01	-.10	.01	-.05	.00	.04	.00	.02	.00
Step 2:																				
Age	.20 **		.28 **		.28 **		.35 **		.26 **		.42 **		.28 **		.17 **		.22 **		.24 **	
Social Activity	-.03	.04 **	.06	.08 **	-.03	.08 **	-.05	.12 **	-.02	.07 **	.03	.18 **	.13 *	.11 **	.02	.03 **	.00	.05 **	.00	.06 **
Step 3:																				
Age x Social Activity	-.01	.00	.01	.00	.08	.01	-.05	.00	.14 *	.02 *	.14 *	.02 *	.29 **	.09 **	.11	.01	-.01	.00	.05	.00

Notes: NART = National Adult Reading Test; VLS = Victoria Longitudinal Study Questionnaire; SRT = simple reaction time; 2-CRT or 4-CRT = two or four-choice reaction time; Visual Search S. or C. = visual search simple or complex; Recognition Imm. or Del. = recognition immediate or delayed.
Step 1, $df = 1, 255$; Step 2, $df = 2, 253$; Step 3, $df = 1, 252$.
*$p < .05$; **$p < .01$

Table 3.5. Hierarchical Regression Analysis: Cognitive Variables Regressed on Age, VLS Hobbies and Home Scale, and the Age x Hobbies and Home Cross-Product Interaction Term for Mean Reaction Time (Mean RT) and Intraindividual Standard Deviation (ISD)

	SRT		2-CRT		4-CRT		Flanker Arrows		Stroop Arrow		Stroop Word		Visual Search S.		Visual Search C.		Recognition Imm.		Recognition Del.	
	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2
mean RT																				
Step 1:																				
NART	-.16 **	.04 **	-.07	.01	-.13 *	.02 *	-.17 **	.04 **	-.19 **	.05 **	-.04	.00	-.07	.01	-.08	.01	.00	.00	-.01	.00
Step 2:																				
Age	.34 **		.34 **		.41 **		.45 **		.53 **		.52 **		.48 **		.29 **		.38 **		.42 **	
Hobbies-Home	-.14 *	.14 **	-.07	.11 **	-.07	.17 **	-.16 **	.25 **	-.16 **	.28 **	-.04	.28 **	-.09	.26 **	.04	.09 **	-.06	.16 **	-.03	.18 **
Step 3:																				
Age x Hobbies and Home	-.04	.00	.11	.01	.08	.01	-.12 *	.01 *	.12 *	.01 *	-.02	.00	-.16 **	.02 **	-.05	.00	-.15 *	.02 *	-.07	.00
ISD																				
Step 1:																				
NART	-.14 *	.03 **	-.05	.01	-.15 *	.03 **	-.15 **	.03 **	-.27 **	.08 **	-.06	.01	-.06	.01	-.03	.00	.05	.00	.03	.00
Step 2:																				
Age	.21 **		.28 **		.29 **		.35 **		.27 **		.43 **		.30 **		.18 **		.22 **		.24 **	
Hobbies and Home	-.13	.05 **	-.07	.08 **	-.11	.09 **	-.18 **	.18 **	-.10	.08 **	-.02	.18 **	-.05	.11 **	-.02	.03 *	-.03	.06 **	-.04	.06 **
Step 3:																				
Age x Hobbies and Home	.04	.00	-.01	.00	-.03	.00	-.15 *	.02 *	-.01	.00	.01	.00	-.15 *	.02 *	.01	.00	-.14 *	.02 *	-.08	.01

Notes: NART = National Adult Reading Test; VLS = Victoria Longitudinal Study Questionnaire; SRT = simple reaction time; 2-CRT or 4-CRT = two or four-choice reaction time; Visual Search S. or C. = visual search simple or complex; Recognition Imm. or Del. = recognition immediate or delayed.

Step 1, df = 1, 255; Step 2, df = 2, 253; Step 3, df = 1, 252.

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

Table 3.6. Hierarchical Regression Analysis: Cognitive Variables Regressed on Age, VLS Passive-Processing Scale, and the Age x Passive-Processing Cross-Product Interaction Term for Mean Reaction Time (Mean RT) and Intraindividual Standard Deviation (ISD)

	SRT		2-CRT		4-CRT		Flanker Arrows		Stroop Arrow		Stroop Word		Visual Search S.		Visual Search C.		Recognition Imm.		Recognition Del.	
	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2
mean RT																				
Step 1:																				
NART	-.19 **	.04 **	-.07	.01	-.15 *	.02 *	-.18 **	.04 **	-.21 **	.05 **	-.05	.00	-.08	.01	-.07	.01	-.02	.00	-.01	.00
Step 2:																				
Age	.34 **		.34 **		.41 **		.45 **		.52 **		.52 **		.48 **		.29 **		.39 **		.42 **	
Passive-Processing	-.08	.12 **	-.01	.11 **	-.06	.17 **	.00	.20 **	-.03	.27 **	-.04	.27 **	-.01	.23 **	.01	.09 **	-.07	.15 **	.01	.18 **
Step 3:																				
Age x Passive-Processing	-.04	.01	-.11	.01	.00	.00	.04	.00	-.05	.00	.04	.00	.19 **	.04 **	.27 **	.07 **	.03	.00	-.01	.00
ISD																				
Step 1:																				
NART	-.16 **	.03 **	-.06	.01	-.17 **	.03 **	-.17 **	.03 **	-.27 **	.08 **	-.06	.01	-.06	.01	-.03	.00	.03	.00	.02	.00
Step 2:																				
Age	.20 **		.28 **		.29 **		.35 **		.27 **		.42 **		.30 **		.17 **		.23 **		.24 **	
Passive-Processing	-.04	.04 **	-.01	.08 **	-.07	.09 **	-.01	.12 **	.04	.07 **	.02	.18 **	.03	.10 **	.00	.03 *	-.10	.06 **	-.03	.06 **
Step 3:																				
Age x Passive-Processing	-.02	.00	-.06	.00	-.02	.00	.01	.00	.01	.00	.07	.01	.25 **	.06 **	.32 **	.10 **	.02	.00	-.04	.00

Notes: NART = National Adult Reading Test; VLS = Victoria Longitudinal Study Questionnaire; SRT = simple reaction time; 2-CRT or 4-CRT = two or four-choice reaction time; Visual Search S. or C. = visual search simple or complex; Recognition Imm. or Del. = recognition immediate or delayed.

Step 1, $df = 1, 255$; Step 2, $df = 2, 253$; Step 3, $df = 1, 252$.

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

Table 3.7. Hierarchical Regression Analysis: Cognitive Variables Regressed on Age, VLS Novel-Processing, and the Age x Novel-Processing Cross-Product Interaction Term for Mean Reaction Time (Mean RT) and Intraindividual Standard Deviation (ISD)

	SRT		2-CRT		4-CRT		Flanker Arrows		Stroop Arrow		Stroop Word		Visual Search S.		Visual Search C.		Recognition Imm.		Recognition Del.	
	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2
mean RT																				
Step 1:																				
NART	-.15 *	.04 **	-.05	.01	-.13 *	.02 *	-.17 **	.04 **	-.21 **	.05 **	-.03	.00	-.07	.01	-.07	.01	.01	.00	.02	.00
Step 2:																				
Age	.35 **		.34 **		.41 **		.46 **		.50 **		.52 **		.48 **		.28 **		.38 **		.42 **	
Novel-Processing	-.03	.12 **	-.06	.11 **	-.03	.16 **	-.03	.20 **	-.04	.27 **	-.06	.28 **	-.03	.23 **	-.04	.09 **	-.05	.15 **	-.11	.19 **
Step 3:																				
Age x Novel-Processing	-.12 *	.04 *	-.06	.00	-.05	.00	-.10	.01	.10	.01	-.02	.00	.02	.00	.06	.00	-.04	.02	-.08	.01
ISD																				
Step 1:																				
NART	-.15 *	.03 **	-.07	.01	-.14 *	.02 *	-.18 **	.04 **	-.21 **	.05 **	-.04	.00	-.08	.01	-.07	.01	-.01	.00	-.01	.00
Step 2:																				
Age	.21 **		.29 **		.30 **		.36 **		.26 **		.42 **		.30 **		.16 *		.23 **		.25 **	
Novel-Processing	.00	.04 **	-.02	.08 **	.03	.08 **	-.01	.12 **	.01	.07 **	-.04	.18 **	.04	.09 **	-.05	.03 *	.02	.05 **	-.05	.06 **
Step 3:																				
Age x Novel-Processing	-.07	.01	-.09	.01	-.10	.01	-.10	.01	.04	.00	-.02	.00	.08	.01	.09	.01	-.02	.00	-.08	.01

Notes: NART = National Adult Reading Test; VLS = Victoria Longitudinal Study Questionnaire; SRT = simple reaction time; 2-CRT or 4-CRT = two or four-choice reaction time; Visual Search S. or C. = visual search simple or complex; Recognition Imm. or Del. = recognition immediate or delayed.

Step 1, $df = 1, 255$; Step 2, $df = 2, 253$; Step 3, $df = 1, 252$.

$^*p < .05$; $^{**}p < .01$

Consideration of the beta weights obtained at Step 2 suggests that having controlled for NART scores, the associations between age and VLS scales and the cognitive variables corresponded to the results obtained in the bivariate correlations reported in Table 3.1. Age and each VLS scale varied in their contribution to the shared variance (R_2) with the outcome variables. For physical activity between 9% and 28% for mean RT and between 1% and 19% for WP variability; for self-maintenance between 9% and 28% for mean RT and between 3% and 18% for WP variability; for social activity between 9% and 27% for mean RT and between 3% and 18% for WP variability; for hobbies and home maintenance between 9% and 28% and between 3% and 18% for WP variability; for passive-processing between 9% and 27% for mean RT and between 3% and 18% for WP variability; and for novel-processing between 9% and 28% for mean RT and between 3% and 18% for WP variability.

Of particular interest, however, was whether entry of the Age x VLS scale cross-product interaction term added to the variance explained in the various cognitive measures over and above those primary effects. As can be seen in Tables 3.2. to 3.7. for the majority of measures, entry of this term did not add significantly to the variance although this varied according to each scale. Overall, for mean RT and WP variability, low activity in the respective scales was associated with an increase in both mean reaction time and WP variability in older age. In other words, lower activity in a particular scale had a greater negative impact on mean RT and WP variability in older age although the results were varied across scales, as outlined below. The effects varied slightly according to task but there were some general findings across all cognitive tasks, here the effects are described according to each individual scale.

Physical activity: for mean RT, the Age x Physical activity interactions for the flanker arrows ($\Delta R^2 = .03$, $p < .01$), Stroop word ($\Delta R^2 = .01$, $p < .05$) and immediate recognition tasks ($\Delta R^2 = .04$, $p < .01$) were all significant. For WP variability, the Age x Physical activity interactions for the 4-CRT ($\Delta R^2 = .01$, $p < .05$), flanker arrows ($\Delta R^2 = .04$, $p < .01$), Stroop word ($\Delta R^2 = .01$, $p < .05$), immediate recognition ($\Delta R^2 = .03$, $p < .01$) and delayed recognition tasks ($\Delta R^2 = .02$, $p < .05$) were also significant (see Table 3.2. and Figures 3.1. to 3.8. for interactions). The interaction graphs were constructed using a median split on age

and VLS physical activity mean score (Age median = 63, *M* = 63.60, *SD* = 7.89; VLS physical activity score median = 15.00, *M* = 16.02, *SD* = 5.64). For mean RT in flanker arrows, there were clear beneficial effects for both age and physical activity. The interaction appears to stem from the older physically active declining less than the older physically inactive and the cognitive benefits for a higher level of physical activity are apparent at both younger and older old age but more significantly so in older old age (see Figure 3.1.) for mean RT in flanker arrows. For mean RT in the Stroop word and immediate recognition tasks, in younger old age, physical activity does not distinguish performance but does clearly confer cognitive benefits in older old age (see Figures 3.2. and 3.3.) for these interactions. For WP variability in the 4-CRT, flanker arrows and Stroop Word tasks, there were clear beneficial effects for both age and physical activity. The interaction here too, appears to stem from the older less physically active performing better (see Figures 3.4. to 3.6.) for these interactions. For WP variability in immediate and delayed recognition, in younger old age, physical activity does not distinguish performance but does clearly confer cognitive benefits in older old age (see Figures 3.7. and 3.8.).

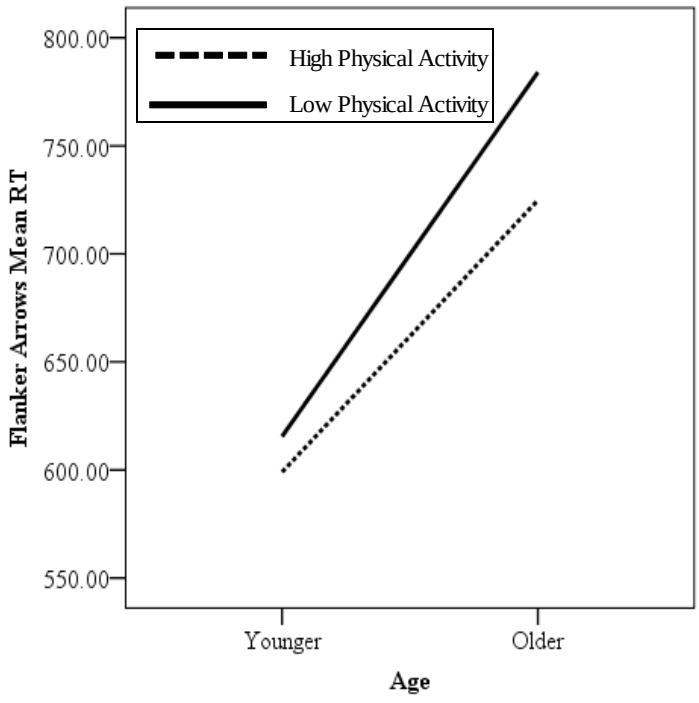

Figure 3.1. The significant Age x Physical Activity interaction in respect to mean RT in the flanker arrows task (High = increased participation).

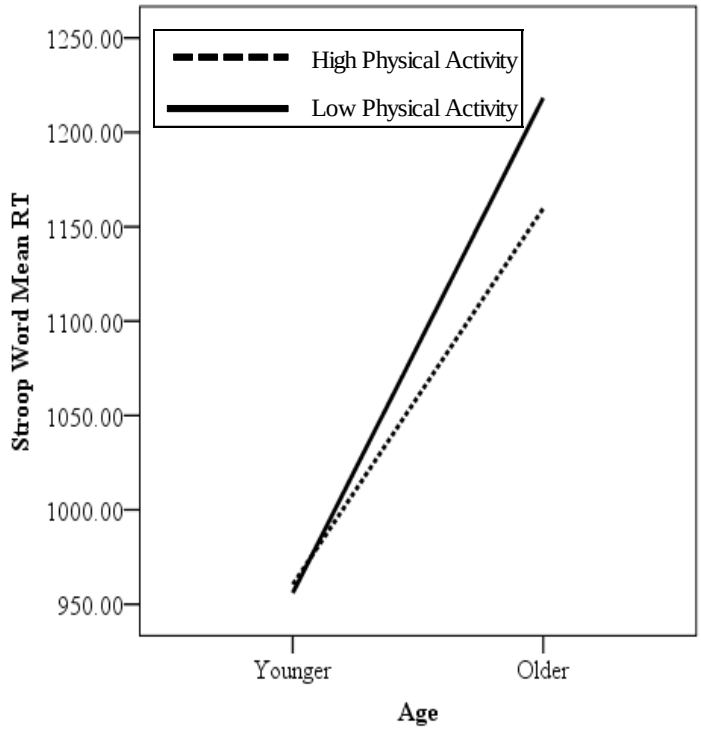

Figure 3.2. The significant Age x Physical Activity interaction in respect to mean RT in the Stroop word task (High = increased participation).

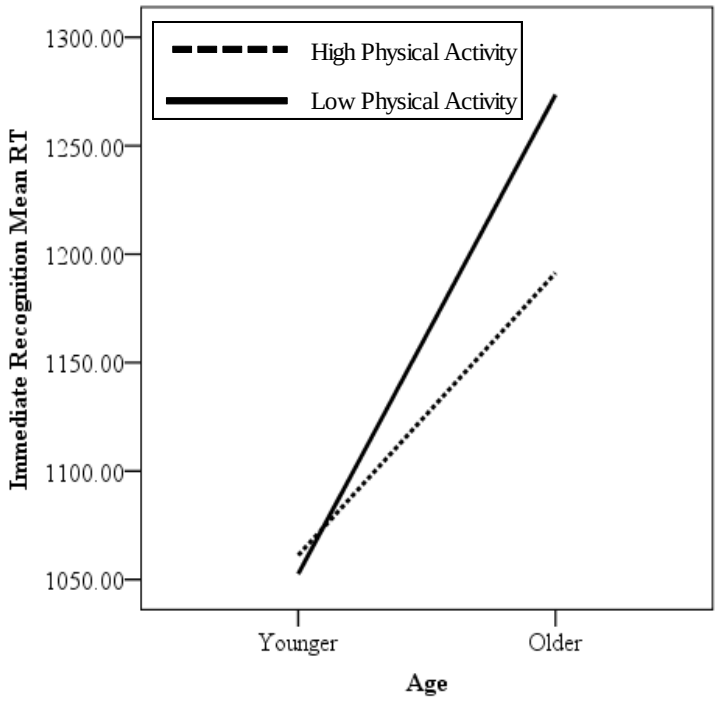

Figure 3.3. The significant Age x Physical Activity interaction in respect to mean RT in the immediate recognition task (High = increased participation).

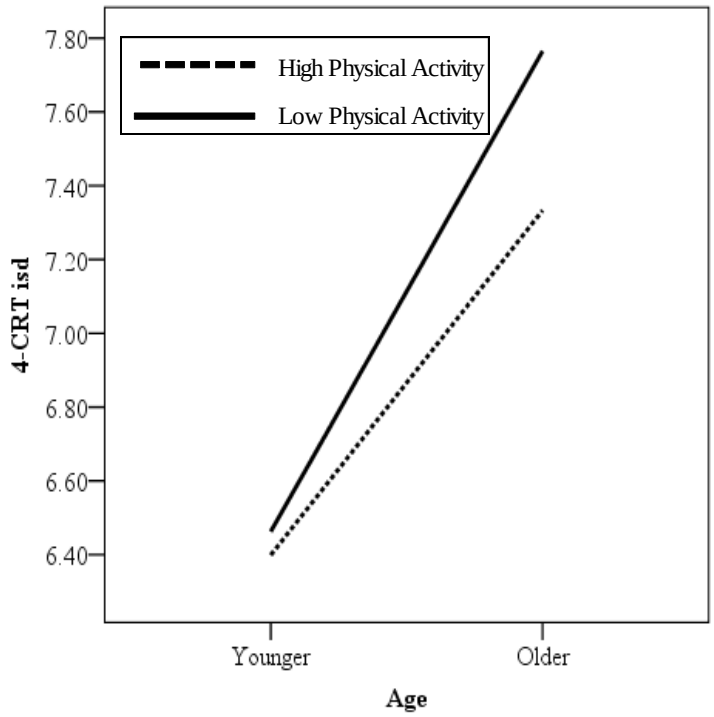

Figure 3.4. The significant Age x Physical Activity interaction in respect to WP variability in the 4-CRT task (High = increased participation).

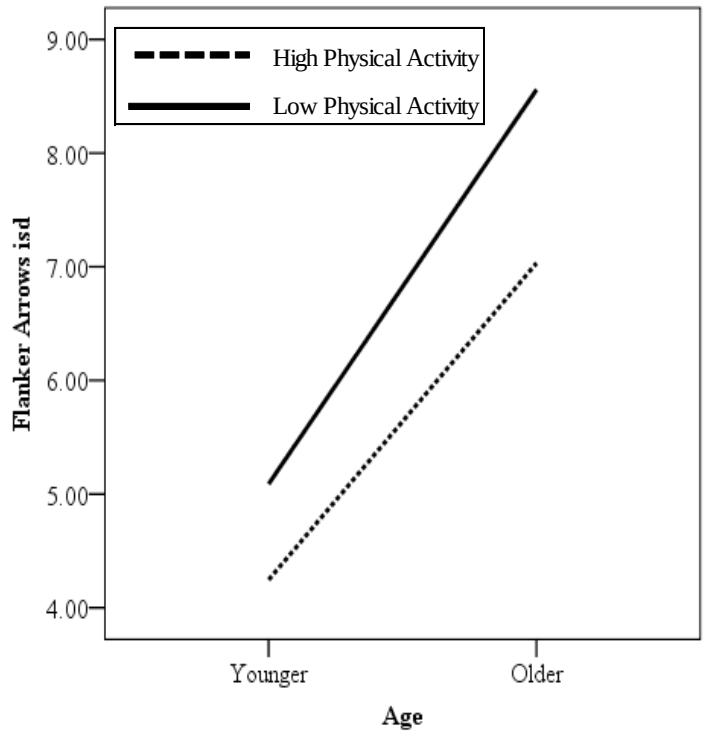

Figure 3.5. The significant Age x Physical Activity interaction in respect to WP variability in the flanker arrows task (High = increased participation).

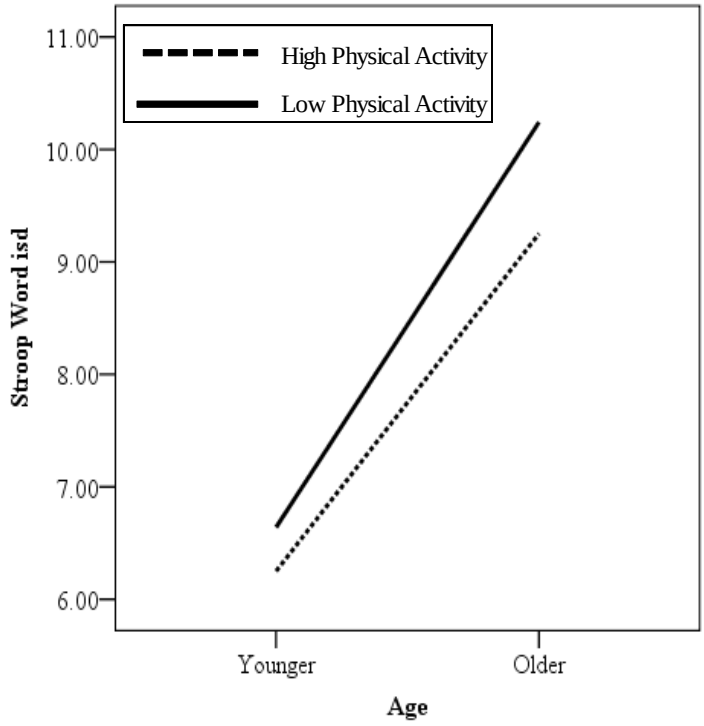

Figure 3.6. The significant Age x Physical Activity interaction in respect to WP variability in the Stroop word task (High = increased participation).

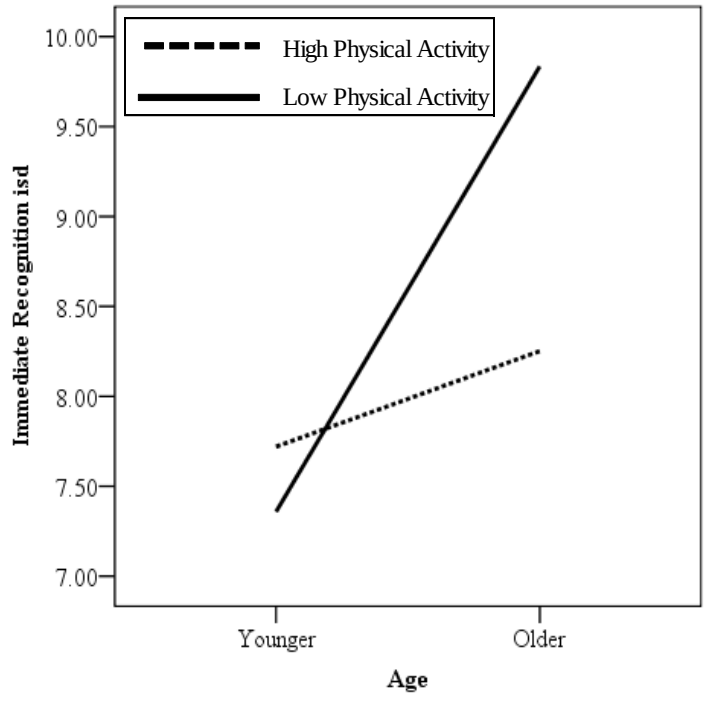

Figure 3.7. The significant Age x Physical Activity interaction in respect to WP variability in the immediate recognition task (High = increased participation).

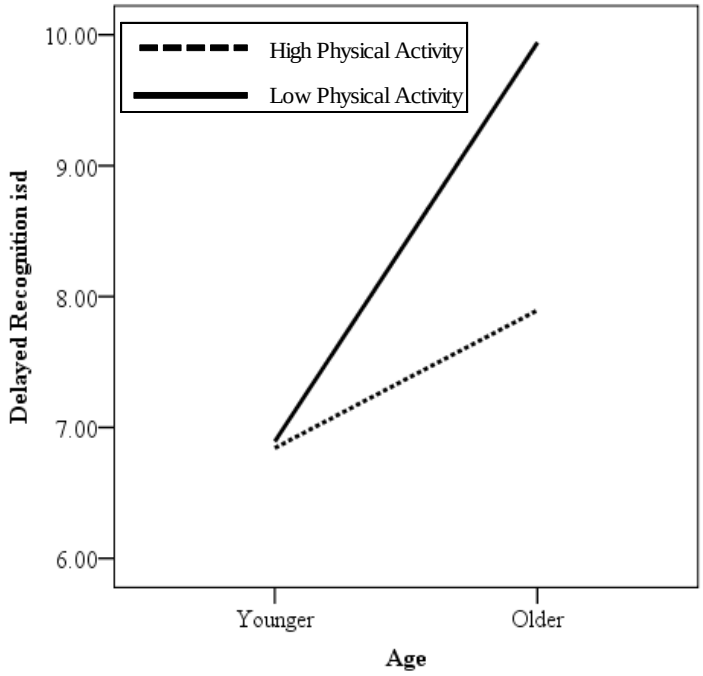

Figure 3.8. The significant Age x Physical Activity interaction in respect to WP variability in the delayed recognition task (High = increased participation).

Self-maintenance scale: for mean RT, the Age x Self-maintenance interaction for the flanker arrows task was significant (ΔR^2 = .01, p < .05) (see Table 3.3. and Figure 3.9. for interaction). The interaction graph was constructed using a median split on age and VLS self-maintenance mean score (Age median = 63, *M* = 63.60, *SD* = 7.89; VLS self maintenance score median = 30.80, *M* = 30.87, *SD* = 7.01). For WP variability, there were no significant interactions. The only significant cross-product interaction was for mean RT in flanker arrows. There were clear beneficial effects for both age and self-maintenance. However, as this was the only significant interaction for this scale, the analysis was not considered further, avoiding spurious conclusions to be made about the self-maintenance scale.

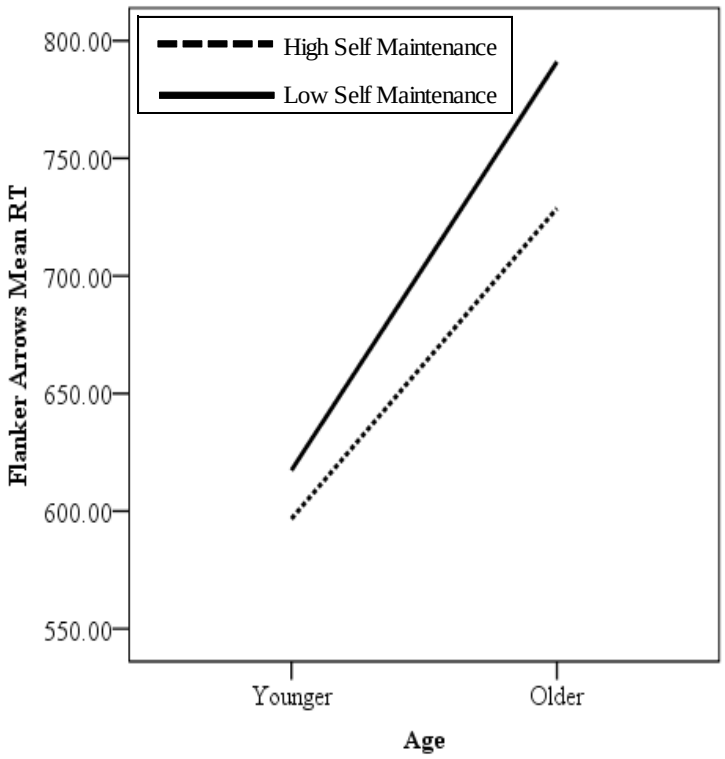

Figure 3.9. The significant Age x Self-maintenance interaction in respect to mean RT in the flanker arrows task (High = increased participation).

Social activity scale: for mean RT, the Age x Social activity interactions for the Stroop arrow (ΔR^2 = .01, p < .05), Stroop word (ΔR^2 = .01, p < .05) and simple visual search tasks (ΔR^2 = .04, p < .01) were all significant. For WP variability, the Age x Self-maintenance interactions for the Stroop arrow (ΔR^2 = .02, p < .05), Stroop word (ΔR^2 = .02, p < .05) and simple visual search tasks (ΔR^2 = .09, p < .01) were also significant (see Table 3.4. and Figures 3.10. to 3.15. for interactions). The interaction graphs were constructed using a median split on age and VLS social activity mean score (Age median = 63, M = 63.60, SD = 7.89; VLS social activity score median = 19.00, M = 20.02, SD = 6.77). For mean RT and WP variability in all the significant interactions, social activity does not distinguish performance but does clearly confer cognitive benefits in older old age for both mean RT and WP variability.

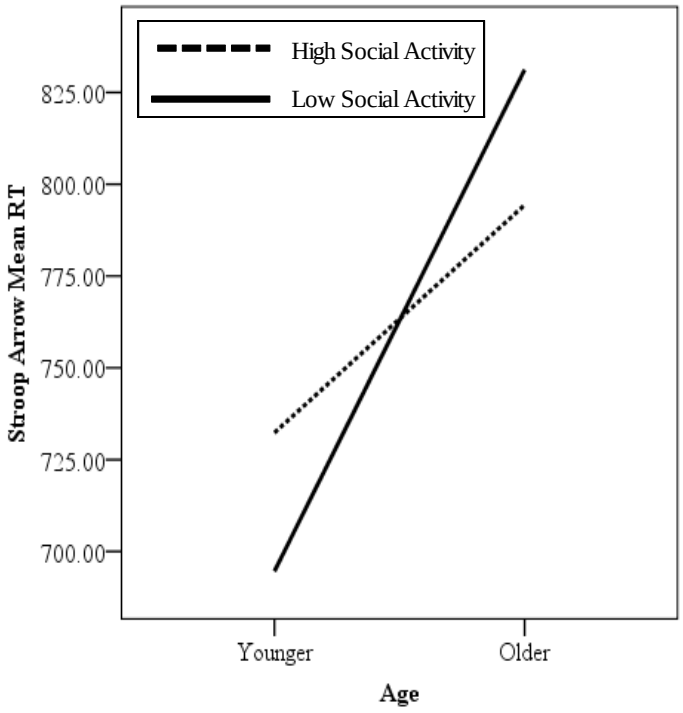

Figure 3.10. The significant Age x Social Activity interaction in respect to mean RT in the Stroop arrow task (High = increased participation).

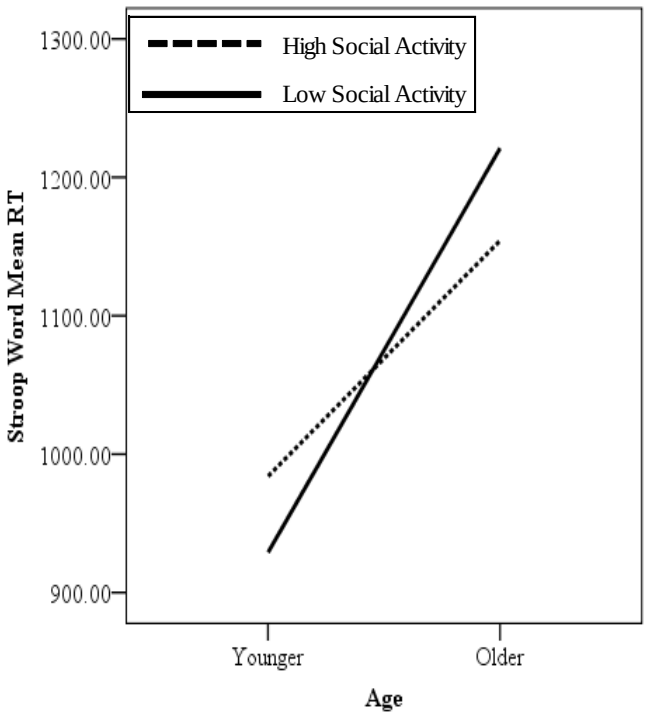

Figure 3.11. The significant Age x Social Activity interaction in respect to mean RT in the Stroop word task (High = increased participation).

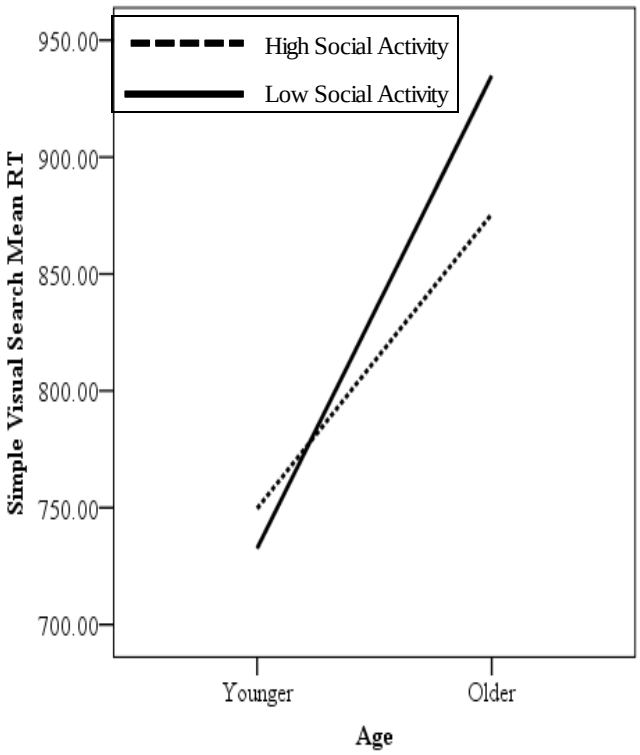

Figure 3.12. The significant Age x Social Activity interaction in respect to mean RT in the simple visual search task (High = increased participation).

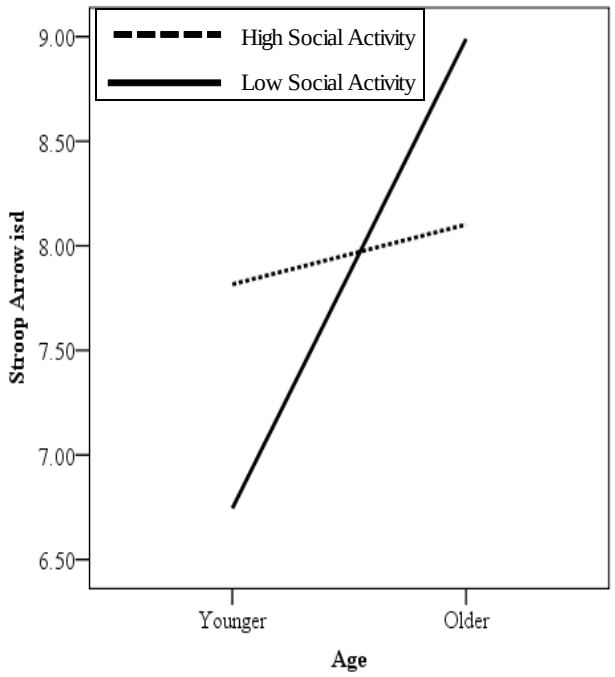

Figure 3.13. The significant Age x Social Activity interaction in respect to WP variability in the Stroop arrow task (High = increased participation).

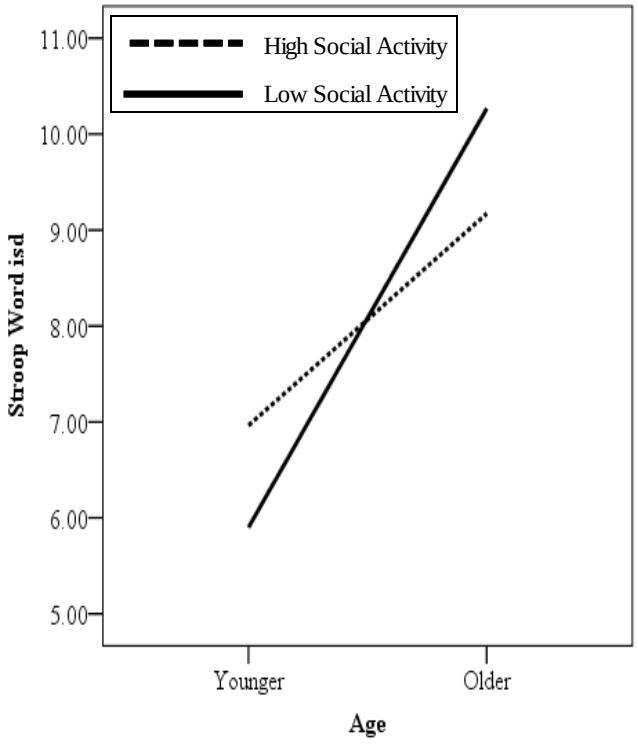

Figure 3.14. The significant Age x Social Activity interaction in respect to WP variability in the Stroop word task (High = increased participation).

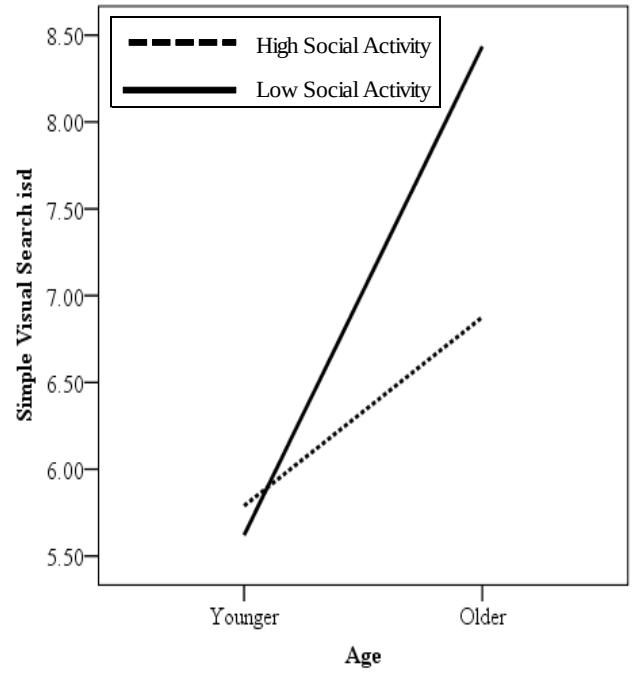

Figure 3.15. The significant Age x Social Activity interaction in respect to WP variability in the simple visual search task (High = increased participation).

Hobbies and home maintenance scale: for mean RT, the Age x Hobbies and home maintenance interactions for flanker arrows (ΔR^2 = .01, p < .05), Stroop arrow (ΔR^2 = .01, p < .05), simple visual search (ΔR^2 = .02, p < .01) and immediate recognition tasks (ΔR^2 = .02, p < .05) were all significant. For WP variability, the Age x Hobbies and home maintenance interactions for flanker arrows (ΔR^2 = .02, p < .05), simple visual search (ΔR^2 = .02, p < .05) and immediate recognition tasks (ΔR^2 = .02, p < .05) were also significant (see Table 3.5. and Figures 3.16. to Figures 3.22. for interactions). The interaction graphs were constructed using a median split on age and VLS hobbies and home maintenance mean score (Age median = 63, M = 63.60, SD = 7.89; VLS hobbies and home maintenance score median = 22.37, M = 24.16, SD = 9.38). Interaction effects were varied according to cognitive task. However, for mean RT in the flanker arrows, Stroop Arrow and immediate recognition tasks, there were beneficial effects for both age and, hobbies and home maintenance activity. The interaction here also appears to stem from the older less active declining more in flanker arrows (see Figure 3.16.) and only marginal differences between younger and older in Stroop arrow and immediate recognition tasks (see Figures 3.17. and 3.19.). For mean RT in simple visual search, in younger old age, hobbies and home maintenance activity does not distinguish performance but does confer cognitive benefits in older old age (see Figure 3.18.). For WP variability in the flanker arrows and immediate recognition tasks, there were beneficial effects for both age and, hobbies and home maintenance. The interaction appears to stem from the older less active declining more (see Figures 3.20. and 3.22.) for these interactions. For WP variability in the simple visual search task, in younger old age, hobbies and home maintenance activity does not distinguish performance but does confer cognitive benefits in older old age (see Figure 3.21.) for this interaction.

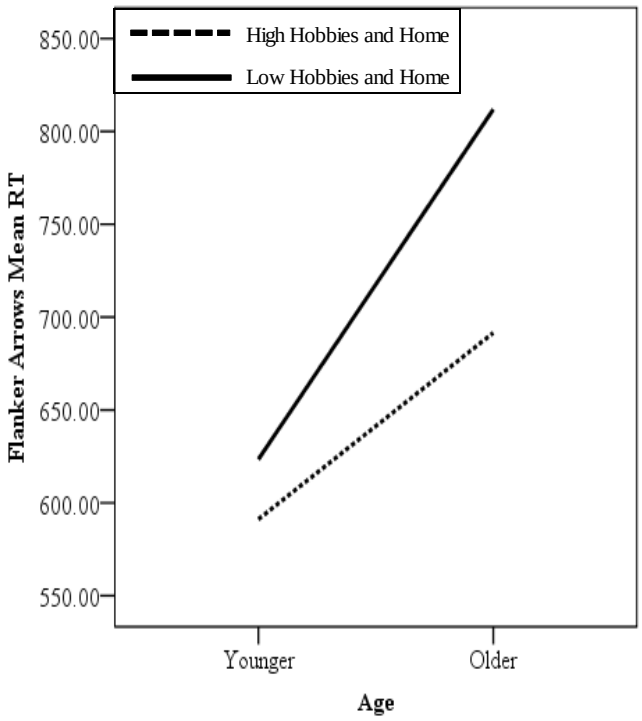

Figure 3.16. The significant Age x Hobbies and Home Maintenance interaction in respect to mean RT in the flanker arrows task (High = increased participation).

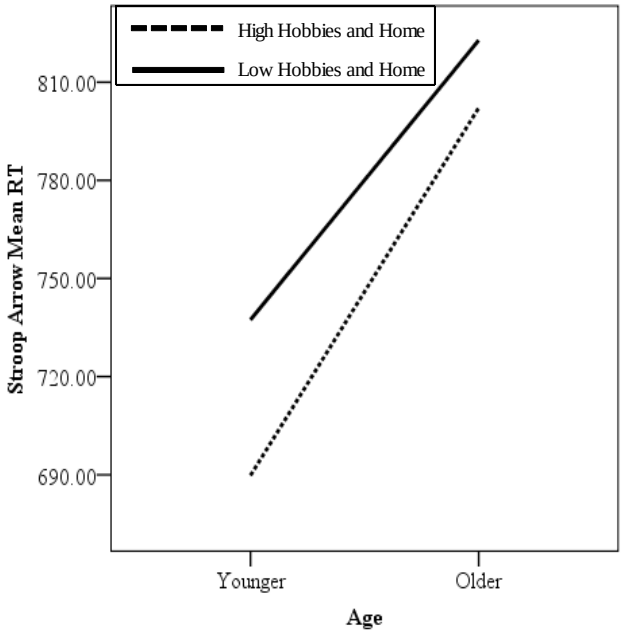

Figure 3.17. The significant Age x Hobbies and Home Maintenance interaction in respect to mean RT in the Stroop arrow task (High = increased participation).

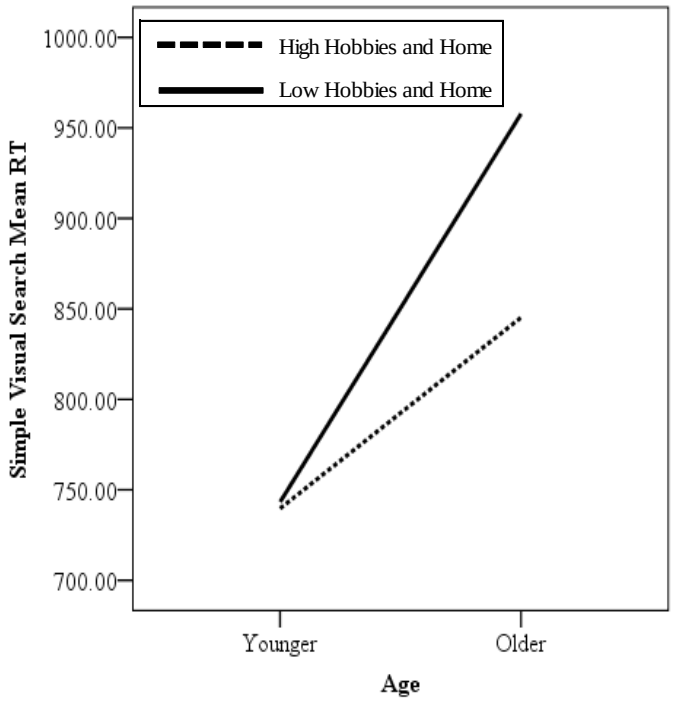

Figure 3.18. The significant Age x Hobbies and Home Maintenance interaction in respect to mean RT in the simple visual search task (High = increased participation).

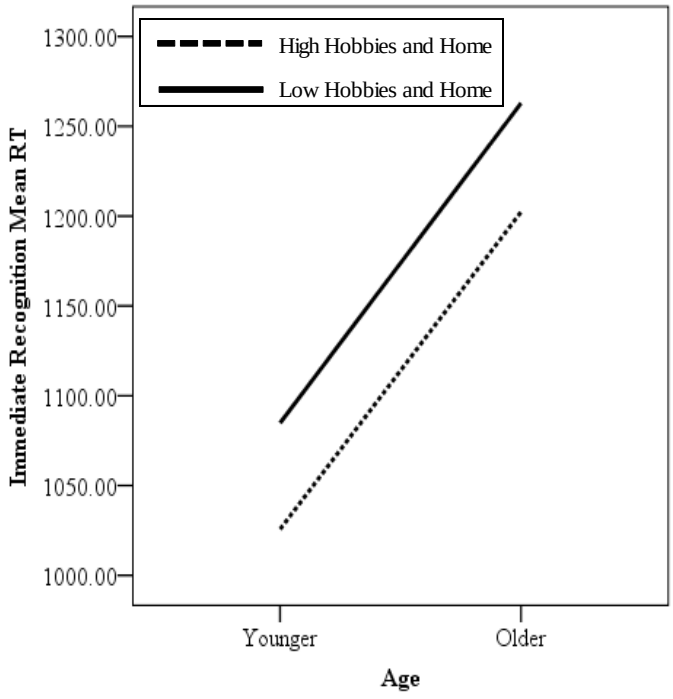

Figure 3.19. The significant Age x Hobbies and Home Maintenance interaction in respect to mean RT in the immediate recognition task (High = increased participation).

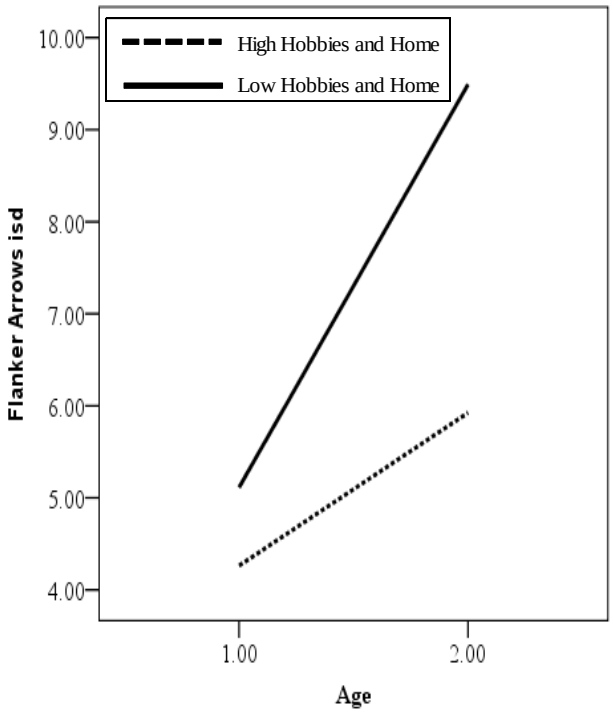

Figure 3.20. The significant Age x Hobbies and Home Maintenance interaction in respect to WP variability in the flanker arrows task (High = increased participation).

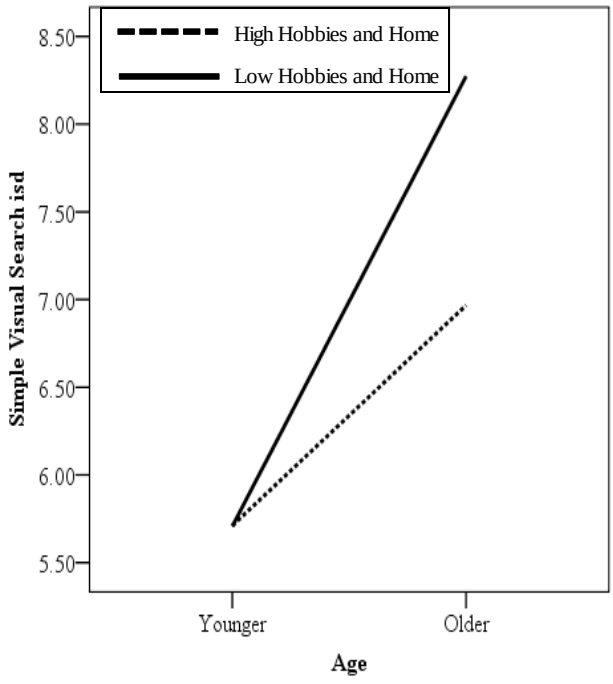

Figure 3.21. The significant Age x Hobbies and Home Maintenance interaction in respect to WP variability in the simple visual search task (High = increased participation).

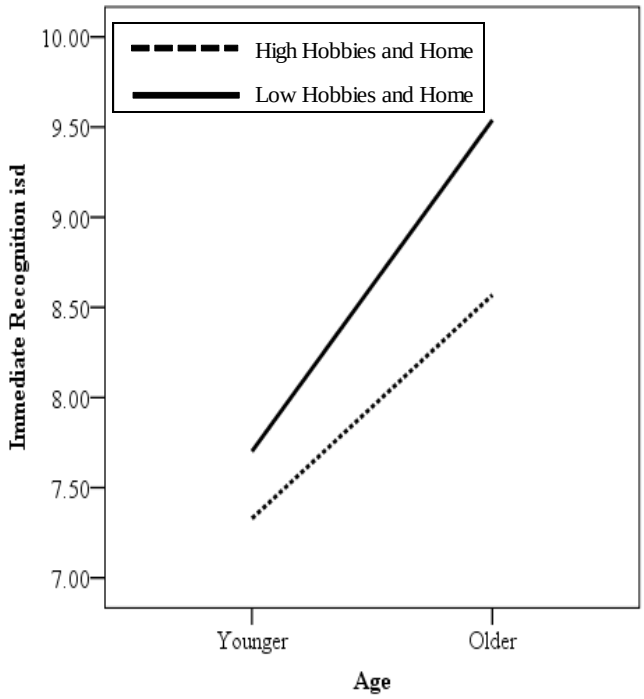

Figure 3.22. The significant Age x Hobbies and Home Maintenance interaction in respect to WP variability in the immediate recognition task (High = increased participation).

Passive-processing scale: for mean RT, the Age x Passive-processing interactions for simple visual search (ΔR^2 = .04, p < .01) and complex visual search tasks (ΔR^2 = .07, p < .01) were all significant. For WP variability, the Age x Passive-processing interactions for simple visual search (ΔR^2 = .06, p < .01) and complex visual search tasks (ΔR^2 = .10, p < .01) were also significant (see Table 3.6. and Figures 3.23. to 3.26. for interactions). The interaction graphs were constructed using a median split on age and VLS passive-processing mean score (Age median = 63, M = 63.60, SD = 7.89; VLS passive-processing score median = 36.00, M = 36.46, SD = 7.47).

The interaction effects varied according to task but there were general findings across all cognitive tasks. For mean RT in simple visual search the effects of passive information processing (passive-processing) were not clear (see Figure 3.23.). However, for mean RT in complex visual search, passive-processing does not distinguish performance but does clearly confer cognitive benefits in older old age (see Figure 3.24.) for this interaction. For WP variability in simple and complex

visual search, in younger old age, passive-processing does not distinguish performance but does confer cognitive benefits in older old age (see Figures 3.25. and 3.26.). However, as the effects for this scale were minimal, the analysis was not considered further.

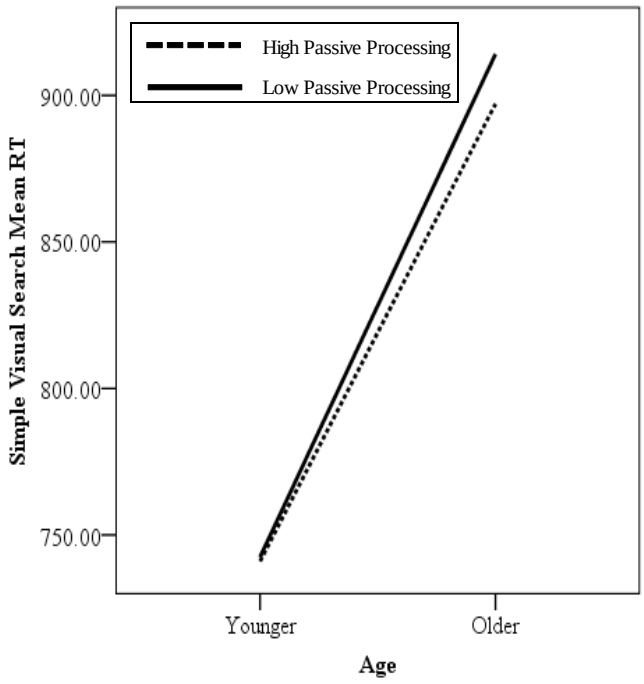

Figure 3.23. The significant Age x Passive Processing interaction in respect to mean RT in the simple visual search task (High = increased participation).

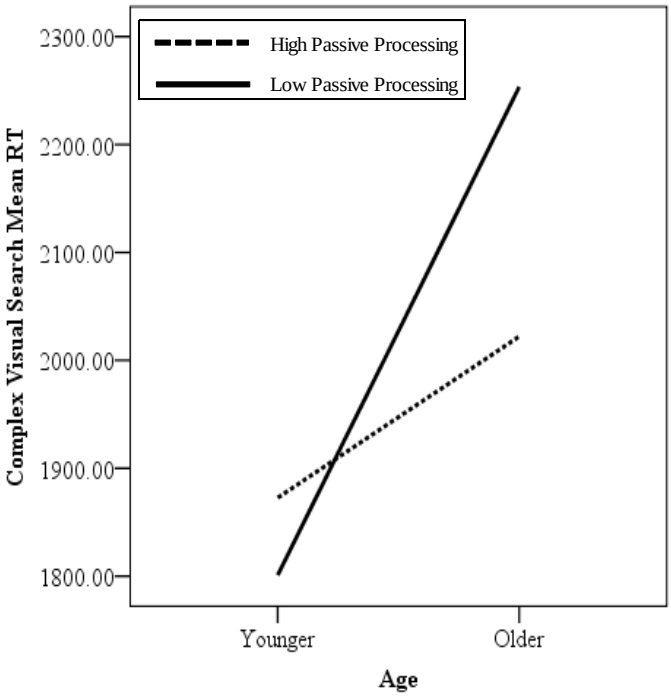

Figure 3.24. The significant Age x Passive Processing interaction in respect to mean RT in the complex visual search task (High = increased participation).

For WP variability in simple and complex visual search, in younger old age, passive-processing does not distinguish performance but does confer cognitive benefits in older old age (see Figures 3.25. and 3.26.). However, as the effects for this scale were minimal, the analysis was not considered further.

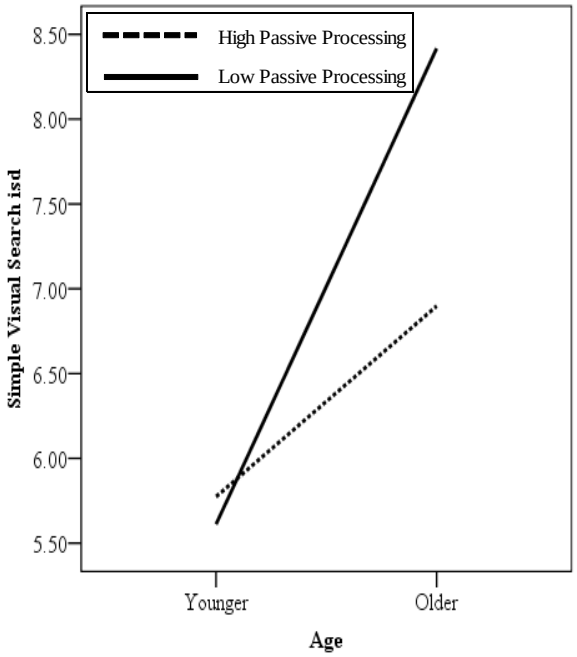

Figure 3.25. The significant Age x Passive Processing interaction in respect to WP variability in the simple visual search task (High = increased participation).

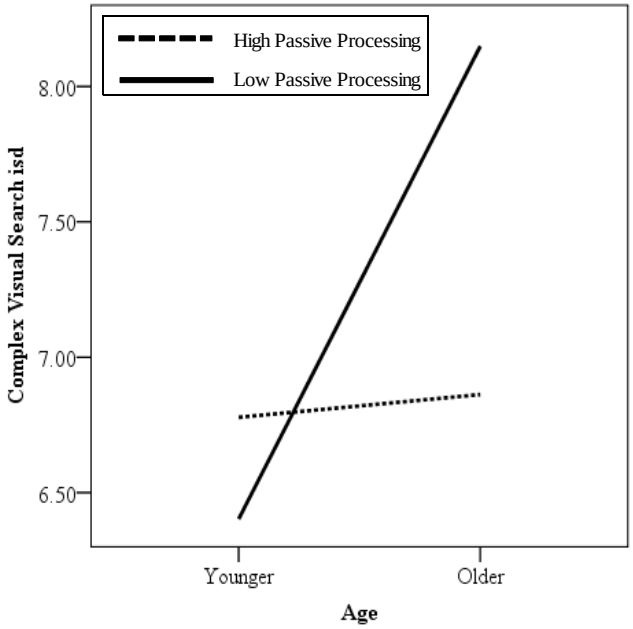

Figure 3.26. The significant Age x Passive Processing interaction in respect to WP variability in the complex visual search task (High = increased participation).

Novel-processing scale: for mean RT, the Age x Novel-processing interaction for SRT (ΔR^2 = .04, p < .05) was significant (see Table 3.7. and Figure 3.27. for interactions). The interaction graph was constructed using a median split on age and VLS novel-processing mean score (Age median = 63, M = 63.60, SD = 7.89; VLS novel-processing score median = 80.00, M = 81.03, SD = 18.04). For WP variability, there were no significant interactions. For novel information processing (novel-processing), the only significant interaction term was for mean RT in the SRT task. For this task, in younger old age, novel-processing did not distinguish performance but does clearly confer cognitive benefits in older old age (see Figure 3.27.). However, as this was the only significant interaction for this scale, the analysis was not considered further.

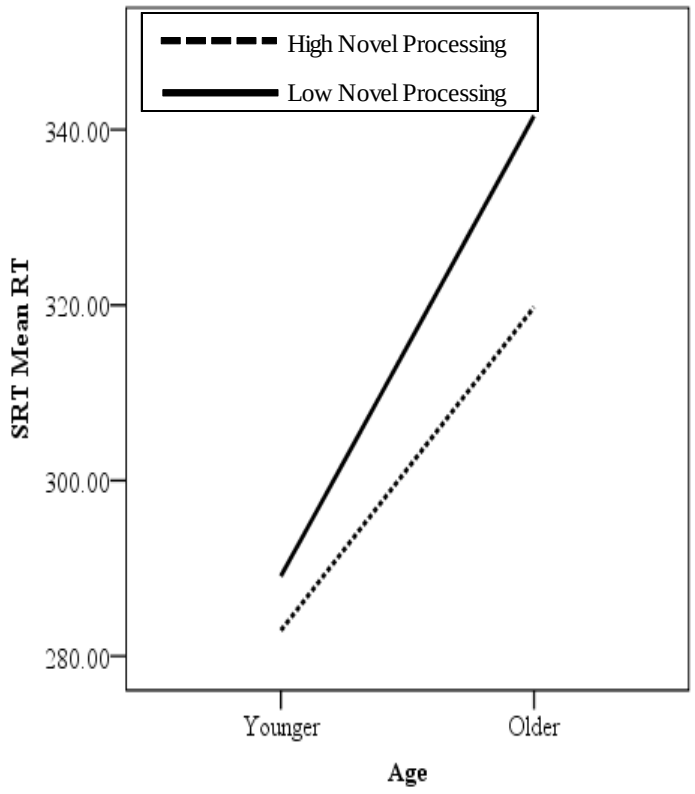

Figure 3.27. The significant Age x Novel Processing interaction in respect to mean RT in the SRT task (High = increased participation).

A further aim of this study was to assess if executive function accounted for the significant Age x VLS scale interactions. In other words, did executive function mediate the Age x VLS scale associations obtained earlier, an example of "mediated-moderation" (Baron & Kenny, 1986). This was of particular interest given that there was some evidence that mean RT and WP variability dissociated in relation to the physical activity scale, indicated by more significant interactions for the ISD measures than for mean RT measures. These additional exploratory analyses stemmed from the theoretical rationale that WP variability reflects fluctuations in executive control and evidence that, as suggested in Study 1, executive control mediates general cognition. Of interest here was also, which, if any, of the VLS scales indicated any mediation by executive function, in particular the effects of physical activity which are said to be mediated by frontal lobe mechanisms (Kramer et al., 2006). Also, as mentioned in the introduction, an engaged lifestyle (intellectual, social and hobbies and home maintenance) has a beneficial effect on maintaining cognition in older age and delaying cognitive decline (Bielak et al., 2012; Small et al., 2012; Wang et al., 2002). Therefore, initially, a further series of hierarchical regression models were run for the physical activity, social activity and hobbies and home maintenance scales. Here, the hierarchical regression analysis also controlled for a composite measure of executive function combining the flanker arrows, Stroop arrow and Stroop word data for both congruent and incongruent conditions for respective mean RT or WP variability analyses. These composite measures were obtained from principal component analysis where a single factor was requested and the factor scores saved.

The resulting composite measure of executive function was entered into repeat regression analyses at Step 1 to ascertain if the effect sizes of the significant interactions obtained in the original equations were attenuated. Attenuation of the shared variance associated with the significant Age x VLS score interaction terms would suggest that executive function mediated associations between age, VLS scale and cognition. The results from these analyses were that some of the previously significant Age x VLS scale interactions became non-significant when executive function was controlled, for both mean RT and WP variability. For the physical activity scale, the following previously significant interactions became non-significant: The mean RT interaction for Stroop word (p = .51) and the WP

variability interactions for 4-CRT (p = .39), Stroop word (p = .72) and delayed recognition (p = .07). For the social activity scale the following previously significant interactions became non-significant: The mean RT interactions for Stroop arrow (p = .32) and Stroop word (p = .25), and the WP variability interactions for Stroop arrow (p = .09) and Stroop word (p = .11). For the hobbies and home maintenance scale the following previously significant interactions became non-significant, the WP variability interaction for immediate recognition (p = .05). Together, these findings suggest that executive function was the mechanism mediating that particular VLS scale in those associations.

Structural equation modelling (SEM) was used to further explore how far interactions between age and the VLS scale were mediated by executive function. Hierarchical regression analysis is able to explain how well variables are able to predict an outcome and whether a predictor variable is still able to predict this outcome when the effects of another variable are controlled for. SEM, however, is a more sophisticated approach that allows simultaneous analyses of multiple variables and constructs (Schumacker & Lomax, 2004). In this particular study it allowed simultaneous analyses of the relations between the cognitive tasks, independent variables and cognitive domains. Age, NART, VLS scale and Age x VLS scale formed the exogenous variables, and psychomotor performance, executive function, visual search and recognition served as the endogenous variables. While Studies 1 and 2 confirmed that the four cognitive domains were significantly associated with executive function and mental health, the present investigation assessed the role of lifestyle activity as measured by the VLS lifestyle questionnaire. The aims of the structural equation models were two-fold. First, to investigate whether WP variability and mean RT varied as a function of age and VLS scale, and second, to investigate if executive function mediated the Age x VLS interactions. For this reason, the three-step model used in the previous studies was used following the recommendations of Baron and Kenny (1986). Various established goodness-of-fit measures were used to evaluate the models, as previously discussed in Study 1.

The models described below were run separately for each of the VLS scales that achieved significant interactions in the earlier multiple regression analyses - physical activity, social activity and, hobbies and home maintenance.

In Model 1, NART, age, VLS scale and the Age x VLS scale cross-product interaction term formed the exogenous variables whilst psychomotor performance, executive function, visual search, and recognition latent constructs formed the endogenous variables (see Figure 3.28.). The important aspect of this model was whether the Age x VLS scale interaction paths attained significance after the primary effects of intelligence (NART score), age and the VLS scale had been taken into account. As noted earlier, including NART scores controls for the possibility that age differences in IQ may underlie differences in the cognitive variables and therefore act to confound associations. In Model 2, all of the paths from the exogenous to the endogenous variables were eliminated except for those to executive function. Additional paths were introduced, however, from executive function to the endogenous variables of psychomotor performance, visual search and recognition (see Figure 3.29.). The focus of interest in this model was whether the Age x VLS path to executive function was significant and whether the paths between executive function and the endogenous variables became significant. Finally, Model 3 combined Models 1 and 2, but with the additional direct paths from age, Age x VLS and NART to the cognitive constructs were reintroduced (see Figure 3.30.).

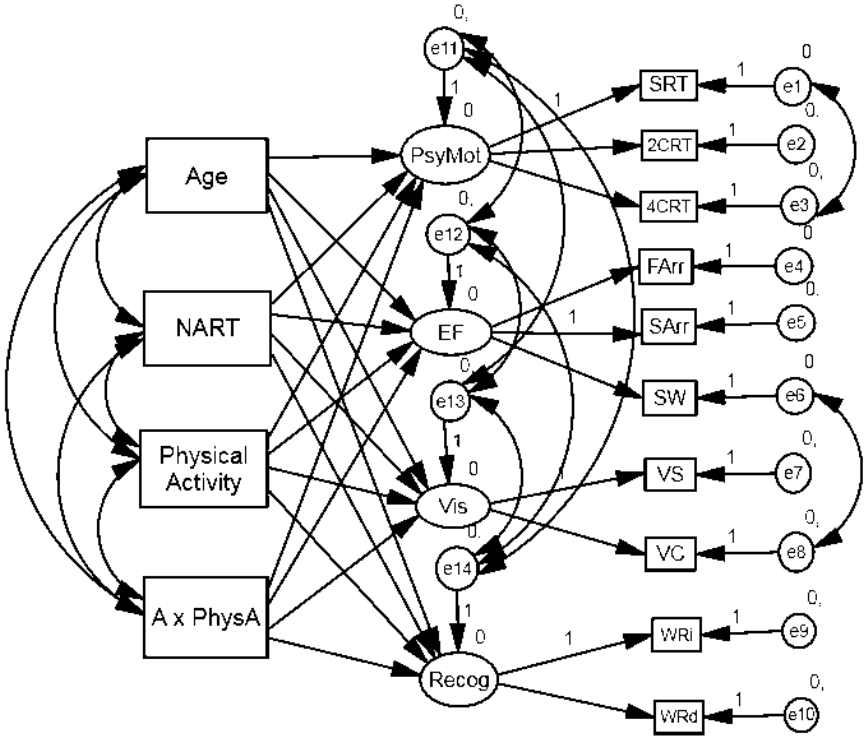

Figure 3.28. Structural Equation Model 1, for Age, Physical activity, Age x Physical activity interaction terms, and cognitive variables.

e1-e14 = error terms 1-14; PsyMot = psychomotor performance; EF = executive function; VS = visual search; WRi = immediate recognition; WRd = delayed recognition; SRT = simple reaction time; 2CRT = two-choice reaction time; 4CRT = four-choice reaction time; FArr = flanker arrows; SArr = Stroop arrow; SW = Stroop word; VS = simple visual search; VC = complex visual search; Recog = recognition; Vis = visual search; PhysA = physical activity; A x PhysA = age x physical activity interaction term; NART = National Adult Reading Test.

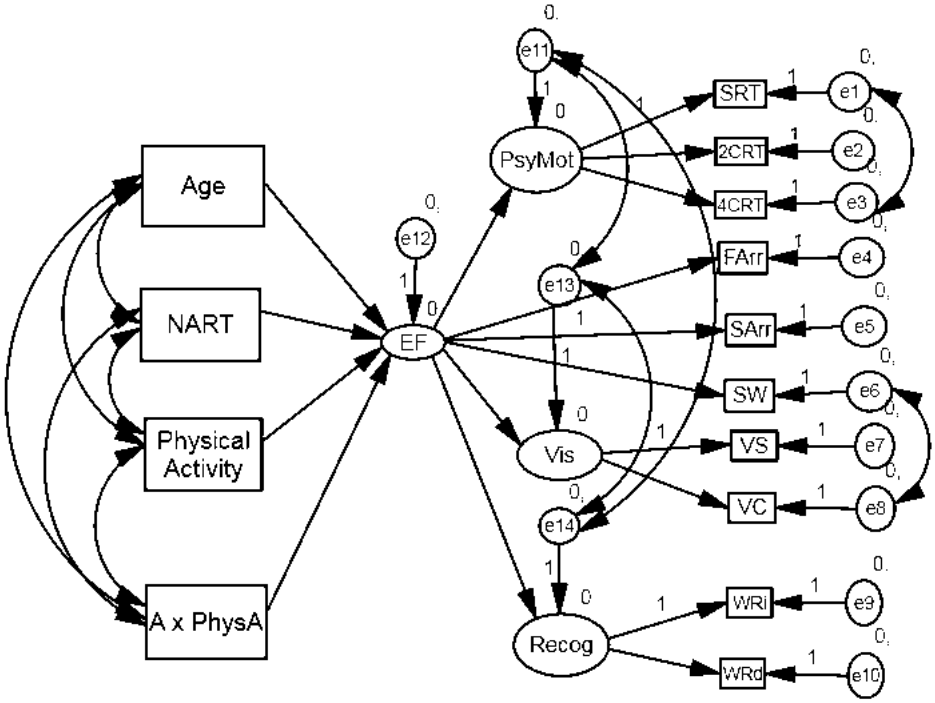

Figure 3.29. Structural Equation Model 2, for Age, Physical activity, Age x Physical activity interaction terms, and cognitive variables.

e1-e14 = error terms 1-14; PsyMot = psychomotor performance; EF = executive function; VS = visual search; WRi = immediate recognition; WRd = delayed recognition; SRT = simple reaction time; 2CRT = two-choice reaction time; 4CRT = four-choice reaction time; FArr = flanker arrows; SArr = Stroop arrow; SW = Stroop word; VS = simple visual search; VC = complex visual search; Recog = recognition; Vis = visual search; PhysA = physical activity; A x PhysA = age x physical activity interaction term; NART = National Adult Reading Test.

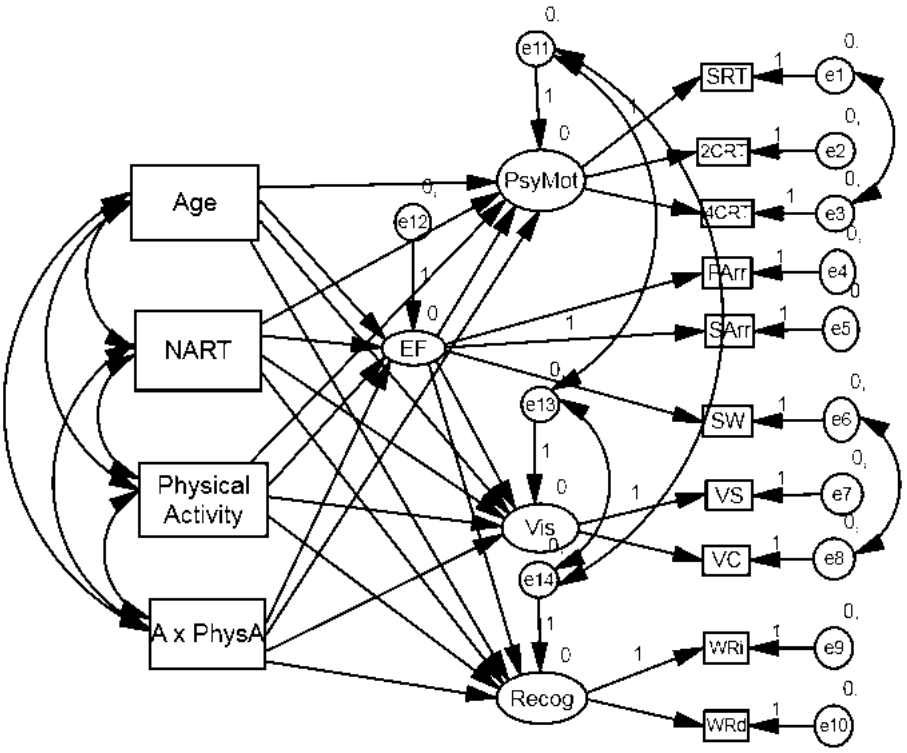

Figure 3.30. Structural Equation Model 3, for Age, Physical activity, Age x Physical activity interaction terms, and cognitive variables.

e1-e14 = error terms 1-14; PsyMot = psychomotor performance; EF = executive function; VS = visual search; WRi = immediate recognition; WRd = delayed recognition; SRT = simple reaction time; 2CRT = two-choice reaction time; 4CRT = four-choice reaction time; FArr = flanker arrows; SArr = Stroop arrow; SW = Stroop word; VS = simple visual search; VC = complex visual search; Recog = recognition; Vis = visual search; PhysA = physical activity; A x PhysA = age x physical activity interaction term; NART = National Adult Reading Test.

For the VLS physical activity scale, although the hierarchical regression analysis controlling for executive function indicated that some of the Age x Physical activity paths became non-significant when executive function was taken into account, this three model approach based on Baron & Kenny (1986) and Bunce et al., (2008b) enabled an investigation of whether executive function was acting as a mediator of Age x VLS associations across all cognitive domains simultaneously (i.e., "mediated-moderation"). This process was then repeated for the social activity and, hobbies and home maintenance VLS scales, just changing the applicable rectangular boxed exogenous variables to reflect the VLS scale in the analysis. The goodness-of-fit statistics and standardized path coefficients for WP variability and mean RT for the three models for all three remaining scales are presented in Tables 3.8. to 3.10.

For the VLS physical activity scale, in Model 1, although chi-square for both mean RT and WP Variability was significant ($X^2 = 82.98$, $p < .01$ and $X^2 = 79.10$, $p < .01$, respectively), the other goodness-of-fit statistics suggested acceptable model fit (mean RT: $X^2/df = 1.63$, NFI = .97, CFI = .94, RMSEA = .05; WP variability: $X^2/df = 1.55$, NFI = .96, CFI = .89, RMSEA = .05). Considering Table 3.8., it can be seen in Step 1 that older age is significantly ($p < .01$) associated with greater WP variability and slower mean RT with all paths to the latent variables (psychomotor performance, executive function, visual search and recognition) significant, as was established in Study 1 (See Figure 3.28. for Model 1). The important outcomes of this step were the significant coefficient pathways were between executive function and physical activity ($p < .01$) and between recognition and physical activity ($p < .01$) for both mean RT and WP variability. This suggested that lower physical activity was associated with slower mean RTs and greater WP variability in executive function and recognition task performance.

In Model 2, paths were directed to and from executive function to see whether it was the possible mechanism by which the Age x Physical activity interaction influenced mean RT and WP variability in recognition (See Figure 3.29.). If executive function was the mechanism, it would be expected that the path between executive function and Age x Physical activity would be significant. Chi-square for both mean RT and WP Variability was significant, $X^2 = 114.44$, $p < .01$ and $X^2 = 115.89$, $p < .01$, respectively; the other goodness-of-fit statistics suggested an

acceptable fit (X^2/df = 1.82, NFI = .91, CFI = .96, RMSEA = .06) and (X^2/df = 1.84, NFI = .84, CFI = .92, RMSEA = .06) respectively. Age and executive function and age were significantly associated ($p < .01$), as they were in Model 1. Executive function and the cognitive domains for both mean RT and WP variability were also positively associated ($p < .01$). This indicates co-variation between mean RT and WP variability in executive function and the other cognitive domains. The path between executive function and physical activity and Age x Physical activity for mean RT and WP variability attained significance ($p < .05$) suggesting that physical activity was associated with mean RT and variability in executive functioning. This fulfils the second part of the criteria for mediation, according to Baron and Kenny (1986).

To test this further, Model 3 combined both Models 1 and 2 with additional direct paths drawn from executive function to psychomotor performance, visual search and recognition (see Figure 3.30.). If executive function was accounting in any way, for the Age x Physical activity interaction with recognition for mean RT and WP variability, then the significant regression paths from Model 1, should become non-significant. Chi-square for both mean RT and WP variability was significant, X^2 = 82.98, $p < .01$ and X^2 = 79.10, $p < .01$, respectively, the other goodness-of-fit statistics suggested a good fit with mean RT, (X^2/df = 1.63, NFI = .97, CFI = .94, RMSEA = .05) and WP variability, (X^2/df = 1.55, NFI = .96, CFI = .89, RMSEA = .05) respectively. Importantly, consideration of Step 3 in Table 3.8., indicates the Age x Physical activity to recognition path for WP variability became non-significant (p = .05) but not for mean RT, in which the path remained significant ($p < .05$). This suggests that executive function was fulfilling a mediation role in the association between age and physical activity in respect to cognition in this domain. Specifically, executive function attenuated the Age x Physical activity effects for WP variability in recognition. By contrast, a similar procedure in respect to social activity and hobbies and home maintenance scales did produce any evidence of mediation by executive function so just a brief summary of the SEM results is described for these two scales.

Table 3.8. Within-Person Variability and Mean Reaction Time Structural Equation Models (Steps): Goodness-of-Fit Measures and Standardized Regression Weights for Physical Activity Scale

		Mean RT			ISD		
Goodness-of-fit		**Step 1**	**Step 2**	**Step 3**	**Step 1**	**Step 2**	**Step 3**
Chi-squared		82.98	114.44	82.98	79.10	115.89	79.10
p value		.00	.00	.00	.00	.00	.00
CMIN/DF		1.63	1.82	1.63	1.55	1.84	1.55
CFI		.97	.96	.97	.96	.92	.96
NFI		.94	.91	.94	.89	.84	.89
RMSEA		.05	.06	.05	.05	.06	.05
Path Coefficients							
Psychomotor	<--Age	.45 **		-.28 **	.41 **		-.24
Executive Function	<--Age	.69 **	.65 **	.69 **	.57 **	.55 **	.57 **
Visual Search	<--Age	.53 **		-.05	.34 **		-.01
Recognition	<--Age	.54 **		.10	.39 **		.09
Psychomotor	<--Physical	-.04		.11 *	-.07		.15
Executive Function	<--Physical	-.15 **	-.12 *	-.09 **	-.19 **	-.15 *	-.19 **
Visual Search	<--Physical	-.05		.07	.04		.15 *
Recognition	<--Physical	-.18 **		-.08	-.22 **		-.12
Psychomotor	<--Age x physical	-.05		.04	-.09		.11
Executive Function	<--Age x physical	-.09	-.10 *	-.09	-.18 **	-.15 *	-.18 **
Visual Search	<--Age x physical	-.07		.01	.05		.15 *
Recognition	<--Age x physical	-.22 **		-.16 *	-.26 **		-.12
Psychomotor	<--EF		.80 **	1.06 **		.86 **	1.15 **
Visual Search	<--EF		.78 **	.85 **		.50 **	.62 **
Recognition	<--EF		.74 **	.64 **		.60 **	.54 **

Notes: CFI = comparitive fit index; NFI = normative fit index; RMSEA = root mean square error of approximation; CMIN/DF = chi-squared/degrees of freedom; Physical = Victoria Longitudinal Study physical activity scale.
*p < .05; **p < .01

For the social activity scale, in Model 1, although chi-square for both mean RT and WP variability was significant, X^2 = 71.88, p < .05 and X^2 = 86.76, p < .01, respectively; the other goodness-of-fit statistics suggested acceptable fit (mean RT: X^2/df = 1.41, NFI = .95, CFI = .98, RMSEA = .04; WP variability: X^2/df = 1.70, NFI = .88, CFI = .94, RMSEA = .05). Considering Table 3.9., it can be seen that older age is significantly (p < .01) associated with greater WP variability and slower mean RT with all the latent variables (psychomotor performance, executive function, visual search and recognition) significant, as was established in Study 1. The important outcomes of this step was the significant path coefficient between visual search and social activity (p < .05) for WP variability, indicating that social activity level is significantly associated with WP variability for visual search. This suggested that lower social activity were associated with slower mean RTs and greater WP variability in visual search. Also important were the significant pathways between executive function and Age x Social activity in mean RT (p < .05) and between

visual search and Age x Social activity for both mean RT and WP variability (p < .01). This suggests that social activity significantly moderates the association of age with visual search for both mean RT and WP variability.

In Model 2, paths were directed to and from executive function to see whether it was the possible mechanism by which the Age x Social activity interaction influenced mean RT and WP variability in visual search. As mentioned previously, this was found to not be the case as the executive function to social activity path was non-significant and the analysis will not be further discussed here. For visual search, although the requirements for mediation are fulfilled in Steps 1 and 2, in Step 3, the path is only marginally attenuated, i.e., no significant evidence of full mediation according to Baron and Kenny (1986).

Table 3.9. Within-Person Variability and Mean Reaction Time Structural Equation Models (Steps): Goodness-of-Fit Measures and Standardized Regression Weights for Social Activity Scale

		Mean RT			ISD		
Goodness-of-fit		**Step 1**	**Step 2**	**Step 3**	**Step 1**	**Step 2**	**Step 3**
Chi-squared		71.88	102.78	71.88	86.76	122.30	86.76
p value		.03	.00	.03	.00	.00	.00
CMIN/DF		1.41	1.63	1.41	1.70	1.94	1.70
CFI		.98	.97	.98	.94	.91	.94
NFI		.95	.92	.95	.88	.83	.88
RMSEA		.04	.05	.04	.05	.06	.05
Path Coefficients							
Psychomotor	<--Age	.45 **		-.24 **	.41 **		-.20
Executive Function	<--Age	.67 **	.64 **	.67 **	.56 **	.53 **	.56 **
Visual Search	<--Age	.51 **		-.02	.29 **		.07
Recognition	<--Age	.55 **		.08	.39 **		.03
Psychomotor	<--Social	-.07		-.08	-.01		.01
Executive Function	<--Social	.01	.00	.01	-.02	.01	-.20
Visual Search	<--Social	.08		.07	.13 *		.13 *
Recognition	<--Social	.01		.00	.00		.01
Psychomotor	<--Age x Social	.00		-.12 *	.05		-.08
Executive Function	<--Age x Social	.11 *	.11 *	.11 *	.13	.15 *	.13
Visual Search	<--Age x Social	.22 **		.13 *	.30 **		.25 **
Recognition	<--Age x Social	.11		.04	.02		-.06
Psychomotor	<--EF		.81 **	1.03 **		.87 **	1.08 **
Visual Search	<--EF		.79 **	.78 **		.56 **	.40 **
Recognition	<--EF		.73 **	.69 **		.56 **	.64 **

Notes: CFI = comparitive fit index; NFI = normative fit index; RMSEA = root mean square error of approximation; CMIN/DF = chi-squared/degrees of freedom; Social = Victoria Longitudinal Study Social Activity Scale.
*p < .05; **p < .01

For the hobbies and home maintenance activity scale, in Model 1, although chi-square for both mean RT and WP variability was significant ($X^2 = 95.61$, $p < .01$ and $X^2 = 90.56$, $p < .01$, respectively), the other goodness-of-fit statistics suggested acceptable model fit (mean RT: $X^2/df = 1.88$, NFI = .93, CFI = .97, RMSEA = .06, WP variability: $X^2/df = 1.78$, NFI = .88, CFI = .94, RMSEA = .06. Considering Table 3.10., it can be seen that older age is significantly ($p < .01$) associated with greater WP variability and slower mean RT with all paths to the latent variables (psychomotor performance, executive function, visual search and recognition) significant, as was established in Study 1. The important outcomes of this step were the significant coefficient pathways between executive function and, hobbies and home maintenance for both mean RT and WP variability ($p < .01$) and ($p < .05$) respectively. This suggested that lower hobbies and home maintenance score were associated with slower mean RTs and greater WP variability in executive function task performance. Also important were the significant pathways between visual search and Age x Hobbies and home maintenance for both mean RT and WP variability ($p < .05$) and between recognition and Age x Hobbies and home maintenance for both mean RT and WP variability ($p < .05$). This suggests that Hobbies and home maintenance significantly moderates the association of age with visual search and recognition for both mean RT and WP variability.

In Model 2, paths were directed to and from executive function to see whether it was the possible mechanism by which the Age x Hobbies and home maintenance interaction influenced mean RT and WP variability in visual search and recognition. As mentioned earlier, this was found to not be the case as although the executive function to hobbies and home maintenance activity path was significant for both mean RT and WP variability, the executive function to Age x Hobbies and Home maintenance activity path was non-significant and the analysis will not be further discussed here.

Table 3.10. Within-Person Variability and Mean Reaction Time Structural Equation Models (Steps): Goodness-of-Fit Measures and Standardized Regression Weights for Hobbies and Home Maintenance Scale

		Mean RT		ISD	
Goodness-of-fit		**Step 1**	**Step 2**	**Step 1**	**Step 2**
Chi-squared		95.61	126.86	90.56	108.81
p value		.00	.00	.00	.00
CMIN/DF		1.88	2.01	1.78	1.73
CFI		.97	.95	.94	.93
NFI		.93	.91	.88	.86
RMSEA		.06	.06	.06	.05
Path Coefficients					
Psychomotor	<--Age	.46 **		.41 **	
Executive Function	<--Age	.69 **	.65 **	.56 **	.54 **
Visual Search	<--Age	.52 **		.33 **	
Recognition	<--Age	.54 **		.38 **	
Psychomotor	<--Hobbies & Home	-.16		-.16 *	
Executive Function	<--Hobbies & Home	-.18 **	-.14 *	-.17 *	-.16 *
Visual Search	<--Hobbies & Home	-.09		-.06	
Recognition	<--Hobbies & Home	-.07		-.06	
Psychomotor	<--Age x Hobbies & Home	.05		-.01	
Executive Function	<--Age x Hobbies & Home	.02	-.04	-.10	-.10
Visual Search	<--Age x Hobbies & Home	-.16 *		-.15 *	
Recognition	<--Age x Hobbies & Home	-.16 *		-.19 *	
Psychomotor	<--EF		.80 **		.87 **
Visual Search	<--EF		.78 **		.53 **
Recognition	<--EF		.73 **		.58 **

Notes: CFQ = comparitive fit index; NFI = normative fit index; RMSEA = root mean square error of approximation; CMIN/DF = chi-squared/degrees of freedom; Hobbies & Home = Victoria Longitudinal Study hobbies and home maintenance scale.
*p < .05; **p < .01

Discussion

This study investigated the association between lifestyle activities and cognition in older adults in relation to both mean RT and WP variability across a comprehensive battery of cognitive tasks. The aim of the study was to extend existing research (Hultsch et al., 1999) that investigated age and lifestyle activities in a sample population of 250 older adults aged 55 to 86 years. In their initial cross-sectional analyses, they found no evidence of a positive association between the self-maintenance or passive information processing scales and cognitive performance. The main findings of this study indicated that there were several significant Age x VLS scale interactions for both mean RT and WP variability. This suggested that the scales were selectively moderating the effect of age on mean RT and WP variability, with lower VLS scale activity associated with slower mean RTs and greater WP variability. A major objective of this study was to use the

moderation and mediation technique employed in Studies 1 and 2 to investigate whether executive function mediated the significant Age x VLS scale interactions in relation to cognition. Previous research suggests fluctuations in executive function underlie WP variability (Bunce et al., 2004; West et al., 2002). Therefore, executive function was investigated as a possible mediator in both hierarchical multiple regression analysis and structural equation modelling, based on research which suggests an active lifestyle overall may mediate neurocognitive decline and possibly delay the onset of neurodegenerative diseases in older age (Dixon, 2011; Stine-Morrow & Basak, 2011).

In the present study, several significant associations were found between cognition and the different VLS scales, indicating that the different activities were selectively associated with age differences in cognition. According to the bivariate correlations, the VLS scales varied in their association with all cognitive tasks for both mean RT and WP variability. The physical activity scale was associated with mean RT in immediate recognition, and WP variability with flanker arrows, Stroop arrow, immediate recognition and delayed recognition. The self-maintenance scale was associated with mean RT in simple visual search, and WP variability with immediate recognition. The social activity scale was associated with WP variability in simple visual search. The hobbies and home maintenance scale was associated with mean RT in SRT, flanker arrows and simple visual search. It was also associated with WP variability in 4-CRT and flanker arrows. The passive information processing scale was not associated with any cognitive variables and the novel information processing scale was associated with mean RT in Stroop arrow, Stroop word and delayed recognition tasks.

The hierarchical regression analyses for both mean RT and WP variability yielded several significant Age x VLS scale interactions, indicating moderating effects of activity in specific scales. For the physical activity scale, the hierarchical regression analyses for both mean RT and WP variability yielded several significant Age x Physical activity interactions. For mean RT, the interactions in respect to flanker arrows, Stroop word and immediate recognition suggested that lower participation in physical activities was associated with slower responding in older adults (see Figures 3.1. to 3.3. for these interactions). For WP variability, the interactions in respect to 4-CRT, flanker arrows, Stroop word, immediate

recognition and delayed recognition suggested that lower participation in physical activities was associated with greater variability in older adults (see Figures 3.4. to 3.8. for these interactions). Having established that physical activity benefitted cognition in old age, a further major objective was to investigate if executive function mediated the significant interactions between age, physical activity, and cognition. Although physical activity has been associated with cognition generally in old age, the effect is most marked in executive control processes such as inhibition, working memory and planning (Kramer et al., 2006). The rationale behind these analyses was that WP variability is associated with age-related neurobiological changes in the frontal regions of the brain which support executive control. In order to explore this, both multiple regression and structural equation modelling were used.

As described in the Results section, the key part of the third stage of the SEM analysis was whether the significant Age x Physical activity interactions obtained in Model 1 were rendered nonsignificant or attenuated having controlled for executive function. For WP variability for recognition, the path became nonsignificant after controlling for executive function. This would indicate that WP variability in executive function mediated relations between age, physical activity and WP variability in recognition. This also suggests a common underlying cause between executive function and recognition in older age and of interest here is that WP variability, known to be associated with neurobiological decline, reflected this association. This VLS scale provides important theoretical insights into how physical activity is positively associated with cognitive function in older age. From a clinical perspective, the study also highlights the importance of how physical activity affects cognition in older age and how physical activity programmes could provide the focus of intervention in primary health care for older people. Study 4 expands on the findings for this scale by investigating an objective measure of aerobic fitness as a moderator, using the same analytical process performed here. In Study 4, aerobic fitness is empirically measured by means of the Rockport 1-mile walking test, yielding a sub-maximal oxygen uptake (VO_{2max}) measure (Kline, Porcari, Hintermeister, Freedson, & Rippe, 1987).

It should also be noted that the executive function to psychomotor performance path coefficient for mean RT was 1.06, $p < .01$ and the executive function to psychomotor performance path coefficient for the ISD measure was 1.15, $p < .01$. Although counterintuitive to most statistical procedures, in structural equation modelling, it is acceptable that a standardised path coefficient is + > 1, which often occurs when variables share a high degree of multi-collinearity (Jöreskog, 1999; Kline, 2005). In this case, the cognitive domains of executive function and psychomotor performance correlated highly to produce coefficient pathways of + > 1 in Model 3 for both mean RT and WP variability. This could be due to the nature of the tasks within each domain which may have overlapped considerably in the cognitive processes they captured. This could also be due to common method variance whereby each of the cognitive variables were subject to the same measurements (mean RT and WP variability) throughout and this may inflate multi-collinearity between variables (Johnson et al., 2011). This was discussed further in Study 1.

For the social activity and hobbies and home maintenance scales, the same analytical procedure was repeated. The hierarchical regression analyses for both mean RT and WP variability yielded several significant positive Age x Social activity and Age x Hobbies and home maintenance interactions, (see Figures 3.10. to 3.15. and Figures 3.16. to 3.22. respectively for these interactions). However, the SEM analysis did not show this variable to be mediated by executive function and this procedure was not considered further. Findings here also failed to yield a high number of significant interactions for the novel information processing scale as Hultsch et al. (1999) found in their studies (Bielak et al., 2007; Hultsch et al., 1999). As this was a cross-sectional study with a physically active population, direct comparisons cannot be made

Evidence of the neurobiological benefits of an active lifestyle have been found in recent studies. Small et al. (2006) reported improvement in verbal fluency and reduced dorsolateral prefrontal cortex (DLPFC) activity after a 14 day lifestyle intervention programme. Reduced DLPFC activity indicates greater efficiency of neural processing. This programme included intellectual and physical activities and change to a healthier diet. This indicates that if improvements to lifestyle

activities can make a difference to the pre-frontal regions in just 14 days, long-term lifestyle engagement would have a positive effect on overall executive function and general cognition in the longer term (Small et al., 2006). Improved executive function was also found in older people who took part in the Experience Corps project (Carlson et al., 2008; Fried et al., 2004). In this programme, participants worked in schools for 15 hours a week and reported that they increased their own physical activity levels and social contact, reducing the time spent watching television. The researchers of this project attributed the improvements due to increased cognitive demands because of the variety of activities the participant had to undertake, such as filing library books, reading to children, managing complex filing system and assisting in general school activities (Stine-Morrow & Basak, 2011). Another research programme recruited participants to the Senior Odyssey project (Stine-Morrow et al., 2008), an intellectual problem solving project in which participants worked together in teams. The initial research findings emerging from this study indicate improvements in fluid ability and working memory. Findings from the present study are largely in line with this work elsewhere. However, an important question is what mechanism may underpin the association between lifestyle activities and cognition in this older group?

The 'engagement hypothesis' of cognitive aging suggests that a lifestyle which continues to include social and intellectual engagement could compensate for some of the age-related declines in cognitive function (Schooler & Mulatu, 2001). Situations in which complex decisions have to be made, for example, playing bridge, quizzes and competitions, usually include social interaction by default. So, it is often found that continuation of intellectual activities includes social benefits as well. There is however, a causal effect as people who have higher intellectual functioning already are more likely to participate in environments of a complex nature, choosing not to withdraw into solitude and less complexity (Schooler & Mulatu, 2001). In addition, those participating in a variety of lifestyle activities experience a higher level of physical and mental health (Strawbridge et al., 1996).

There are also some limitations to a self-report scale where activities are defined and categorised in such a way as to limit the choice that can be made, and excluding other valid activities that are not defined. A proposal has been to

concurrently administer the VLS questionnaire or other lifestyle questionnaires alongside reports, diaries or third person observations (Jopp & Hertzog, 2010). Given the practical limitations of the present study though, such extensive questioning was not possible. It should also be noted that although the entire VLS questionnaire had high internal consistency with a Cronbach alpha of .76, some of the individual scales yielded low Cronbach alphas, indicating that their measurement had low internal consistency and this is a limitation in this study.

To conclude, in this sample of 257 community-dwelling, healthy older adults aged 50-90 years, there was evidence that physical activity, social activity and hobbies and home maintenance was positively associated with cognition, as measured by their respective VLS scales. Significant interactions were found in all the VLS scales, indicating that some moderation of age-cognition relations was occurring across all lifestyle activity scales. Importantly, it was found that certain cognitive domains benefitted the most from an active lifestyle, for example, executive function and recognition in the physical activity scale, executive function and visual search in the social activity scale and, visual search and recognition in the hobbies and home maintenance scales. It has been suggested that an active lifestyle could be domain specific in its effects, whereby certain activities could influence specific cognitive domains (Bielak, 2010). Here there was some evidence of executive function gaining the most benefit from an active lifestyle. There was also some evidence also that executive function mediated the significant effects of physical activity in respect to recognition domain for WP variability. This finding is consistent with the view that physical activity attenuates the underlying neurobiological deterioration that contributes to cognitive decline in old age (Bunce & Murden, 2006; Erickson & Kramer, 2009). In conclusion, this study suggests that participation in lifestyle activities has a positive effect on cognitive performance in old age, which has important implications for the management of older people in primary health care settings. Given the positive benefits found for physical activity using a self-report measure in the present study, the next investigation assesses an objective measure of physical fitness in relation to age and cognition.

Study 4

Aerobic fitness as a moderator of age-related cognitive decline

Introduction

There is substantial evidence that physical fitness slows cognitive decline, delays dementia in older age and benefits overall cognition (Arcoverde et al., 2008; Bunce & Murden, 2006; Carlson et al., 2008; Colcombe & Kramer, 2003; Colcombe, Kramer, Erickson, et al., 2004; Erickson & Kramer, 2009; Flicker et al., 2011; Kramer, Colcombe, McAuley, Scalf, & Erickson, 2005; Kramer & Erickson, 2007b; Kramer et al., 2006; Larson et al., 2006; McAuley, Kramer, & Colcombe, 2004; McAuley et al., 2011; Spirduso, 1980; van Praag, 2009; Voss et al., 2010; Weinstein et al., 2011). In addition, high aerobic fitness is associated with more efficient blood oxygen and nutrient delivery to the brain (Marks, Katz, Styner, & Smith, 2011). In the Main Introduction, a general background was presented discussing how physical fitness affects cognitive function in older age. Here, a summary of the main points is presented, in accordance with the aims of this study.

Evidence suggests that physical fitness has a positive effect on cognition due to neurobiological benefits associated with physical fitness that include greater pre-frontal cortex volume (Colcombe et al., 2003; Colcombe et al., 2006; Weinstein et al., 2011), increased hippocampal volume (Erickson & Kramer, 2009), increase in cerebral blood flow (Burdette et al., 2010; Pereira et al., 2007; Swain et al., 2003), and superior biogenesis of neuronal mitochondria (Steiner, Murphy, McClellan, Carmichael, & Davis, 2011) and neurotransmitter synthesis (Dishman et al., 2006; Tillerson, Caudle, Reveron, & Miller, 2003). From a physiological perspective, physical fitness is also associated with greater cardiovascular capacity which aids the efficiency with which oxygen and nutrients are delivered to the brain due to the increase in cerebral blood flow (Vogiatzis et al., 2011) and consequent increased oxidation which particularly benefits executive function supported by the frontal lobes (Ide & Secher, 2000). These biological benefits are likely to

attenuate cognitive decline (Bunce & Murden, 2006; Bunce et al., 1993). For cognitive neuropsychologists, one focus of interest has concerned the benefits afforded to the prefrontal cortex and its associated cognitive functions, particularly executive control. The attributes of executive control were discussed in more detail in Study 1.

With regard to recent research, Colcombe et al. (2004) investigated physical fitness, neural structure, and functional correlates using both structural magnetic resonance imaging (MRI) and functional magnetic resonance imaging (fMRI). The participants were divided into lower and higher VO_{2max} (direct measurement of maximal oxygen consumption, measured by the volume of oxygen used in one minute per kilogram of body weight with a high VO_{2max} indicating higher fitness) and participants with higher VO_{2max} displayed greater brain activation in attentional tasks. The structural MRI study showed that cortical density was higher in the frontal and parietal regions. The study suggested that a higher level of cardiovascular fitness could improve plasticity (changes in neural structure) and thereby help maintain cognitive function in older age. In a second part of this investigation, participants were invited to take part in an exercise programme for six months. They were randomly divided into two groups, a stretching and toning group, and a physical cardiovascular group. Cognitively, the aerobic group showed an 11% reduction in attentional interference and the toning group (control) only a 2% reduction (Colcombe, Kramer, McAuley, Erickson, & Scalf, 2004). This study showed that physical exercise has a beneficial effect on both cognitive function and neural plasticity but the indications were that aerobic exercise was associated with greater benefits. Other research, on mice found a reduction of Aβ-42 deposits, which is the main component of the amyloid plaques and cerebrovascular amyloid deposits found in Alzheimer's disease (Desdouits, Buxbaum, Desdouits-Magnen, Nairn, & Greengard, 1996) and an improvement in behavioural function in mice who exercised (Cho et al., 2003). Another finding was that moderate exercise in young mice increased life span, decreased oxidative stress and prevented the decline of cytochrome oxidase activity (a beta-amyloid precursor protein), which, in turn, prevented decline of behavioural activity (cognition) during middle age (Navarro, Gomez, Lopez-Cepero, & Boveris, 2004). This did not occur in older mice, however, which is consistent with findings that older (75 years +) individuals do not experience the same benefits to cognition from physical fitness as 'younger'

older people (Bunce & Murden, 2006; Kramer et al., 2005). This suggests that physical fitness may produce diminishing returns whereby the benefits to cognition in old age diminish with increasing age. This was demonstrated in a study by Bunce and Murden (2006) who found that aerobic exercise had a beneficial effect on free recall in older persons but, as with the mouse research of Navarro et al. (2003), the effect reduced with increasing age.

Other cognitive research investigating physical fitness showed some improvement in psychiatric problems amongst a group of 101 persons aged 60 years who took part in physical exercise (Blumenthal et al., 1991). The study, however, did not show participants improving on cognitive performance. There were various confounding factors that could have explained this, such as the existing exercise status of the participants. The subjects in this study were healthy and functioning at a high level to start with and it was proposed within the study that perhaps a group that was less healthy and high functioning would have shown more cognitive improvement. Bunce and Murden (2006) also discuss this and suggest their results could also be due to the nature of the memory task used, that required high cognitive support. In a cross-sectional study by Ruuskanen and Ruoppila (1995) it was found that psychological well-being was higher amongst a group of older individuals (65-74 years) who exercised regularly. This was not found in the older age group, 75 years and over. A possible reason for this finding was that a high level of psychological well-being was in fact the reason that people stayed physically active in older age, indicating a causal relationship (Ruuskanen & Ruoppila, 1995). The relationship between psychological well-being and physical activity is not examined here but it is an important causal aspect to consider in the light of the results of Study 2 (mental health) and this present study (aerobic fitness).

Laurin et al. (2001) conducted a study of 6,434 participants over the age of 55 years to take part in a study investigating physical fitness and cognition. At a 5-year follow-up, 4,615 participants underwent a repeat of the clinical and screening evaluations. It was found that those participants who took part in physical exercise had a lower incident of cognitive impairment and even dementia compared to those who did not participate in physical exercise (Laurin, Verreault, Lindsay, MacPherson, & Rockwood, 2001). The incident rate of cognitive

impairment lowered according to the amount of exercise undertaken with higher exercise levels associated with even less incidence of dementia and cognitive impairment. Yaffe et al. (2001) recruited women in a longitudinal intervention study to investigate whether walking could delay or prevent cognitive decline 6 to 8 years later. Cognitive decline was measured using the mini-mental state examination (MMSE) (Folstein et al., 1975) (Yaffe, Barnes, Nevitt, Lui, & Covinsky, 2001). The group of 5,925 women over the age of 65 reported how much exercise they completed per week. After adjusting for confounding lifestyle factors, the women who walked the greatest distance per week exhibited 17% cognitive decline while those who walked the least exhibited 24% cognitive decline.

Furthermore, regular walking was associated with a decline in incident dementia in men (Abbott et al., 2004). Like Yaffe et al. (2001), who recruited women, it was found that men who walked the most, had the least incidence of dementia or cognitive decline. The group of 2,257 men aged 71-93 years were assessed from 1991-1993 and followed up twice during 1994-1996 and 1997-1999. Larson et al. (2006) conducted a study of 1,740 elderly people over the age of 65, drawn from an initial random sample of 6,782. The study used the Cognitive Ability Screening Instrument (CASI) to assess cognitive function (Teng et al., 1994). Participants were followed for an average of 6.2 years investigating whether regular exercise (three times a week for 15 minutes) was associated with a reduction in incident dementia. Exercise was defined as walking, hiking, bicycling, physicals or callisthenics, swimming, water physicals, weight training or stretching, or any other physical exercise (Larson et al., 2006).

As the above research suggests, physical fitness is positively associated with cognitive benefits in older age. The frontal brain regions supporting the executive control processes (executive function) have been shown to derive the largest positive benefits from physical fitness (Kramer et al., 2006), particularly the cognitive benefits afforded by aerobic exercise (Colcombe, Kramer, McAuley, et al., 2004). This present study therefore set out to explore the association of age and aerobic fitness on cognitive performance by means of a two-stage analysis which assessed moderator-mediator relations similar to Studies 2 and 3. Initially, it investigated whether aerobic fitness, as measured by VO_{2max}, was associated with age and cognitive function. Specifically, in an initial moderator analysis using

hierarchical multiple regression, the cognitive variables were regressed onto the Age x VO_{2max} cross-product interaction term. In effect, this procedure assessed whether the association between age and the cognitive variable varied according to the level of aerobic fitness (the moderator variable), as measured by $VO_{2max.}$ If the Age x VO_{2max} interaction achieved significance over and above the primary effects for age and $VO_{2max,}$ it suggests that moderation has occurred. In a second analysis using structural equation modelling, executive function was taken into account in the analyses to see if any of the significant Age x VO_{2max} interactions in the initial analysis were attenuated or became non-significant. If such a finding was produced, it suggests that the association of age and aerobic fitness in respect to cognition is mediated by executive function. Such a finding would be consistent with the view that executive control, supported by the frontal lobes, is a key beneficiary of aerobic fitness. The cognitive domains examined included psychomotor performance, executive function, visual search and recognition. Importantly, as with previous work reported in this thesis, the present study contrasted the pattern of results for mean RT and WP variability. By focusing on an age range of 50 to 90 years, the study provides valuable insights into age, aerobic fitness and cognitive relations in this older age group.

Method, Data Analysis and Procedure

See Study 1 for these sections.

Measurement

Aerobic fitness

The Rockport Fitness Walking Test (Kline et al., 1987), a sub-maximal measure of aerobic fitness was used to provide an estimate of VO_{2max}. This measure has the benefits of being both quantifiable and objective. The testing procedure was as follows. Resting pulse was recorded before a1-mile (1,609m) walk on a motorized treadmill commenced. Participants were required to walk as fast as they could without running. Walking was defined as having foot contact with the treadmill at

all times. The treadmill walk was timed and recorded and the participant's pulse rate was taken again immediately on completion of the 1-mile walk. The sub maximal measure of VO_{2max} was computed according to the formula:

132.853 - (0.0769 × weight) - (0.3877 × Age) + (6.315 × gender) - (3.2649 × time) - (0.1565 × heart rate)

(Kline et al., 1987)

where weight is in pounds (lbs), gender defined as male = 1 and female = 0, time expressed in 100ths of minutes, heart rate in beats/minute, and age in years. Higher scores derived from this measure indicate higher aerobic fitness.

Results

Bivariate correlations, together with means and standard deviations for both the VO_{2max} measure and the cognitive variables, are presented in Table 4.1. The correlations between age and the cognitive variables have already been described in Study 1.

Here, the focus is on the correlations between VO_{2max}, age and the cognitive variables and are highlighted in bold in the table. In addition to the initial bivariate correlation analysis, a series of hierarchical regression models were used to provisionally explore the relationship between age, aerobic fitness, and the individual cognitive variables, using both mean RT and the WP variability measure as dependent variables. WP variability was measured by the computations of intraindividual standard deviation (ISD) described in the Method section of Study 1.

Table 4.1. Bivariate Correlations Between Biographical, Aerobic Fitness and Cognitive Variables

	Variable	*M (SD)*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	Age	63.60 (7.89)	—																							
2	Gender-women	154 (*n* = 257)	-.18 **	—																						
3	NART	120.33 (7.39)	-.04	-.12	—																					
4	**Aerobic Fitness**	**25.93 (17.25)**	**-.45 ** **	**-.17 ** **	**.00**	**—**																				
5	SRT (ms)	309.61 (75.05)	.35 **	.05	-.19 **	**-.37 ** **	—																			
6	SRT isd	6.87 (3.37)	.21 **	.03	-.16 **	**-.28 ** **	.72 **	—																		
7	2-CRT (ms)	363.82 (77.49)	.34 **	-.13 *	-.08	**-.35 ** **	.55 **	.38 **	—																	
8	2-CRT isd	6.71 (3.00)	.28 **	-.04	-.07	**-.31 ** **	.35 **	.36 **	.51 **	—																
9	4-CRT (ms)	553.35 (116.63)	.41 **	-.22 **	-.16 *	**-.32 ** **	.48 **	.34 **	.67 **	.43 **	—															
10	4-CRT isd	7.02 (2.81)	.29 **	-.10	-.17 **	**-.23 ** **	.30 **	.25 **	.41 **	.40 **	.73 **	—														
11	Flanker Arrows (ms)	685.28 (204.41)	.46 **	.07	-.20 **	**-.35 ** **	.52 **	.31 **	.41 **	.38 **	.51 **	.45 **	—													
12	Flanker Arrows isd	6.34 (6.06)	.35 **	.06	-.18 **	**-.34 ** **	.44 **	.28 **	.28 **	.34 **	.40 **	.44 **	.92 **	—												
13	Stroop Arrow (ms)	766.01 (117.41)	.52 **	-.03	-.23 **	**-.36 ** **	.48 **	.34 **	.56 **	.45 **	.65 **	.50 **	.55 **	.44 **	—											
14	Stroop Arrow isd	7.97 (3.20)	.28 **	.06	-.29 **	**-.29 ** **	.36 **	.31 **	.40 **	.36 **	.49 **	.47 **	.40 **	.35 **	.76 **	—										
15	Stroop Word (ms)	1079.39 (263.69)	.52 **	-.12	-.06	**-.45 ** **	.38 **	.26 **	.36 **	.32 **	.48 **	.40 **	.49 **	.43 **	.54 **	.37 **	—									
16	Stroop Word isd	8.19 (4.52)	.43 **	-.06	-.08	**-.39 ** **	.30 **	.23 **	.26 **	.29 **	.36 **	.35 **	.45 **	.43 **	.43 **	.35 **	.85 **	—								
17	Visual Search S. (ms)	827.18 (230.35)	.49 **	-.22 **	-.10	**-.31 ** **	.30 **	.22 **	.31 **	.27 **	.43 **	.31 **	.49 **	.42 **	.52 **	.35 **	.55 **	.43 **	—							
18	Visual Search S. isd	6.73 (4.54)	.31 **	-.16 *	-.08	**-.14 ***	.14 *	.10	.11	.14 *	.28 **	.23 **	.28 **	.23 **	.35 **	.29 **	.39 **	.31 **	.88 **	—						
19	Visual Search C. (ms)	1998.14 (671.32)	.30 **	-.13 *	-.09	**-.20 ** **	.20 **	.11	.21 **	.10	.30 **	.18 **	.29 **	.21 **	.38 **	.30 **	.49 **	.43 **	.55 **	.48 **	—					
20	Visual Search C. isd	7.09 (3.41)	.18 **	-.07	-.04	**-.13 ***	.08	.00	.09	.00	.22 **	.14 *	.17 **	.12	.27 **	.25 **	.34 **	.32 **	.49 **	.51 **	.89 **	—				
21	Recognition Imm. (ms)	1149.50 (297.41)	.39 **	-.04	-.03	**-.29 ** **	.26 **	.19 **	.33 **	.27 **	.34 **	.30 **	.43 **	.37 **	.40 **	.31 **	.43 **	.34 **	.42 **	.31 **	.34 **	.25 **	—			
22	Recognition Imm. isd	8.34 (5.00)	.22 **	.02	.03	**-.22 ** **	.17 **	.12 *	.15 *	.22 **	.17 **	.16 *	.29 **	.30 **	.20 **	.16 *	.27 **	.23 **	.31 **	.24 **	.27 **	.24 **	.82 **	—		
23	Recognition Del. (ms)	1086.76 (279.67)	.42 **	-.01	-.03	**-.31 ** **	.23 **	.08	.27 **	.29 **	.28 **	.22 **	.27 **	.20 **	.38 **	.27 **	.38 **	.34 **	.33 **	.21 **	.26 **	.21 **	.51 **	.39 **	—	
24	Recognition Del. isd	7.97 (4.54)	.24 **	.05	.02	**-.22 ** **	.09	.00	.14 *	.21 **	.13 *	.19 **	.18 **	.18 **	.21 **	.15 *	.23 **	.24 **	.18 **	.13 *	.14 *	.16 *	.33 **	.32 **	.81 **	—

Notes: NART = National Adult Reading Test; (ms) = milliseconds for reaction time; isd = intraindividual standard deviation; SRT = simple reaction time; 2-CRT or 4-CRT = two or four-choice reaction time; Visual Search S. Or C. = visual search simple or complex; Recognition Imm. or Del. = recognition immediate or delayed; Gender = Male - 1, Female - 2.
*p < .05; **p < .01

Additionally, structural equation modelling was used to further explore the extent to which executive function mediated the association between aerobic fitness and age in respect to cognitive performance. This was achieved by investigating the relationship between age and the latent constructs formed by the cognitive domains of psychomotor performance, executive function, visual search and recognition for both mean RT and WP variability.

Consideration of Table 4.1. indicates that correlations between $VO_{2\ max}$, and both age and gender were significant ($p < .01$), and those between $VO_{2\ max}$ and the cognitive variables were all negative and significant (all ps < .01), except for WP variability in simple and complex visual search which were ($p < .05$). This indicates that higher aerobic fitness was associated with lower WP variability and faster mean RT for all cognitive variables. The mean VO_{2max} value was $M = 25.93$, $SD = 17.25$. This was comparable to the values obtained by Bunce and Murden (2006), $M = 25.72$, $SD = 7.30$ and $M = 38.90$, $SD = 5.61$ for their less fit and fitter participants aged 60 to 75 years ($M = 66.61$), $n = 39$. To be noted is the smaller age range and number of participants.

A series of hierarchical multiple regression models were then used to explore the relationship between age, aerobic fitness and the cognitive variables. As National Adult Reading Test (NART) scores were significantly associated with both the mean RT and WP variability of the 4-CRT, flanker arrows and Stroop arrow tasks, this variable was controlled for at Step 1 of all of the regression models. By controlling for NART (adjusted IQ score), the possibility that age differences in IQ confound with age differences in performance on the cognitive tasks is addressed. At Step 2 of the regressions, the primary effects for chronological age and $VO_{2\ max}$ were entered. At Step 3, the Age x $VO_{2\ max}$ cross-product interaction term was entered. Importantly, if Step 3 added significantly to the variance (R^2) explained in the cognitive variable after taking the primary effects for age and $VO_{2\ max}$ into account, it would suggest that the strength of the association between age and cognitive performance varied according to $VO_{2\ max}$.

The results of the hierarchical regression models are presented in Table 4.2. All predictor variables were centred and resulting *z*-scores used throughout the analyses (see Study 1 for additional information on centring). Consideration of the beta weights obtained at Step 2 suggests that having controlled for NART scores, the associations between age and $VO_{2\ max}$ and the cognitive variables corresponded to the results obtained in the bivariate correlations reported in Table 4.1. Age and $VO_{2\ max}$ varied in their contribution to the shared variance (R^2) with the outcome variables, with between 9% and 33% for mean RT and between 3% and 23% for WP variability. Of particular interest, however, was whether entry of the Age x $VO_{2\ max}$ cross-product interaction term added to the variance explained in the various cognitive measures. As can be seen in Table 4.2., for more than half of the measures, the entry of this term added significantly to the variance.

For mean RT, the Age x $VO_{2\ max}$ interactions were significant for the flanker arrows ($\Delta R^2 = .02$, $p < .01$), Stroop word ($\Delta R^2 = .04$, $p < .01$), simple visual search ($\Delta R^2 = .02$, $p < .01$), complex visual search ($\Delta R^2 = .03$, $p < .01$) and the immediate recognition tasks ($\Delta R^2 = .01$, $p < .05$). For WP variability, the Age x $VO_{2\ max}$ interactions were also significant for the 4-CRT ($\Delta R^2 = .05$, $p < .01$), flanker arrows ($\Delta R^2 = .05$, $p < .01$), Stroop arrow ($\Delta R^2 = .02$, $p < .05$), Stroop word ($\Delta R^2 = .09$, $p < .01$), complex visual search ($\Delta R^2 = .03$, $p < .01$) and immediate recognition tasks ($\Delta R^2 = .02$, $p < .05$). The interaction plots for these effects are presented in Figures 4.1. to 4.11. Overall, it can be seen that for mean RT and WP variability, low $VO_{2\ max}$ is associated in an increase in both mean reaction time and within-person variability in older age. In other words, lower $VO_{2\ max}$ had a greater negative impact on mean RT and WP variability in older age.

Table 4.2. Hierarchical Regression Analysis: Cognitive Variables Regressed on Age, VO_{2max} and the Age x VO_{2max} Cross-Product Interaction Term for Mean Reaction Time (Mean RT) and Intraindividual Standard Deviation (ISD)

	SRT		2-CRT		4-CRT		Flanker Arrows		Stroop Arrow		Stroop Word		Visual Search S.		Visual Search C.		Recognition Imm.		Recognition Del.	
	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2
mean RT																				
Step 1:																				
NART	-.18 **	.04 **	-.08	.01	-.14 *	.02 *	-.18 **	.04 **	-.21 **	.05 **	-.04	.00	-.08	.01	-.07	.01	-.01	.00	-.01	.00
Step 2:																				
Age	.22 **		.22 **		.33 **		.36 **		.44 **		.40 **		.42 **		.25 **		.31 **		.35 **	
VO2	-.27 **	.17 **	-.25 **	.16 **	-.13	.19 **	-.12	.23 **	-.13 *	.29 **	-.18 **	.33 **	-.05	.24 **	-.01	.09 **	-.10	.16 **	-.14 *	.20 **
Step 3:																				
Age x VO2	.01	.00	-.10	.00	-.10	.01	-.16 **	.02 **	-.06	.00	-.21 **	.04 **	-.17 **	.02 **	-.19 **	.03 **	-.13 *	.01 *	-.05	.00
ISD																				
Step 1:																				
NART	-.16 *	.03 **	-.06	.01	-.16 **	.03 **	-.17 **	.03 **	-.28 **	.08 **	-.06	.01	-.07	.01	-.03	.00	.04	.00	.03	.00
Step 2:																				
Age	.10 **		.18 **		.21 **		.24 **		.16 *		.30 **		.30 **		.14 *		.14 *		.17 *	
VO2	-.26 **	.08 **	-.23 **	.12 **	-.03	.09 **	-.13	.16 **	-.16 *	.11 **	-.12	.23 **	.05	.09 **	.01	.03 *	-.09	.07 **	-.11	.08 **
Step 3:																				
Age x VO2	.06	.00	.01	.00	-.24 **	.05 **	-.25 **	.05 **	-.15 *	.02 *	-.33 **	.09 **	-.13	.01	-.18 **	.03 **	-.16 *	.02 *	-.09	.01

Notes: NART = National Adult Reading Test; VO2 = aerobic capacity ; SRT = simple reaction time; 2-CRT or 4-CRT = two or four-choice reaction time; Visual Search S. Or C. = visual search simple or complex; Recognition Imm. or Del. = recognition immediate or delayed.

Step 1, $df = 1, 255$; Step 2, $df = 2, 253$; Step 3, $df = 1, 252$.

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

The effects varied according to task but there were some general findings across all cognitive tasks. For mean RT in both flanker arrows and Stroop word, there were clear beneficial effects for both age and aerobic fitness. The interaction appears to stem from the older less fit declining more (see Figures 4.1. and 4.2.) for mean RT in flanker arrows and Stroop word interactions. The interaction graphs were constructed using a median split on age and VO_{2max} (Age median = 63, *M* = 63.60, *SD* = 7.89; VO_{2max} median = 29.06, *M* = 25.26, *SD* = 15.51). For mean RT in simple visual search, in younger old age, aerobic fitness does not distinguish performance but does clearly confer cognitive benefits in older old age (see Figure 4.3.). On the other hand, for complex visual search, the effects of aerobic fitness were less clear (see Figure 4.4.). For mean RT in immediate recognition, the benefits of aerobic fitness are apparent at both younger and older old age with only marginal differences between them (see Figure 4.5.).

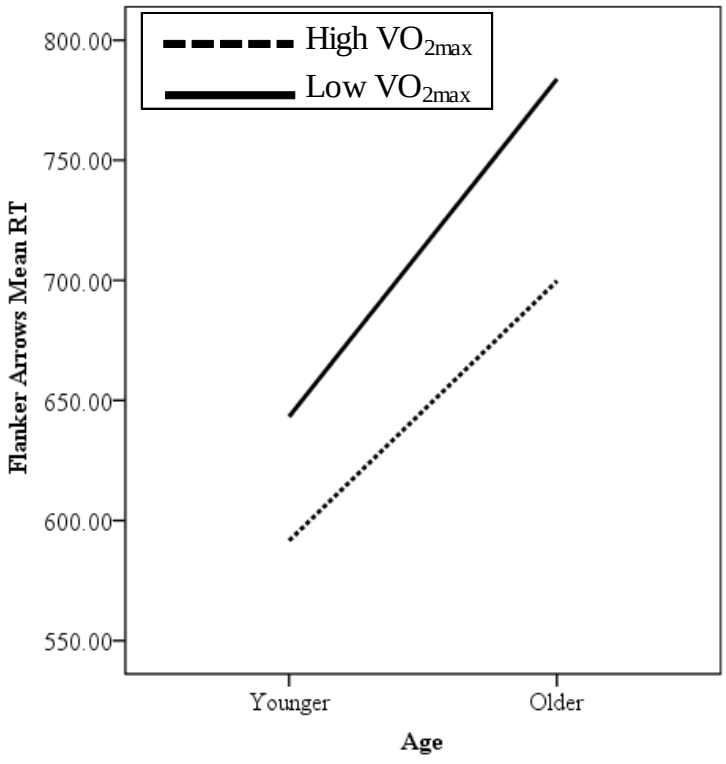

Figure 4.1. The significant Age x VO_{2max} interaction in respect to mean RT in the flanker arrows task (VO_{2max} = aerobic fitness; High VO_{2max} = increased aerobic fitness).

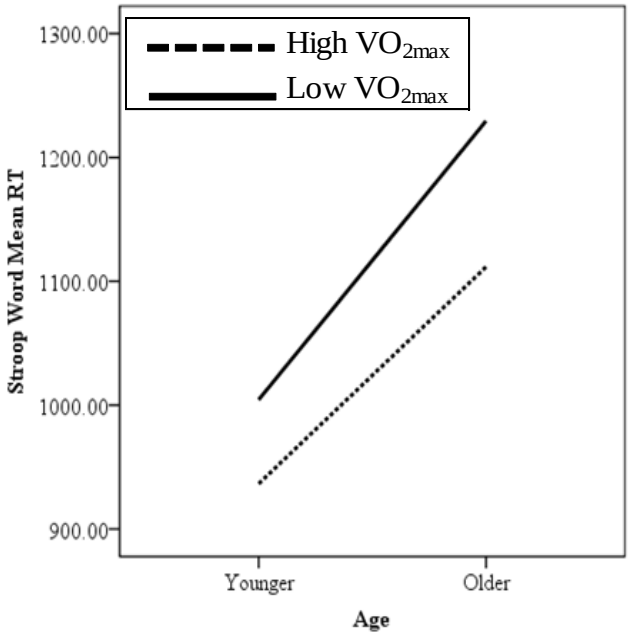

Figure 4.2. The significant Age x VO_{2max} interaction in respect to mean RT in the Stroop word task (VO_{2max} = aerobic fitness; High VO_{2max} = increased aerobic fitness).

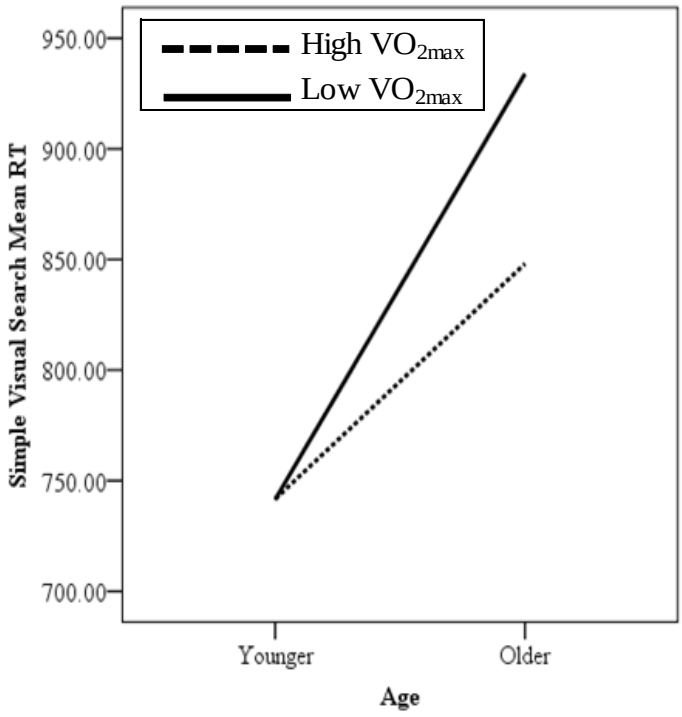

Figure 4.3. The significant Age x VO_{2max} interaction in respect to mean RT in the simple visual search task (VO_{2max} = aerobic fitness; High VO_{2max} = increased aerobic fitness).

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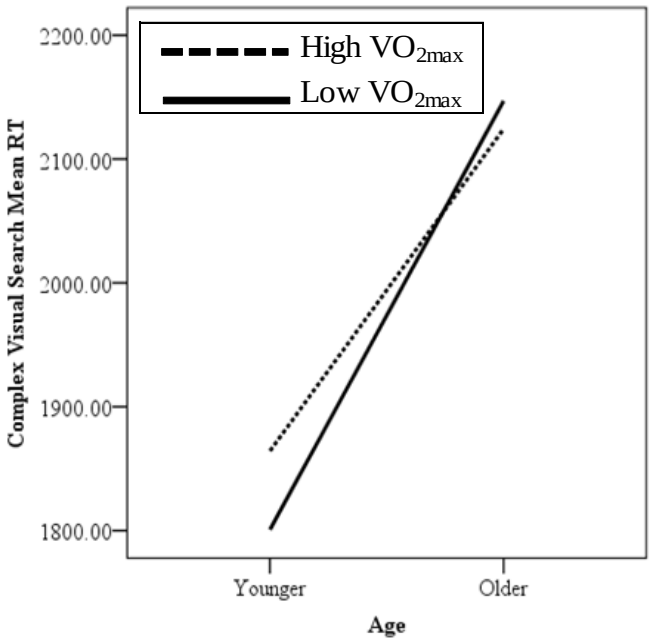

Figure 4.4. The significant Age x VO_{2max} interaction in respect to mean RT in the complex visual search task (VO_{2max} = aerobic fitness; High VO_{2max} = increased aerobic fitness).

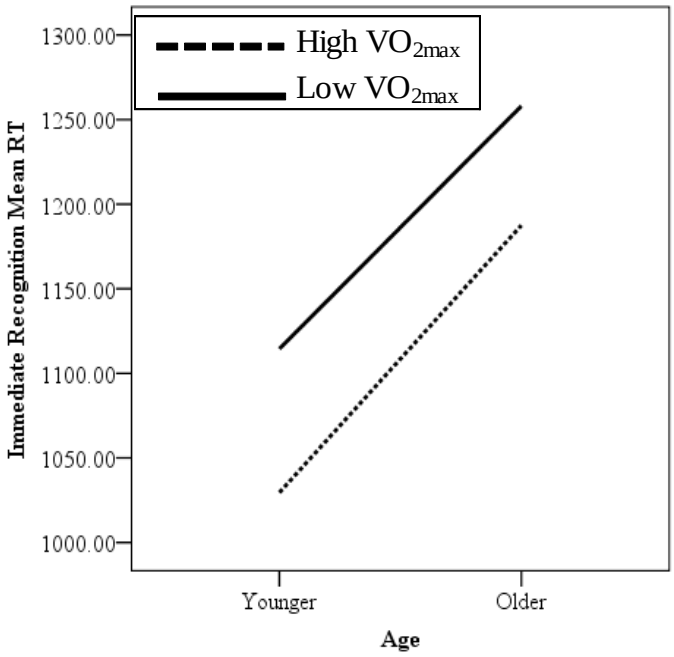

Figure 4.5. The significant Age x VO_{2max} interaction in respect to mean RT in the immediate recognition task (VO_{2max} = aerobic fitness; High VO_{2max} = increased aerobic fitness).

For WP variability, there were clear benefits for all cognitive tasks where significant interactions were obtained. For WP variability in 4-CRT, complex visual search and immediate recognition tasks the benefits of aerobic fitness are apparent at both younger and older old age with only marginal differences between the them (see Figures 4.6. to 4.8.) for these interaction plots. For WP variability in flanker arrows, Stroop arrows and Stroop word, aerobic fitness has clear benefits in older old age (see Figures 4.9. to 4.11.).

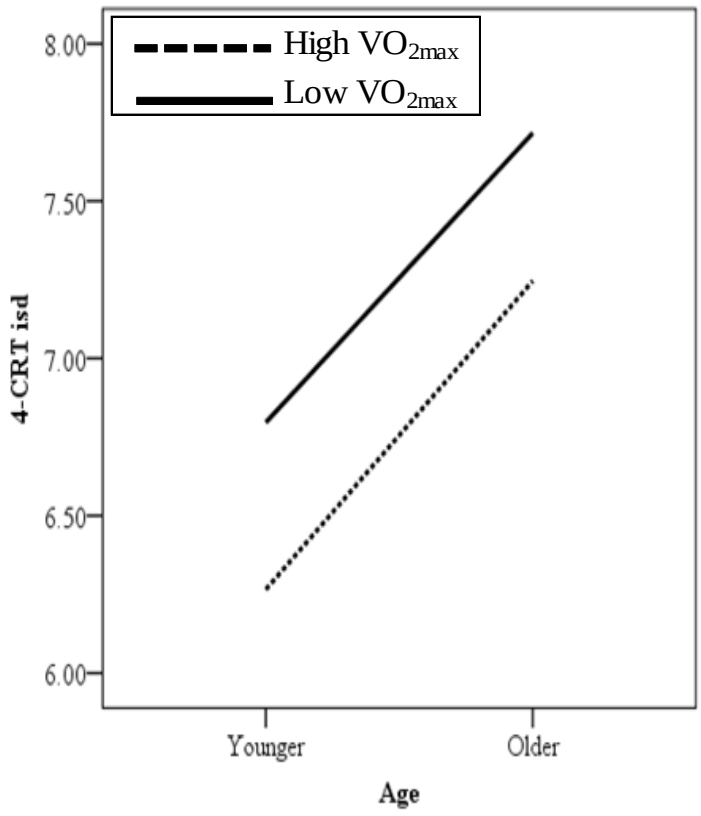

Figure 4.6. The significant Age x VO_{2max} interaction in respect to WP variability in the 4-CRT task (VO_{2max} = aerobic fitness; High VO_{2max} = increased aerobic fitness).

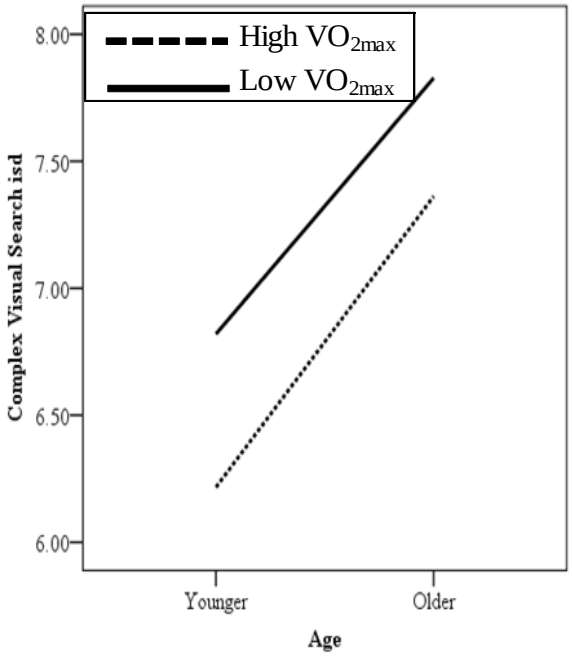

Figure 4.7. The significant Age x VO_{2max} interaction in respect to WP variability in the complex visual search task (VO_{2max} = aerobic fitness; High VO_{2max} = increased aerobic fitness).

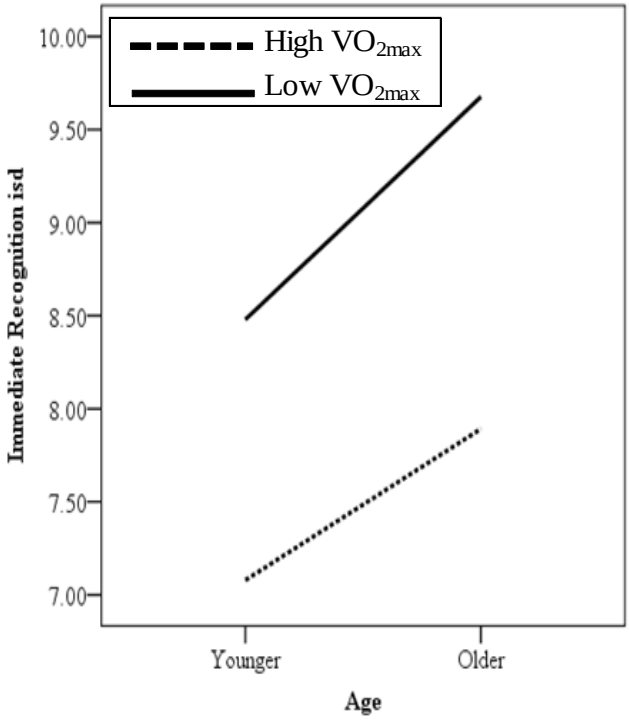

Figure 4.8. The significant Age x VO_{2max} interaction in respect to WP variability in the immediate recognition task (VO_{2max} = aerobic fitness; High VO_{2max} = increased aerobic fitness).

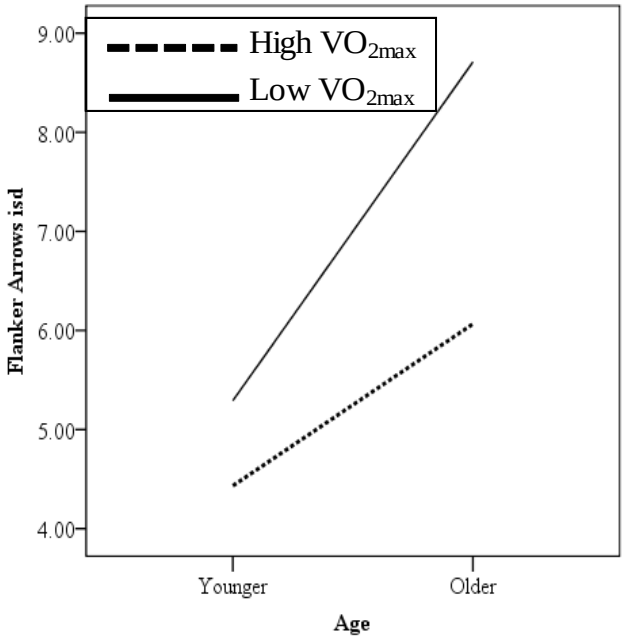

Figure 4.9. The significant Age x VO_{2max} interaction in respect to WP variability in the flanker arrows task (VO_{2max} = aerobic fitness; High VO_{2max} = increased aerobic fitness).

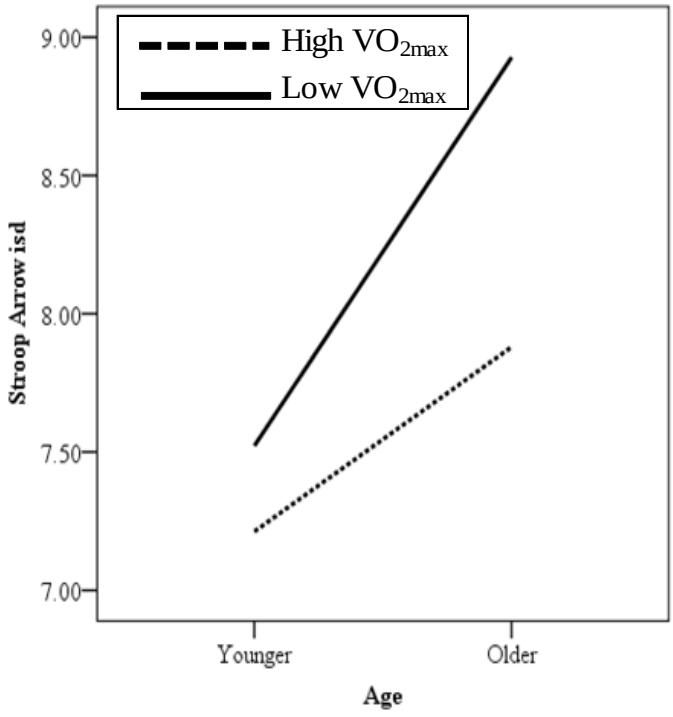

Figure 4.10. The significant Age x VO_{2max} interaction in respect to WP variability in the Stroop Arrow task (VO_{2max} = aerobic fitness; High VO_{2max} = increased aerobic fitness).

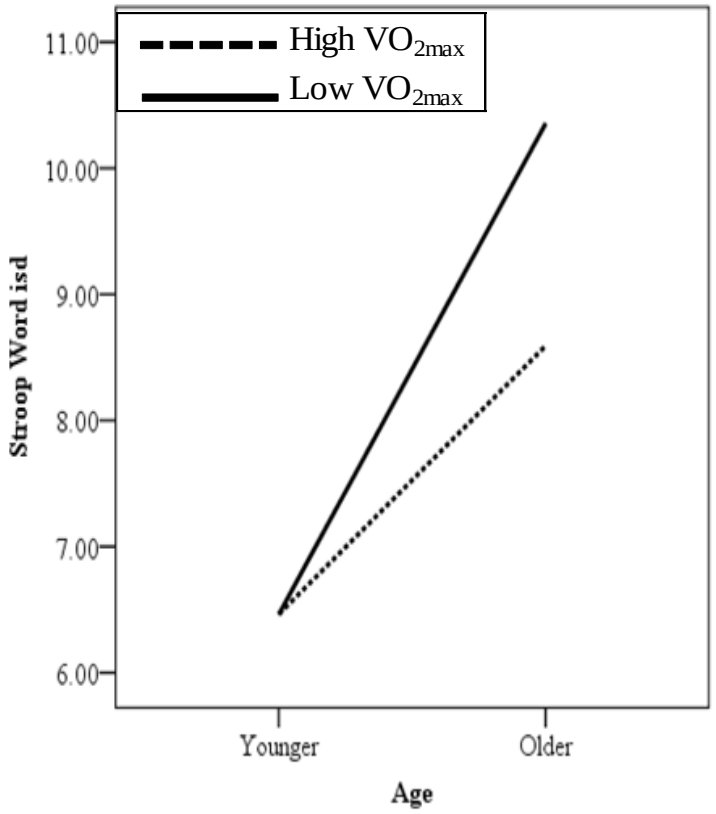

Figure 4.11. The significant Age x VO_{2max} interaction in respect to WP variability in the Stroop Word task (VO_{2max} = aerobic fitness; High VO_{2max} = increased aerobic fitness).

A further aim of this study was to assess if executive function accounted for the significant Age x $VO_{2\ max}$ interactions. In other words, did executive function mediate the Age x VO_{2max} associations obtained earlier, an example of "mediated-moderation" (Baron & Kenny, 1986). These additional exploratory analyses stemmed from the theoretical rationale that WP variability reflects fluctuations in executive control and evidence that the effects of aerobic fitness are mediated by frontal mechanisms (Kramer et al., 2006). Therefore, a further series of hierarchical regression models were run where significant interactions were obtained. Here, the hierarchical regression analysis additionally controlled for a composite measure of executive function that combined the flanker arrows, Stroop arrow and Stroop word data for both congruent and incongruent conditions for respective mean RT or WP variability analyses. These composite measures were

obtained from principal component analysis where a single factor was requested and the factor scores saved.

The resulting composite measure of executive function was entered into repeat regression analyses at Step 1 to ascertain if the effect sizes of the significant interactions obtained in the original equations were attenuated. Attenuation of the shared variance associated with the significant Age x $VO_{2\ max}$ interaction terms would suggest that executive function mediated associations between age, $VO_{2\ max}$ and cognition. The results from these analyses were that, with one exception, all of the previously significant Age x $VO_{2\ max}$ interactions became non-significant when executive function was controlled, for both mean RT and WP variability The exception was WP variability in Stroop Word, that remained significant (p <.01). This suggests that, in the main, executive function was the mechanism mediating $VO_{2\ max}$ in those associations.

Structural equation modelling (SEM) was then used to further explore how far interactions between age and aerobic fitness were mediated by executive function. Hierarchical regression analysis is able to explain how well variables are able to predict an outcome and whether a predictor variable is still able to predict this outcome when the effects of another variable are controlled for. SEM, however, is a more sophisticated approach that allows simultaneous analyses of multiple variables and constructs (Schumacker & Lomax, 2004). In this particular study, it allowed simultaneous analyses of the relations between the age, aerobic fitness and the cognitive domains specified as latent constructs. Age, NART, $VO_{2\ max}$ and Age x $VO_{2\ max}$ formed the exogenous variables, and psychomotor performance, executive function, visual search and recognition served as the endogenous variables. As was established in Studies 1 and 2, the four cognitive domains were significantly associated with either executive function or mental health and this was further explored in this study with aerobic fitness. The aims of the structural equation models were two-fold. First, to investigate whether WP variability and mean RT varied as a function of age and aerobic fitness, and second to investigate if executive function mediated the Age x $VO_{2\ max}$ interactions. For this reason, a three-step model process (see below) was used that followed the recommendations of Baron and Kenny (1986). Various established goodness-of-fit measures were used to evaluate the models, as previously discussed in Study 1.

In Model 1, NART, age, $VO_{2\ max}$ and the Age x $VO_{2\ max}$ cross-product interaction term formed the exogenous variables whilst psychomotor performance, executive function, visual search, and recognition latent constructs formed the endogenous variables (see Figure 4.12.). The important aspect of this model was whether the Age x $VO_{2\ max}$ interaction paths attained significance after the primary effects of intelligence (NART score), age and $VO_{2\ max}$ had been taken into account. Including NART scores controls for the possibility that age differences in IQ may underlie differences in the cognitive variables and therefore acts to confound associations. In Model 2, all of the paths from the exogenous to the endogenous variables were eliminated except for those to executive function. Additional paths were introduced, however, from executive function to the endogenous latent constructs of psychomotor performance, visual search and recognition (see Figure 4.13.). The focus of interest in this model was whether the Age x $VO_{2\ max}$ path to executive function was significant and whether the paths between executive function and the endogenous variables became significant. Finally, Model 3 combined Models 1 and 2 (see Figure 4.14.). The aim of this step was to see if any of the significant Age x $VO_{2\ max}$ paths identified in Model 1 became non-significant after executive function was taken into account. Following Baron & Kenny (1986), this final model formally confirms whether executive function mediates the association between exogenous and endogenous variables in the earlier models. The goodness-of-fit statistics and standardized path coefficients for WP variability and mean RT for the three models are presented in Table 4.3. The reasoning for using both mean RT and WP variability was discussed in Study 1, where the theoretical background of these measures was presented.

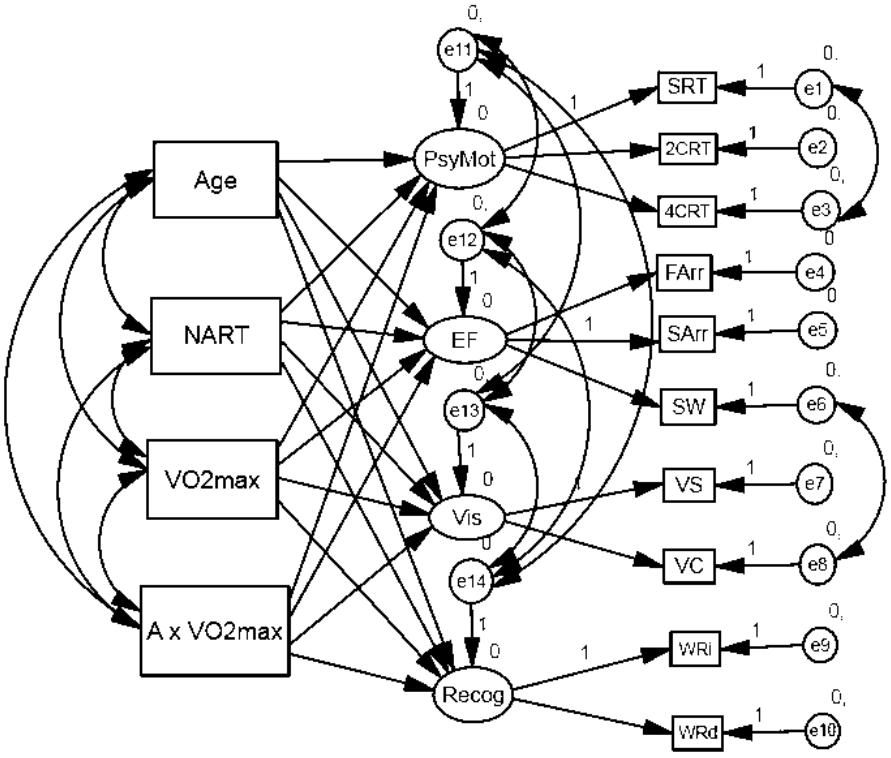

Figure 4.12. Structural Equation Model 1, for Age, $VO_{2\ max}$, Age x $VO_{2\ max}$ interaction terms, and cognitive variables.
e1-e14 = error terms 1-14, PsyMot = psychomotor performance, EF = executive function, Vis = visual search, Recog = recognition, SRT = simple reaction time, 2CRT = two-choice reaction time, 4CRT = four-choice reaction time, FArr = flanker arrows, SArr = Stroop arrow, SW = Stroop word, VS = simple visual search, VC = complex visual search, WRi = immediate recognition, WRd = delayed recognition, VO_{2max}, A x VO_{2max} = age x VO_{2max} interaction term, NART = National Adult Reading Test.

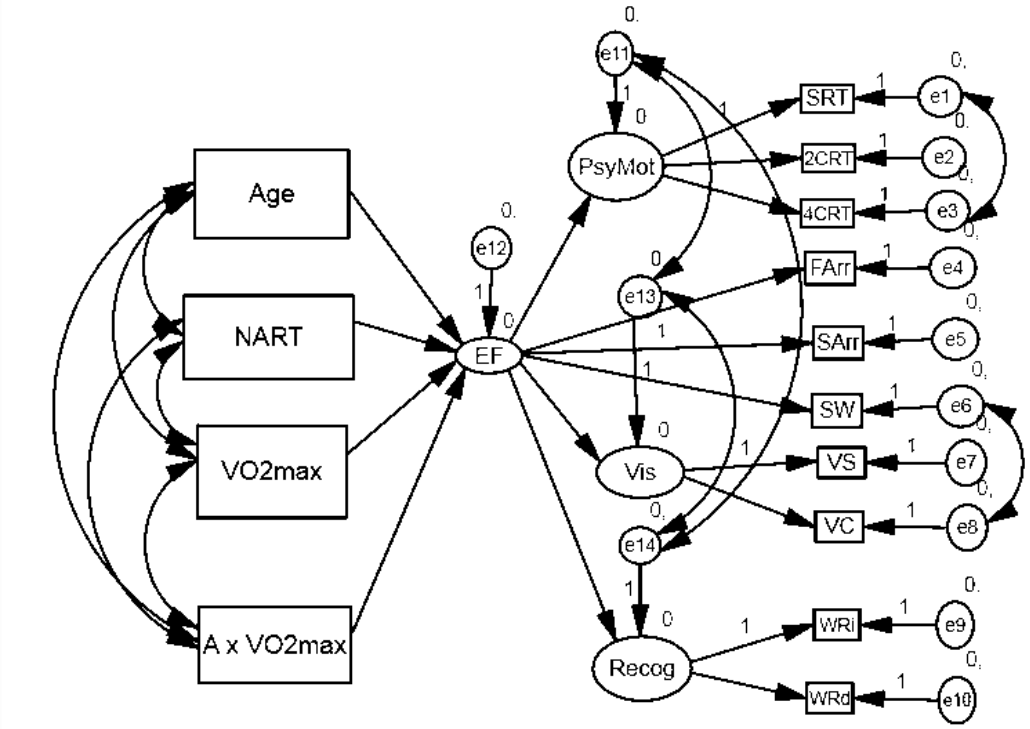

Figure 4.13. Structural Equation Model 2, for Age, $VO_{2\ max}$, Age x $VO_{2\ max}$ interaction terms, and cognitive variables.
e1-e14 = error terms 1-14, PsyMot = psychomotor performance, EF = executive function, Vis = visual search, Recog = recognition, SRT = simple reaction time, 2CRT = two-choice reaction time, 4CRT = four-choice reaction time, FArr = flanker arrows, SArr = Stroop arrow, SW = Stroop word, VS = simple visual search, VC = complex visual search, WRi = immediate recognition, WRd = delayed recognition, VO_{2max}, A x VO_{2max} = age x VO_{2max} interaction term, NART = National Adult Reading Test.

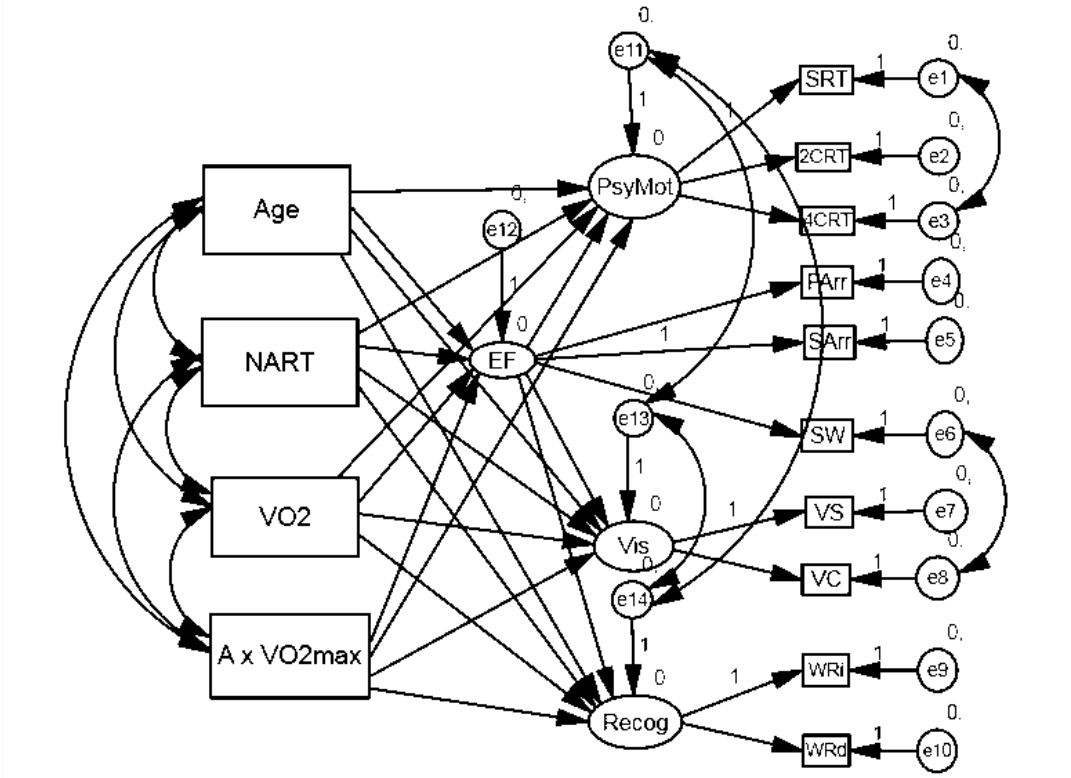

Figure 4.14. Structural Equation Model 3, for Age, $VO_{2\ max}$, Age x $VO_{2\ max}$ interaction terms, and cognitive variables.
e1-e14 = error terms 1-14, PsyMot = psychomotor performance, EF = executive function, Vis = visual search, Recog = recognition, SRT = simple reaction time, 2CRT = two-choice reaction time, 4CRT = four-choice reaction time, FArr = flanker arrows, SArr = Stroop arrow, SW = Stroop word, VS = simple visual search, VC = complex visual search, WRi = immediate recognition, WRd = delayed recognition, VO_{2max}, A x VO_{2max} = age x VO_{2max} interaction term, NART = National Adult Reading Test.

Although the hierarchical regression analysis controlling for executive function indicated that some of the Age x VO_{2max} paths became non-significant when executive function was taken into account, this three model approach based on Baron & Kenny (1986) and Bunce et al., (2008b) enabled investigation of whether executive function was acting as a mediator of Age x VO_{2max} associations across all cognitive latent constructs simultaneously (i.e., "mediated-moderation"). The goodness-of-fit statistics and standardized path coefficients for WP variability and mean RT for the three models are presented in Table 4.3.

Table 4.3. Goodness-of-Fit Measures and Standardized Regression Weights for VO_{2max} For both Mean RT and WP Variability

		Mean RT			ISD		
Goodness-of-fit		**Step 1**	**Step 2**	**Step 3**	**Step 1**	**Step 2**	**Step 3**
Chi-squared		82.38	105.30	82.38	92.18	119.30	92.18
p value		.00	.01	.00	.00	.00	.00
CMIN/DF		1.62	1.67	1.62	1.81	1.89	1.81
CFI		.98	.97	.98	.95	.93	.95
NFI		.94	.93	.94	.89	.86	.89
RMSEA		.05	.05	.05	.06	.06	.06
Path Coefficients							
Psychomotor Performance	<--Age	.34 **		-.26 **	.27 **		-.25
Executive Function	<--Age	.55 **	.53 **	.54 **	.39 **	.39 **	.39 **
Visual Search	<--Age	.47 **		-.01	.33 **		.07
Recognition	<--Age	.46 **		.07	.26 **		.02
Psychomotor	<--VO_{2max}	-.23 **		-.01	-.24 **		.05
Executive Function	<--VO_{2max}	-.20 **	-.20 **	-.20 **	-.21 **	-.21 **	-.21 **
Visual Search	<--VO_{2max}	-.04		.13	.05		.19 *
Recognition	<--VO_{2max}	.16		-.02	-.17		-.03
Psychomotor Performance	<--Age x VO_{2max}	-.06		.13 *	-.14		.39 **
Executive Function	<--Age x VO_{2max}	-.18 **	-.16 **	-.18 **	-.39 **	-.33 **	-.39 **
Visual Search	<--Age x VO_{2max}	-.21 **		-.06	-.18 *		.08
Recognition	<--Age x VO_{2max}	-.13		-.01	-.23 *		.03
Psychomotor Performance	<--EF		.80 **	1.07 **		.82 **	1.35 **
Visual Search	<--EF		.79 **	.87 **		.51 **	.67 **
Recognition	<--EF		.73 **	.70 **		.58 **	.64 **

Notes: CFQ = comparitive fit index; NFI = normative fit index; RMSEA = root mean square error of approximation; CMIN/DF = chi-squared/degrees of freedom; VO_{2max} = aerobic fitness .
*p < .05; **p < .01

In Model 1, although chi-square for both mean RT and WP Variability was significant (X^2 = 82.38, p < .01 and X^2 = 92.18, p < .01, respectively), the other goodness-of-fit statistics suggested acceptable model fit (mean RT: X^2/df = 1.62, NFI = .94, CFI = .98, RMSEA = .05; WP variability, X^2/df = 1.81, NFI = .89, CFI = .95, RMSEA = .06). Considering Table 4.3., it can be seen that older age is significantly (p < .01) associated with greater WP variability and slower mean RT with all paths to the latent variables (psychomotor performance, executive function, visual search and recognition) significant, as was established in Study 1 (see Figure 4.12.). The important outcomes of this step were the significant coefficient pathways between psychomotor performance and VO_{2max} (p < .01) and between executive function and VO_{2max} (p < .01) for both mean RT and WP variability. This suggests that lower VO_{2max} was associated with slower mean RT and greater WP variability in psychomotor performance and executive function task performance. Also important were the significant pathways between executive function and Age x VO_{2max} for both mean RT and WP variability (p < .01) and between visual search and Age x VO_{2max} for both mean RT and WP variability (p < .01 and p < .05 respectively). Additionally, there was a significant path between recognition and Age x VO_{2max} (p < .05) for WP variability. This suggests that VO_{2max} significantly moderates the association of age with executive function and visual search for both mean RT and WP variability, and also the association between age and recognition for WP variability.

In Model 2, paths were directed to and from executive function to see whether it was the possible mechanism by which the Age x VO_{2max} interactions influenced mean RT and WP variability in visual search and WP variability in recognition (see Figure 4.13.). If executive function was the mechanism, it would be expected that the paths between these latent variables and executive function would be significant. In terms of model fit, chi-square for both mean RT and WP variability was significant, X^2 = 105.30, p < .05 and X^2 = 119.30, p < .01, respectively, and the other goodness-of-fit statistics suggested an acceptable fit (mean RT: X^2/df = 1.67, NFI = .93, CFI = .97, RMSEA = .05; WP variability: X^2/df = 1.89, NFI = .86, CFI = .93, RMSEA = .06).. Age and executive function were significantly associated (p < .01), as they were in Model 1. Executive function and the cognitive domains for both

mean RT and WP variability were also positively associated (p < .01). This indicates co-variation between mean RT and WP variability in executive function and the other cognitive domains. The path between executive function and VO_{2max} and Age x VO_{2max} for mean RT and WP variability also attained significance (p <.01) suggesting that aerobic fitness was associated with mean RT and variability in executive functioning. This fulfils the second part of the criteria for mediation, according to Baron and Kenny (1986).

To test this further, Model 3 combined both Models 1 and 2 (see Figure 4.14.). Chi-square for both mean RT and WP variability was significant, X^2 = 82.38, p < .01 and X^2 = 92.18, p < .01, respectively, and the other goodness-of-fit statistics suggested an acceptable fit (mean RT: X^2/df = 1.62, CFI = .98, NFI = .94, RMSEA = .05; WP variability: X^2/df = 1.81, CFI = .95, NFI = .89, RMSEA = .06). If executive function was accounting for the Age x VO_{2max} interaction with visual search for mean RT and, visual search and recognition for WP variability, then the direct regression paths between the interaction and those constructs should become non-significant. Importantly, consideration of Step 3 in Table 4.3., indicates the Age x VO_{2max} to visual search path for both mean RT and WP variability became non-significant (p = .39 and p = .45), respectively, and the Age x VO_{2max} path to recognition in WP variability also became non-significant (p = .45). This suggests that executive function was fulfilling a mediation role in the association between age and aerobic fitness in respect to cognition in these domains. Specifically, executive function attenuated the Age x VO_{2max} effects for mean RT and WP variability in visual search and also WP variability in recognition. Additionally, the significant path between VO_{2max} and psychomotor performance for WP variability obtained from Step 1 also became non-significant in Step 3 (p = .66) indicating that executive function was fulfilling a mediating role in this association too.

Discussion

This study investigated the association between aerobic fitness and cognition in older adults in relation to both mean RT and WP variability across a comprehensive battery of cognitive tasks. The aim of the study was to extend existing research (Bunce & Murden, 2006) that investigated age and aerobic fitness, using the same mediation and moderation procedures as described in Study 2 of this thesis. This study similarly used a cross-sectional design as Bunce & Murden (2006), but focused on the older age range of 50 to 90 years. An important aspect of the study was to understand how aerobic fitness predicted cognition in older age and whether this association was mediated by executive function. The main findings indicated that there were significant Age x Aerobic fitness interactions in respect to cognitive variables for both mean RT and WP variability. These interactions indicated that aerobic fitness was moderating the effect of age on mean RT and WP variability, with lower aerobic fitness associated with slower mean RTs and greater WP variability. Importantly, these interactions were mediated by executive function.

An objective of this study was to build on the previous work of Bunce & Murden (2006) who found higher aerobic fitness was positively associated with episodic memory. However, they found that the strength of association between aerobic fitness and free recall diminished between the ages of 60 and 75 years. Considerations in that earlier study were that their results may have been affected by a gender imbalance with more men than women taking part, the small sample, restricted age range (60 to 75 years) and restricted range of cognitive measures. By contrast, the present study used a larger sample (N=257) aged 50 to 90 years. The study was additionally motivated by evidence that greater WP variability may be an early marker of neurobiological disturbance and that physical fitness may delay neurobiological changes in the frontal regions (Bunce, 2001; Colcombe & Kramer, 2003; Colcombe, Kramer, Erickson, et al., 2004; Hultsch et al., 2002). An association between WP variability and aerobic fitness in the present study is consistent with this possibility. The additional focus of this study was to investigate the mechanism behind the significant Age x VO_{2max} effects using a test of mediation (Baron and Kenny, 1986) focusing on the role of executive function as

previous research suggests fluctuations in executive function to underlie WP variability. (Bunce et al., 2004; West et al., 2002). Therefore, executive function was investigated as a possible mediator in both hierarchical multiple regression analysis and structural equation modelling.

According to the bivariate correlations, VO_{2max} was significantly associated with all of the cognitive tasks for both mean RT and WP variability (most *ps* < .01) indicating that higher aerobic fitness was related to faster mean RTs and lower ISDs. The hierarchical regression analyses for both mean RT and WP variability yielded several significant Age x VO_{2max} interactions. For mean RT, the interactions in respect to flanker arrows, Stroop word, simple and complex visual search, and immediate recognition suggested that a lower VO_{2max} was associated with slower responding in older adults (see Figures 4.1. - 4.5. for these interactions). For WP variability, significant Age x VO_{2max} interactions were found for 4-CRT, flanker arrows, Stroop arrow, Stroop word, complex visual search and immediate recognition (see Figures 4.6. – 4.11. for these interactions). In Bunce and Murden (2006), consideration of their significant interaction indicated that although aerobic fitness was associated with superior free recall regardless of age, the association became weaker with increasing age, suggesting that although there are relative benefits of aerobic fitness to cognition in later life, the benefits diminish with increasing age. In this present study, support for this was minimal, possibly due to the larger sample and also the greater range of cognitive tasks. It is also possible that the sample population in this present study was above average in terms of physical fitness for older individuals. The only indication of diminishing benefits of aerobic fitness to cognition was in respect to mean RT for immediate recognition and WP variability in complex visual search. One explanation for this is that aerobic fitness has less impact on cognition with increasing age. An alternative explanation is that age-related neurobiological changes have a stronger negative influence on cognition than the positive effect that physical fitness affords. However, to conclude here, this effect was weak and absent for the majority of variables.

Having established that aerobic fitness benefits cognition in old age, a further major objective of the present study was to investigate if executive function mediated the significant interactions between age, aerobic fitness, and cognition.

Although physical fitness has been associated with cognition generally in old age, the effect is most marked in executive control processes such as inhibition, working memory and planning (Kramer et al., 2006). The rationale behind these analyses was that WP variability is associated with age-related neurobiological changes in the frontal regions of the brain which support executive control. In order to explore this, both multiple regression and structural equation modelling were used that controlled for executive function. If the previously significant Age x VO_{2max} interactions became non-significant having controlled for executive control, it would indicate that the construct was mediating the association.

Following the initial exploratory analyses involving hierarchical multiple regression, structural equation models were run following the theoretical guidelines of Baron and Kenny (1986) to formally assess if executive function accounted for any of the significant interaction effects of Age x VO_{2max}. Latent constructs were included in the models representing psychomotor performance, executive function, visual search and recognition. In the first model (see Figure 4.12.), significant Age x VO_{2max} interactions were obtained for Mean RT in executive function and visual search, and for WP variability in executive function, visual search and recognition. Also, for Mean RT and WP variability, the paths between VO_{2max} and psychomotor performance and executive function were significant, indicating that higher aerobic fitness was associated with slower mean RTs and decreased WP variability. In Model 2 of the SEM three stage process, direct paths from the exogenous variables (Age, NART, VO_{2max}, Age x VO_{2max}) to the latent constructs (psychomotor performance, executive function, visual search and recognition) were omitted and direct paths from executive function to the latent constructs were introduced (see Figure 4.13.). The important aspect of this model was that the paths from executive function to VO_{2max} (aerobic fitness) and the Age x VO_{2max} interaction term for both mean RT and WP variability were significant ($p <$ .01), indicating an association between executive function and aerobic fitness. Additionally, executive function was significantly associated with cognitive performance in the other cognitive domains. Together, these findings fulfil one of the prerequisites of mediation according to Baron & Kenny (2006).

Model 3 combined Models 1 and 2, reintroducing the direct paths between the exogenous and endogenous variables (see Figure 4.14.). Additionally, the coefficient paths between executive function and psychomotor performance, visual search and recognition latent variables were retained. The key part of this final stage of the modelling was whether the significant Age x VO_{2max} interactions obtained in Model 1 were rendered nonsignificant having controlled for executive function. Notably, in mean RT for visual search, the originally significant paths did indeed become nonsignificant. In WP variability for visual search and recognition, the paths also became nonsignificant. Importantly, this indicates that mean RT and WP variability in executive function mediated relations between age, aerobic fitness and mean RT and WP variability in visual search and WP variability in recognition. These results show that executive function plays a key role in mediating the effects of aerobic fitness on cognition in older age, in the present study, for both mean RT and WP variability. In addition to the mediation of the Age x VO_{2max} interactions by executive function, the previously significant direct paths from psychomotor performance to VO_{2max} for both mean RT and WP variability became nonsignificant. This indicates that increased psychomotor performance for these measures was associated with a higher level of aerobic fitness, and was also mediated by executive function.

In considering the above findings, it should also be noted that the executive function to psychomotor performance path coefficient for mean RT was 1.01, $p < .01$ and the executive function to psychomotor performance path coefficient for the ISD measure was 1.05, $p < .01$. In structural equation modelling, that a standardised path coefficient is + > 1, which often occurs when variables share a high degree of multi-collinearity (Jöreskog, 1999; Kline, 2005). In this case, the cognitive domains of executive function and psychomotor performance correlated highly to produce coefficient pathways of + > 1 in Model 3 for both mean RT and WP variability. This could be due to the nature of the tasks within each domain which may have overlapped considerably in the cognitive processes they captured. This could also be due to common method variance whereby each of the cognitive variables were subject to the same measurements (mean RT and WP variability) throughout and this may inflate multi-collinearity between variables (Johnson et al., 2011). This was discussed further in Study 1.

However, the results of the hierarchical regression analysis clearly suggested that although aerobic fitness has a positive influence on cognition, this is attenuated with increasing age. This was particularly noticeable in respect to WP variability. A likely explanation for this could be that there is a confound between age and fitness level whereby as absolute fitness levels declined with increasing age, there was a reduced effect on cognition. Bunce and Murden (2006) proposed that this could be due to the age-related deterioration of the neural systems subsuming the benefits of the higher aerobic condition.

This study provides important theoretical insights into how aerobic fitness is positively associated with cognitive function in older age, and evidence suggesting effects were mediated by executive control in certain cognitive domains, was obtained. From a clinical point of view, the study also highlights the importance of how physical fitness, particularly aerobic fitness, affects cognition in older age and how physical fitness programmes could provide the focus of intervention in primary health care provision for older people. Considerations here are that the sample group may have been of above average fitness as they were recruited from fitness and sports centres and were required to be able to walk 1 mile for entry into the study. A further consideration was that the measure of aerobic fitness (VO_{2max}) was estimated from a sub-maximal walking test rather than a direct measure of maximal oxygen uptake. However, research shows that the Rockport one-mile walking test provides a valid sub-maximal estimate of oxygen uptake (Kline et al., 1987).

To conclude, in this sample of 257 community-dwelling, healthy older adults aged 50-90 years, there was evidence that aerobic fitness, as measured by VO_{2max}, moderated the association between age and cognition and that executive function mediated this effect. This finding is consistent with the view that aerobic fitness attenuates the underlying neurobiological deterioration that contributes to cognitive decline in old age. The benefits of aerobic fitness are clearly apparent with some evidence suggesting that cognitive deficits were greater in the less fit older aged persons. The evidence in support of diminishing returns as in Bunce and Murden (2006) was minimal. It is possible in that earlier study that the smaller sample and restricted range of measures had a bearing on the findings.

The findings of this study, together with those of Studies 2 and 3 indicate that there are significant positive (lifestyle activities and aerobic fitness) and negative (poor mental health) moderators of cognition in older age. Importantly, much of the work so far suggests that a range of influences on age difference in cognition are mediated by executive function. Moreover, the key role of that construct in determining the degree of intraindividual variability has been highlighted throughout this thesis. Therefore, Study 5 looks at executive function and within-person variability more closely using functional Magnetic Resonance Imaging (fMRI). Specifically, the neural correlates of intraindividual variability are investigated in a task making high demands on executive processes.

Study 5

The neural correlates of response time variability in adults aged 60 to 80 years

Introduction

The focus of this thesis so far has been on age differences in within-person variability and the affects of moderating factors such as mental health, lifestyle activity and physical fitness. Also, of interest has been the mediating affect of executive function supported by the frontal lobes which exhibit neurobiological decline in older age (Crawford, Bryan, Luszcz, Obonsawin, & Steward, 2000; Kramer et al., 1999; Raz & Rodrigue, 2006; West, 1996). Also important in the present context is the use of measures of intraindividual RT variability as an outcome measure. As has been detailed throughout this thesis, this measure has received considerable interest in cognitive ageing and neuropsychological research. However, little is known of the brain mechanisms that are associated with the variability captured by this measure. The present study, therefore, focuses on the neural correlates of within-person variability in cognitive performance using fMRI. More specifically, it focuses on the neural correlates of faster relative to slower responding in order to gain insights into the neural mechanisms contributing to intraindividual variability. Research suggests that intermittent slower response times could be due to attentional lapses and one hypothesis is that these represent failures of executive control (McVay & Kane, 2010; Unsworth et al., 2010; Weissman et al., 2006). Following the important mediating role of executive control that was demonstrated in Studies 1 to 4, the present study explored the association between the so-called "default mode network" (DMN) and within-person variability, and the possible association with attentional lapses as reflected by intermittent slower responding in task performance.

The DMN is a set of mainly frontal brain regions that display activations when individuals lie at rest in a positron emission tomography (PET) or functional magnetic resonance imaging (fMRI) scanner, undertaking no task-related activity.

It is proposed that DMN activity is associated with daydreaming, self musings, wandering thoughts and externally focussed thoughts and interactions (Buckner, 2011). When a person undertakes a task-related activity, the DMN should deactivate, allowing only the task-related brain regions to activate in order to perform a task efficiently. However, sometimes a conflict between the DMN and task-related activity occurs resulting in compromised task performance. In consequence, the DMN has been used to explain failures of response inhibition and executive function, and also attentional lapses due to the shared frontal lobe regions supporting these functions (Christoff, Gordon, Smallwood, Smith, & Schooler, 2009; Provost, Petrides, & Monchi, 2010; Schooler et al., 2011). The association between the DMN and executive function is highly relevant considering the focus of the studies so far, investigating the mediation role of executive function. One method to investigate this association was to explore and compare the neural bases of slower and faster responding in order to identify differences between brain activity during possible attentional lapses (intermittently slower responses) and efficient task-related responding (faster responses). This was based on existing research which suggested that slower responding was associated with momentary lapses in attention (Bunce et al., 1993) or failure of the default mode network (DMN) to deactivate during a task driven activity (Weissman et al., 2006).

WP variability has also been associated with attentional lapses (Bunce et al., 2004) and increased decline and variability in neurobiological structures and mechanisms in older age (MacDonald, Hultsch, et al., 2006). Several studies have associated momentary lapses in concentration and task unrelated thoughts with slower responding in older adults (Bunce et al., 1993; Smallwood et al., 2004; Smallwood & Schooler, 2006; Weissman et al., 2006). These attentional lapses have been attributed to failures in top-down processing and higher-order processes such as executive function that are detrimental to overall cognitive performance (Sonuga-Barke & Castellanos, 2007) including reaction times and WP variability. Elsewhere in the literature, different labels have been used to describe similar constructs. For example, 'mind-wandering' refers to a psychological baseline from which people depart when attention is no longer task orientated (Mason et al., 2007). This has also been termed 'stimulus independent thought' (SIT). Gilbert et al. (2007) expand further to differentiate between SIT and SOT

(stimulus-oriented thought), the latter defined as a switch of focus to the external environment. It was proposed in their study that when considering attentional lapses, both SIT and SOT should be considered empirically together (Gilbert, Dumontheil, Simons, Frith, & Burgess, 2007). However, a SOT is difficult to measure due to the requirement of an individual to record it through 'thought probes' or questionnaires and then the SOT has to be defined. Although this was not a focus of this present study, it is a possible factor contributing to slower responses. It is also suggested that attentional lapses are when the mind wanders due to lack of demand for concentration, even during a demanding task-related activity (Hu et al., 2012). It has also been proposed that an attentional lapse is a state of 'decoupled attention' and is a stable cognitive characteristic, which is both definable and measurable through self-reports and measures of brain function (Christoff et al., 2009; Hu et al., 2012; McVay & Kane, 2009; Schooler et al., 2011). Schooler et al. (2011) expand on this and define four basic functions of mind wandering. These are future planning, creative solutions, adaptive attentional cycling and dishabituation which allows the mind to refresh during continued processing (Schooler et al., 2011). The 'decoupling' of attention is when mental events occur which are not related to the perception of the attentional stimulus and subsequently decoupling of perception and attention take place, which can be detrimental to cognitive performance. This is because it results in a subsequent attentional lapse which has also been defined as when attention is withdrawn from the current sensory input and focus is then placed on 'self-relevant' musings, internal thoughts, daydreaming and emotional feelings (Hu et al., 2012; Smallwood, Fitzgerald, Miles, & Phillips, 2009). It has also been described as a task-unrelated thought (TUT), that is proposed to take place during the processing of an external task (Barron, Riby, Greer, & Smallwood, 2011). Despite being defined in numerous terms, the overriding consensus is that attentional lapses are associated with slower responding, increased variability and higher error rates due to the possible uncoupling between perception and attention processes (Bunce et al., 1993; Hu et al., 2012; Smallwood et al., 2004; Smallwood & Schooler, 2006; Weissman et al., 2006).

Attentional lapses have also been associated with the failure of executive control as noted briefly at the outset of this introduction (Bunce et al., 2004; Kane et al., 2007; Unsworth et al., 2010; West et al., 2002). In the Main Introduction, executive

function in older age and its relation to general cognition was explored. Here a brief re-cap is presented in accordance with the aims of this study. It has been proposed that fluctuations in the efficiency of executive control are associated with the maintenance of goal-directed behaviour (West et al., 2002). In addition, executive control has also been defined as the ability to resolve conflicts between thoughts and responses (Hu et al., 2012). If there are fluctuations in the control of goal-directed behaviour, there will be conflict between thought processes and behavioural responses. It has been shown that as task demands increase, especially those requiring a high level of executive control, lapses of attention and performance variability increase (West et al., 2002). Also, as task demands increase, so will the demand on attentional resources necessary to inhibit inappropriate responses, resulting in increased response inconsistency (Bunce et al., 2004). Increased variability has been associated with the neurobiological changes occurring in the frontal regions that support attention and executive control (Bunce et al., 2008a; Bunce et al., 2004; Weissman et al., 2006). Unsworth et al. (2010) explored the relationship between attention and executive control by conducting a latent variable analysis on data collected within a sustained attention task. It was found that the slowest responses were correlated with executive control *and* lapses in sustained attention, whereby lower executive control was exhibited during slowest responses and not during fastest responses. If executive control is compromised due to age-related neurobiological changes, there is a greater likelihood of the occurrence of attentional lapses and an associated increase in behavioural variability and slower responding (Unsworth et al., 2010). Unsworth et al. (2010) also acknowledge that the results they obtained suggest a relationship between the slowest responses, lapses in sustained attention and possible failure of the DMN to deactivate. This suggests that attentional lapses during task performance are associated with the *failure* of executive control or a momentary reduction of top-down and higher order processing (Sonuga-Barke & Castellanos, 2007; Weissman et al., 2006).

Importantly, variation in task performance *has* been associated with DMN interference, and its failure to deactivate (Buckner, Andrews-Hanna, & Schacter, 2008; Grady, Springer, Hongwanishkul, McIntosh, & Winocur, 2006; Greicius, Srivastava, Reiss, & Menon, 2004; Greicius, Supekar, Menon, & Dougherty, 2009; Lustig et al., 2003; Mason et al., 2007; McKiernan, D'Angelo, Kaufman, & Binder,

2006; Raichle et al., 2001; Raichle & Snyder, 2007; Sonuga-Barke & Castellanos, 2007; Weissman et al., 2006). Mason et al. (2007) conducted an fMRI study in which they investigated whether the DMN remained active during a rest period. Their hypothesis was that if there was activity in the DMN during rest periods, it could be attributed to mind wandering in the absence of a task-related activity. They also proposed that, participants who reported a greater amount of mind wandering would also have increased DMN activity. Their study took place over a period of five days during which for the first four days, participants were trained on blocks of verbal and visuospatial working-memory tasks. On day five, they conducted an fMRI investigation to identify periods of greater mind wandering by tracking DMN activity. Their results suggested that when cognitive demands were low and there was lower processing demands, activity in the DMN increased and during this time there was also an increase in self-reported SIT (Mason et al., 2007).

Additional DMN research by Weissman et al. (2006) investigated the neural correlates of attentional lapses using a global-local selective attention task, the same task is described in the Method section of this study. Their study suggested that reduced activity in the frontal regions results in decreased deactivations in the DMN, causing ineffective suspension of task-irrelevant processes (e.g., daydreaming, attentional lapses) with consequent slower responding in task-related performance (Weissman et al., 2006). They proposed that attentional lapses originated from a reduction of activity in the frontal control regions (executive control), moments before the target stimulus is presented. This would result in slower responses to the stimulus. Consistent with their prediction, they found a reduction in target-related activity, before stimulus onset, in the right inferior frontal gyrus (IFG) corresponding to slower reaction times. Their results suggested that reduced activity in the frontal control regions was the result of attentional lapses even before stimulus presentation (Weissman et al., 2006). In addition, they found that slower reactions times (RTs) were associated with fewer deactivations in the DMN during task performance, indicating there was a relationship between failure of the DMN to deactivate, attentional lapses and slower responding. In addition, it was proposed that the DMN underlies attentional lapses because there is no full reallocation of attentional resources, resulting in a failure of the DMN to fully deactivate and then resulting in slower

responding. In contrast, faster responding was associated with larger deactivations of the DMN. As briefly mentioned at the beginning of this introduction, in addition to DMN activity, mind wandering was closely associated with the executive function network.

Research has also explored the relationships between executive function and the DMN. Christoff et al. (2009) examined the role of the executive control during mind wandering. Focusing on two main regions of executive control, the dorsal anterior cingulate cortex and the dorsal lateral prefrontal cortex (DLPFC), which are highly active during a cognitive task of high mental demand. They proposed an overlap of processing between mind wandering and executive control due to the common executive control (prefrontal) regions associated with both executive control and the DMN. They used a self-report procedure to measure mind wandering through a 'thought probe', which asked participants two simple questions whilst performing a go/no-go task. The questions asked about both their mental state before the probe and whether their attention was focussed on the task, providing a subjective but empirical measure of mind wandering. A secondary measure utilised errors during task performance and fMRI as an indication of mind wandering. It was found that both reported and unreported episodes of mind wandering were associated with activations in the DMN and the executive control network regions with the 'unaware' occasions of mind wandering eliciting strong activity in both these areas. These regions included the medial and lateral pre-frontal cortex (BA10), dorsal anterior cingulate cortex (ACC) (BA32), right DLPFC (BA9/10) and posterior cingulate/precuneus (BA31, BA7), areas previously implicated in the DMN (Buckner et al., 2008; Christoff et al., 2009). Of significance in this study was the finding that there was an overlap between the areas involved in mind wandering and those areas responsible for executive control suggesting that there *was* parallel recruitment of both executive and DMN regions. This was found to have the strongest association in the absence of meta-awareness (when participants were asked to respond via the thought probe). When using the probe, the medial prefrontal part of the DMN was active when participants reported they were mind wandering and also just before they made an error, indicating, in both circumstances, a decrease in task-related attention. Reductions in task-related attention can undermine cognitive performance on tasks of high demand (Christoff et al., 2009). The overlap in

processing resources between the DMN and executive control suggests why mind wandering (attentional lapses) adversely affects performance on demanding tasks requiring increased executive attention.

The core set of brain regions that comprise the DMN are the ventral medial prefrontal cortex (VMPC), dorsal medial prefrontal cortex (DMPC), the posterior regions (cingulate and precuneus) and the parietal cortices (lateral and medial) (Buckner et al., 2008; Lustig et al., 2003; Weissman et al., 2006). Table 5.1. provides an outline of the main DMN regions according to Brodmann Area (BA), based on Buckner et al., 2008 and Lustig et al., 2003.

Table 5.1. Main Regional Areas of the Default Mode Network (DMN) According to Brodmann Area (Buckner et al., 2008; Lustig et al., 2003)

Brodmann Area	Brain Region
BA 10, 24, 32	Ventral medial prefrontal cortex (VMPFC)
BA 29/30, 23/31	Posterior cingulate/retrosplenial cortex (PCC/Rsp)
BA 39/40	Inferior parietal lobule (IPL)
BA 21	Lateral temporal cortex (LTC)
BA 24, 32, 10, 9	Dorsal medial prefrontal cortex (DMPFC)

It also includes the hippocampus and areas in the medial temporal lobe that are associated with episodic memory (Buckner et al., 2008). This network of brain regions represents an integrated system in which activity is increased when an individual is left to their own thoughts or passively viewing a stimulus and is not engaged in an active task (Buckner et al., 2008; Raichle et al., 2001). During goal-directed tasks, activity in the DMN decreases, leaving only task-specific activations. Unlike task-specific activations, the DMN is consistently associated with the same regions (Raichle et al., 2001). To differentiate between direct task-related brain activity and DMN activity, DMN activations are called 'deactivations' to contrast it from the task-related 'activations' (Buckner et al., 2008).

Considering the relationship between the DMN and fluctuations or failures of executive control, research suggests that the DMN is associated with neurobiological decline in Alzheimer's disease (Buckner, 2011; Lustig et al., 2003). Neuropathology in this disorder has been shown to affect the DMN resulting in decreased deactivation of the DMN during task-related performance (Buckner, 2011; Klunk et al., 2004). Lustig et al. (2003) conducted an fMRI study with 82 participants, including 32 young adults, 27 older adults and 23 older adults with early-stage dementia of the Alzheimer's type (DAT) (Lustig et al., 2003). They found that deactivation in the lateral parietal regions was similar across all groups during task performance. However, in the medial frontal regions, deactivations were reduced in the older adults but not in the DAT group. In addition, deactivations in the medial parietal and posterior cingulate cortex (PCC) were progressively reduced across the three groups. They also found that initially, this region was activated in all three groups and then deactivated, but in the DAT group deactivations failed to occur throughout the task. Greicius et al. (2004) further explored the relationship between failure of the DMN to deactivate and disease pathology in a study in which they examined age-matched participants with and without DAT. They also found that DAT disrupted the DMN (Greicius et al., 2004). Buckner (2011) considered the history and aetiology of the DMN in a recent paper and pointed out that the DMN is a relatively new finding and its function, aim and associations are still largely undiscovered. What is clear, however, is the network of regions it spans and that it is associated with both attentional lapses and executive control.

To summarise, research suggests that there is a close association between attentional lapses, the DMN, executive function, and WP variability due to the common supporting role of frontal lobe regions. Fuster (1989) describes the prefrontal cortex as the region in which there is a "hierarchical organization of behaviour" and West (1996) states that this organisation of behaviour allows high-level processing through the processes of construction and execution of behavioural responses, as well as the suppression of 'task-irrelevant' information processing (Fuster, 1989; West, 1996). Considering that older age is associated with early neurobiological decline of the prefrontal region, it is possible that disruptions in executive control, decreased deactivation of the DMN and increased attentional lapses, may explain the greater variability in reaction times obtained

from cognitive tasks. In particular, it is suggested here and elsewhere (Bunce et al., 2004; MacDonald, Hultsch, et al., 2006; Weissman et al., 2006) that greater intraindividual variability could be indicative of this early neurobiological decline in normal ageing.

In the present fMRI study, a global-local behavioural task measuring selective attention and incorporating congruent and incongruent conditions was used to investigate reaction time variability. Using the associated fMRI data, it was expected that the task would be successful in producing deactivations in the DMN, indicative of possible attentional lapses during slower behavioural responses, along the lines of existing research using the same research paradigm (Weissman et al., 2006). Importantly, it was expected that a failure to deactivate the DMN would underlie slower behavioural RTs whereas faster responding would be associated with successful deactivation of that network. An open question was whether this effect would grow stronger in conditions of higher task demands.

Method

Participants

Thirty (fifteen women) cognitively intact, right-handed, community-dwelling persons aged 60 to 80 years (M = 65.58, SD = 13.28) initially participated in this study. Excessive head motion resulted in the loss of data and the participants available for analysis was 21 (ten women) aged 60 to 80 years (M = 67.90, SD = 5.74). Participants were initially recruited for the larger behavioural study (Studies 1 to 4) from local health clubs, sport clubs, community groups and the general local community through printed advertisements and oral presentations about the study (see Study 1 for more information on participants). All participants had recorded MMSE scores of 25 and over and had no reported history of neurological trauma or disorders, and had normal or corrected-to-normal vision. Participants were verbally screened at recruitment and additionally provided with an Information Sheet and Initial Screening Form

(screening for metallic implants and objects), which were completed and checked before attending the scanning session (see Appendices XII and XIII for fMRI Information Sheet and Initial Screening Form).

Cognitive Task

A global-local task was used where stimuli were large letters T and H, made up of smaller letter Ts and Hs, presented either congruently or incongruently (see Figure 5.1.) The dimension of the large global letters were 6 x 4 cm and the small local letters were 0.8 x 0.8 cm. The visual angle for the large letters was 4.3º and the smaller letters was 0.57º. In an event-related design, 6 separate sessions of 96 trials (48 congruent, 48 incongruent) were presented Before each session, full instructions for that session were read aloud to the participant, i.e., 'For this session, identify the *large* global letter, if 'H' press the left hand button and if 'T', press the right hand button' or 'For this session, identify the *small* local letter, if 'H' press the left hand button and if 'T', press the right hand button'. The participant had been shown the stimuli and read the same instructions before the scanning session begain. The six sessions were run in succession with a brief break of approximately 30 seconds in which the instructions were repeated. In three of the sessions, participants were instructed to indentify the 'global' letter (i.e. large T or H), while in the other three sessions they were instructed to identify the 'local' letter (i.e. small T or H). These were alternated global, local, global, local, global, local. The inter-stimulus interval ranged between 500 and 2500 ms and was pseudorandomised and if the participant did not respond within that time period for that particular trial, the next stimulus was presented and that trial would have no response recorded.

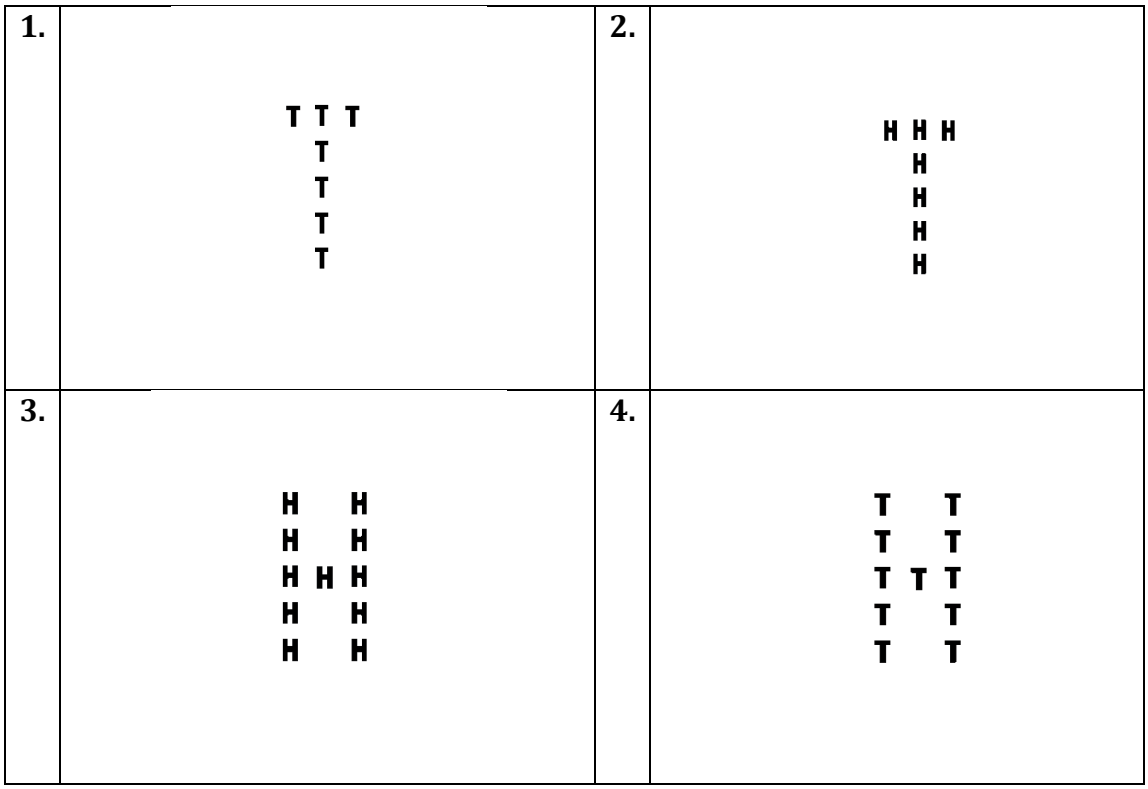

Figure 5.1. Experimental stimuli showing congruent and incongruent letters T and H. 1. Congruent T, 2. Incongruent T, 3. Congruent H, 4. Incongruent H.

Procedure

The scanner used is located at the Combined University's Brain Imaging Centre, Royal Holloway, University of London. The experiment and procedure of testing was fully explained to the participants and the stimuli were briefly shown to each participant. The participants then entered the control room where they were invited to remove all metal objects from their person and plastic prescription spectacles were offered for those participtants who normally wore spectacles. Participants completed a Consent Form and Second Screening Form (See Appendices XIV and XV for these forms), signed in the presence of the scanner operator (Authorised Person). At this point it was ensured that all participants were safe to go in the scanner. The head coil was placed over their head and secured with foam wedges. The participant was provided with an emergency buzzer which could be pressed at any time. The experiment was run using EPrime

version 1.2. (Psychology Software Tools, 2006) from a DELL laptop connected to the external projector of the scanner, located behind the participant's head. The projected image was viewed by the participant with a 45 degree angled mirror. The participant held a 4 button response box on their lap, of which two buttons were required, for signalling left-most for 'H' and right-most for 'T', two hands were used. Instructions for each session were repeated before commencement, six times, before each session, through the intercom system. Throughout the scanning procedure, which lasted approximately fifty minutes, between each block, the participant was asked if they were comfortable and whether they were happy to continue to the next session. After the experiment was completed, the participant left the scanner and was fully debriefed.

Ethical Procedure

The research was carried out in accordance with Brunel University's ethical guidelines and procedures for research involving human participants. The Research Ethics Committee of the School of Social Sciences (see Appendix XI for Ethical approval) granted ethical approval for the fMRI study prior to recruitment of participants. In addition, the fMRI study was conducted according to the 'Rules of Operation of the Combined University's Brain Imaging Centre'.

fMRI Data Acquisition

fMRI images were collected using a Siemens 3 Tesla high-field scanner (Magnetom Trio, Siemens, Erlangen, Germany), using a standard Siemens eight-channel array headcoil. Functional images were repeatedly acquired with an axial, echoplanar (EPI) sequence of the whole brain (TR = 2.0 seconds; voxel size 3 x 3 x 3 mm; number of volumes = 179; number of slices = 34; FOV = 192 x 192 mm). A high-resolution (1mm) anatomical scan of the whole brain was also acquired.

Data analysis

fMRI

For each individual participant, the initial data files were converted from the Digital Imaging and Communications in Medicine (DICOM) format into nifti (.nii.gz) files. The raw functional data were motion-corrected using SPM5 and MATLAB (MathWorks, 2007) and slice-timing correction was used in processing the data (www.fil.ion.ucl.ac.uk/spm/software/spm5/). The imaging data were realigned, coregistered and normalised with the anatomical images to fit a standard single subject brain template (single_subj_T1.nii). Images were then smoothed (6 mm). SPM5 was also used for statistical processing. A manually edited SPM5 batch job file containing the experimental design was loaded into SPM5. The reaction time data was exported from E-Prime version 1.2. into an Excel spreadsheet. The batch job file was written to load the xls. file, image files and then register onset and remove all incorrect trials.

This study utilised a general linear model approach as implemented in SPM5. A single design matrix was created, which incorporated all six sessions of response time data (global, local, global, local, global, local). Within this design, conditions were combined across the six sessions to provide four main datasets, global congruent, global incongruent, local congruent and local incongruent data (sessions 1, 3 and 5 were combined and split into congruency for the global datasets and sessions 2, 4 and 6 were combined and divided into congruency for local datasets). The design process then ordered the response time data trials of the four conditions from fastest to slowest and then divided these trials into terciles; fast, medium and slow response time data. This provided a total of 12 available event contrasts (see Figure 5.2. for the design matrix flowchart). The design script was loaded into SPM5 where models of the expected time courses for fast, medium, and slow event types were compared with the actual timecourses.

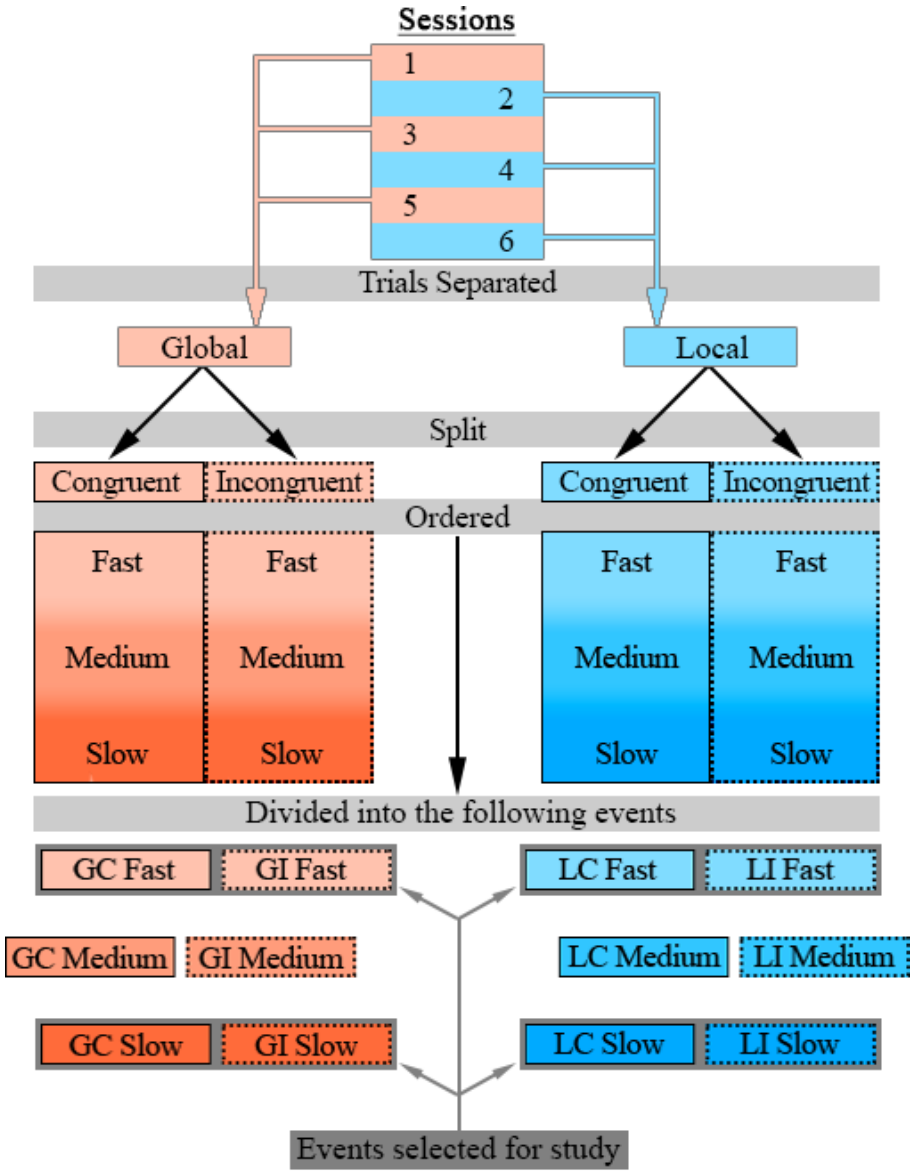

Figure 5.2. Design matrix flowchart showing the division of response time data.

The focus of this study was on the fast and slow event contrasts of the congruent and incongruent conditions for both global and local combined sessions examining each combined condition against baseline, for example, a contrast for all the fast trials in the global congruent condition formed a single event contrast, GC fast > baseline. Using these contrasts, all the individual participant data was initially processed, then a group analysis was conducted, combining the 21 sets of participant data together to obtain an aggregated measure of activity for each event contrast (GC and GI fast, LC and LI fast, GC and GI slow, LC and LI slow),

using the 2nd level analysis function in SPM 5, see Figure 5.2. which shows the division of response time data into the respective event contrasts.

Results

Behavioural Results

Inspection of the behavioural data revealed that the overall error rates for all participants across the whole task was 3.8% . The error rates for the individual global and local sections of the task and the respective conditions (congruent/incongruent) are presented in Table 5.2.

Table 5. 2. Task Accuracy - Percentage Incorrect

Task	Congruence	*M*	*SD*
Global	Congruent	4.37	15.69
	Incongruent	7.34	15.11
Local	Congruent	1.19	1.62
	Incongruent	2.35	2.89

Table 5. 3. Descriptive Variables According to Task and Congruence for mean RT

Task	Congruence	*M*	*SD*
Global	Congruent	278.97	514.78
	Incongruent	340.26	604.98
Local	Congruent	267.65	511.08
	Incongruent	278.41	526.60

Correct responses only were used in the formal analyses reported here. Reaction times were subject to a 2 (condition: global vs local) x 2 (congruency) ANOVA. Significant main effects suggested that RTs were slower in the global condition relative to the local condition (278.97 ms and 267.65 ms respectively), $F(1,20) = 11.43$, $p < .05$. Also, RTs were slower when the stimuli were incongruent in both

the global and local condition (340.26 ms and 278.41 ms respectively), F(1,20) = 116.96, $p < .001$. These main effects, however, were modified by a significant interaction between condition and congruence, F(1,20) = 28.72, $p < .001$. In line with expectations, reaction times were slower for incongruent stimuli, and this effect was more marked in the global condition (see Table 5.3. and Figure 5.3.). As the performance of the behavioural task indicated that the incongruent condition was of higher cognitive demand, the fMRI analysis could proceed with the expectation that the incongruent condition would produce evidence of increased DMN deactivations in the global condition.

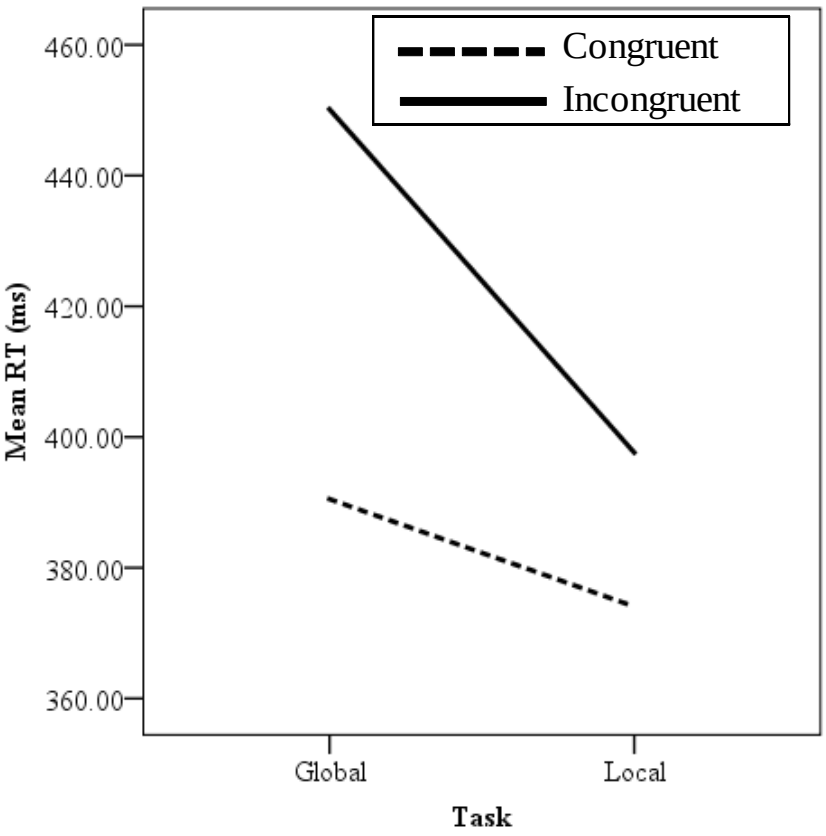

Figure 5.3. The significant condition x congruence interaction in respect to mean RT.

fMRI Results

The main aim in the fMRI analysis was to investigate the neural correlates for faster and slower responses in the individual RT distribution. All the fMRI results discussed here are at the group analyses level. The focus here was on whether there was greater activity in the DMN (i.e., a failure to deactivate) during the slower RTs compared to the faster RTs. For each particpant, within each condition, behavioural RT data were reordered from fast to slow for each of the six sessions and then divided into three terciles representing fast, medium and slow RTs. Within each condition, haemodynamic response functions were extracted for each tercile at the individual level (using SPM5), and were then aggregated at the group level for further analyses. For the purposes of this study, the focus was on the contrasts between the faster and slower terciles overall. We set a very conservative threshold of 10 voxels at $p < 0.0001$ (uncorrected) for identifying significant activation in each area.

In Table 5.4., The regions with (*) checked indicate that these regions were showing significant activity during that condition and congruency. This activity could be both task-related activations or DMN deactivations. In the slower RTs, more DMN regions were checked (*), compared to during the faster RTs, see highlighted regions on Table 5.4., indicating the regions associated with the DMN. The activations were plotted according to both condition and congruency as the slower RTs were more evident during the incongruent trials. The overall activations were present in the pre-motor, primary and somatosensory cortices (BA2, 4, 5, 6, 7, 40) as well as the visual cortex (BA17, 18, 19) and auditory and parietal cortices (BA42, 44). Importantly, additional activations consistent with the DMN were found in the pre-frontal cortex (BA10), the temporal and cingulate cortices (BA21, 23, 24) and the inferior parietal lobule (BA39). Such activations were more frequent for slower trials, and in the more demanding incongruent (as indicated by slower mean RTs, see Table 5.3.). Examples of activations in the DMN regions are presented in Figures 5.4. to 5.7., the colorimeter scale displays t-values for activated voxels.

Table 5.4. Areas of Brain Activation According to Brodmann Area (BA) for each Condition and Congruency - Default Mode Network (DMN) Regions Highlighted

	BA2	BA4	BA5	BA6	BA7	BA9	BA10	BA11	BA17	BA18	BA19	BA21	BA22	BA23	BA24	BA30	BA38	BA39	BA40	BA42	BA44
GC fast																					
GI fast			*	*		*	*			*	*									*	*
LC fast																					
LI fast				*								*	*			*	*			*	
GC slow			*	*				*	*		*	*			*					*	
GI slow		*	*	*	*		*		*		*		*	*	*		*	*			
LC slow					*							*			*				*		
LI slow	*	*		*					*		*										

Notes: BA = Brodmann area; GC = global congruent; GI = global incongruent; LC = local congruent; LI = local incongruent.

Location of the main significant clusters of activations were acquired by accessing the 'Whole brain statistics' function in SPM5 and mapping the regional coordinates in Brain Voyager Brain Tutor, version 2.0. (Goebel, 2007). Regions of interest were located using the X, Y, Z talairach coordinates for significant areas of the voxel cluster acquired from the whole brain statistics in SPM5. DMN regions were mapped according to the guidelines of Buckner et al. (2008), see Table 5.1. for DMN regions.

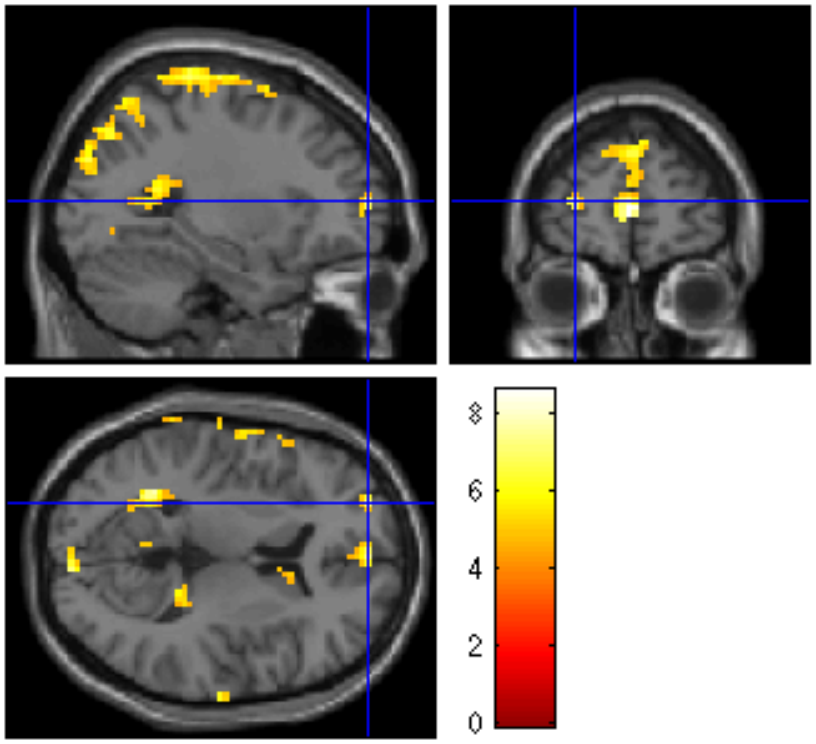

Figure 5.4. A significant cluster of brain activation in the pre-frontal cortex (BA10) during slow responses in the global incongruent condition, indicated by cross-hairs. [X,Y,Z] = (-27, 57, 9) $p < 0.0001$

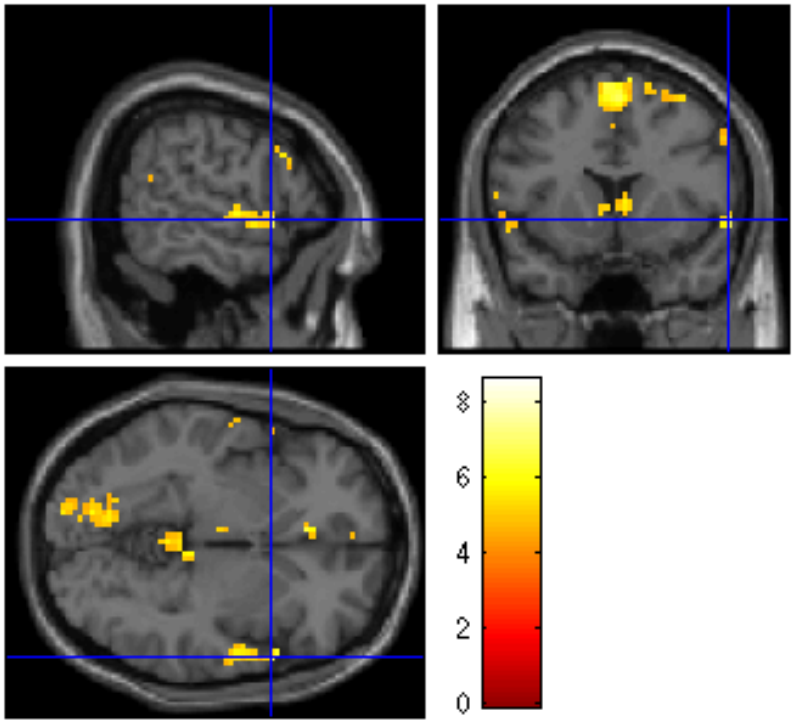

Figure 5.5. A significant cluster of brain activation in the inferior parietal lobule (BA39) during slow responses in the global incongruent condition, indicated by cross-hairs. [X,Y,Z] = (60, 12, -3) $p < 0.0001$

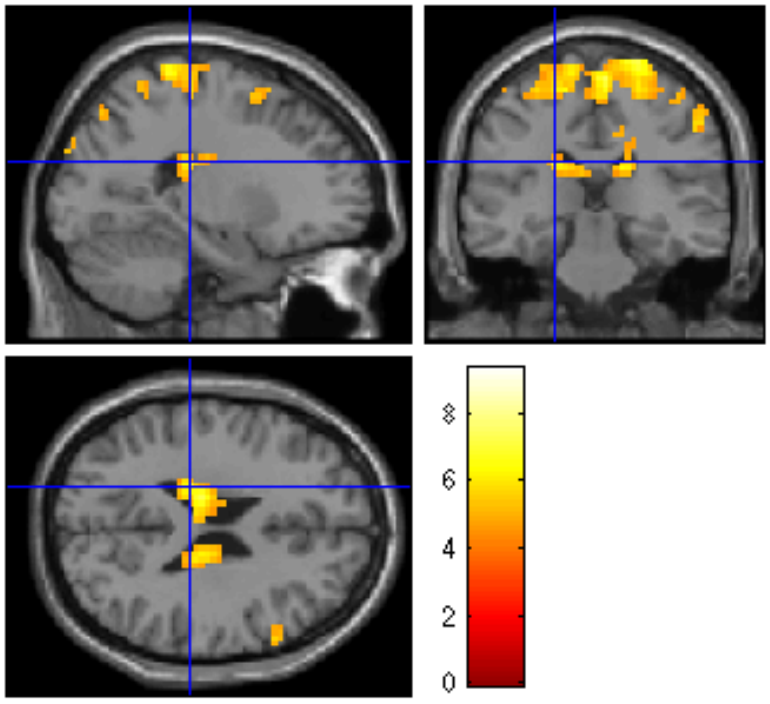

Figure 5.6. A significant cluster of brain activation in the anterior cingulate cortex (BA24) during slow responses in the local incongruent condition, indicated by cross-hairs. [X,Y,Z] = (-21, -27, 24) $p < 0.0001$

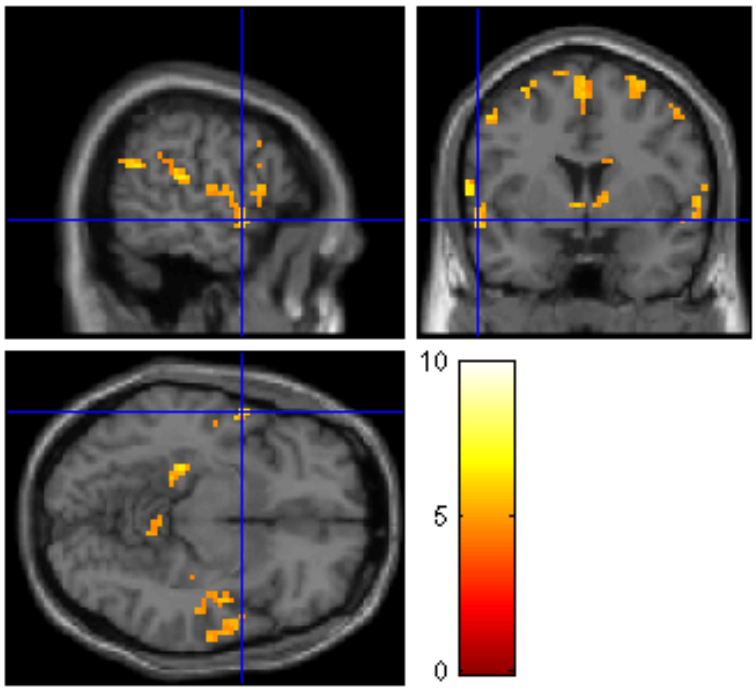

Figure 5.7. A significant cluster of brain activation in the lateral temporal cortex (BA21) during slow responses in the global congruent condition, indicated by cross-hairs. [X,Y,Z] = (-57, 3, -9) $p < 0.0001$

Discussion

This study investigated the neural correlates of slower relative to faster responding and the association with possible attentional lapses and, using fmri, activity in the DMN. The aim of the study was to extend existing research (Weissman et al., 2006) that suggests attentional lapses impair goal-directed performance, resulting in intermittent slow responding, which in turn is associated with the failure of the DMN to deactivate. The study was also based on the association of executive function, attentional lapses and WP variability due to their common neurobiological substrates and the suggestion that increased variability in older age could be due to fluctuations in attentional or executive control (Bunce et al., 2004; Bunce et al., 1993; West et al., 2002).

Weissman et al. (2006) investigated the neural correlates of momentary lapses of attention in sixteen participants aged 18 to 35 years using a global-local attention

task, details of which were described in the introduction to this present study. They explored not only whether momentary lapses in attention were associated with the failure of the DMN to deactivate but also whether this stemmed from the pre-response phase of task performance. The aim of the study *here* was to use a similar design to explore whether slower responding in older adults was associated with failure of the DMN to deactivate relative to faster responses. Twenty one volunteers aged 60 to 80 years participated in the study. Participants were physically active and cognitively intact as they were recruited from the wider behavioural study which required them to be able to walk one mile and participate in a battery of cognitive tasks.

Exploration of the behavioural data indicated that the global-incongruent condition produced the highest rate of inaccuracy and slowest RTs, (see Tables 5.2. and 5.3.). This indicated that condition to be more challenging for this group of older participants and contrasts with Weissman et al. (2006) who found that the local condition produced the slowest RTs compared to the global condition. This is in agreement with existing research suggesting it is easier to identify a global shape than it is to identify its component parts, (referred to as 'global precedence') (Navon, 1977). In this present study, the opposite was found and there was a 'local precedence' such that the local component was faster to identify than the global configuration. Existing research on global-local precedence is limited but one research study in this area found that 'global precedence', the ability to identify the global shape quicker than the local component parts, diminishes with older age (Bruyer & Scailquin, 2000). The findings of the present study add to this work and support the possibility that with increasing age, the precedence effect switches from global to local. Clearly, further research is needed to confirm this. Incongruence also had an increased negative effect on mean RT in the global condition, indicating that this was the more challenging condition for participants (see Figure 5.4. for mean RT interaction graph).

The main objective of the present study, however, was to investigate the brain activity associated with faster trials relative to slower trials. Therefore, the reaction time data were ordered from fastest to slowest for each individual within each condition and divided into terciles, and the brain activity for fastest and slowest terciles contrasted. The activations corresponding to the faster and slower

terciles for both congruent and incongruent, global and local tasks were mapped onto brain activations. Here, it was possible to identify both activations that were task-related (e.g., visual and somatosensory regions) and those that were non-task related in the DMN regions (deactivations) using talairach co-ordinates, [X,Y,Z].

It was found that there was an increased number of deactivations in the DMN during slow responses overall, than fast responses (BA10, 21, 23, 39.40) compared to (BA9, 10, 21, 30). Importantly, when specific conditions and congruence are considered, there were nine examples of the failure of the DMN to deactivate (as evidenced by significant deactivations) during slower responses compared to four during the fast responses, (see Table 5.4.). These areas are part of the core regions associated with the DMN according to Buckner et al. (2008) and Lustig et al. (2003), (see Table 5.1.). This indicated therefore, that slower responding was associated with a failure of the DMN to deactivate during a task-related activity. This pattern was particularly marked in the more demanding global-incongruent condition that produced the slowest behavioral RTs overall (see Table 5.3. and Figure 5.3.). These findings are consistent with work elsewhere in younger adults (Weissman et al., 2006) where there were more DMN activations corresponding to slow responses than fast responses. In two of the conditions, global congruent and local congruent for fast responding, no activations were found at the thresholds chosen for analyses ($p < 0.0001$, 10 voxels +). This absence of activations did not occur in any of the conditions for slow responses, (see Table 5.4.).

Importantly, BA9, 10 and 11 make up the prefrontal cortex and although the faster responses had fewer activations in total, during the global incongruent condition task-related activations in both BA9 and 10 were present whereas during the slower responses, it was only in BA10 for this same condition and congruence. This could indicate some conflict in this region as both BA9 and 10 are part of the DMN and prefrontal cortex. Furthermore, non-task related activations were present in BA23 and 24 for the global congruent and incongruent condition and the local congruent condition for slow reponses. No activations were present in these regions for faster responses (see Table 5.4., BA23 and 24, highlighted in blue). Significantly, BA23 and 24 are the posterior and anterior cingulate cortex (PCC and ACC) and form part of the limbic system which is involved in the emotion system (Goebel, 2007). As the DMN is intricately associated with attentional lapses

whereby focus moves from a task-related to internally generated self reflections (Buckner et al., 2008; Raichle et al., 2001; Smallwood et al., 2011; Smallwood et al., 2004), the relevance of these regions being activated during slower responses and not faster is important when considering the aims of this study. Specifically, it suggests that task-irrelevant thoughts with emotional content may have occurred during slower responses.

This study extended existing research suggesting that attentional lapses cause slower responding and greater variability in older age and that this, in turn, is associated with a failure of or fluctuation in executive control, and decreased deactivation in the DMN. The role of executive function as a mediator of general cognition was explored in Studies 1 to 4. It was of considerable interest here to explore the relationship between executive function and the DMN. The rationale for this was that WP variability is associated with age-related neurobiological changes in the frontal regions of the brain which support both executive control and the DMN. If attentional lapses are evidence of a failure of executive control, it could be that failure of the DMN to deactivate that is linked to increased WP variability. Specifically, the DMN is supported by similar frontal regions as executive control (ventral and dorsal medial prefrontal cortices), as discussed in more detail in the introduction (Buckner, 2011; Buckner et al., 2008; Greicius et al., 2009; Lustig et al., 2003). The findings obtained in this study are consistent with suggestions that increased DMN activity may compete with the attentional or executive control mechanisms necessary for optimal task performance, resulting in slower responses. If DMN activity reflects attentional lapses, it could also reflect a failure of executive control and the ability of the executive control system to cope with the interference between attentional lapses and task performance (McVay & Kane, 2010).

In addition, Weissman et al. (2008) found that momentary lapses in attention were associated with increased activity particularly in the ACC region (BA 24). In the present study, activity was found in the ACC during slow responding in the global congruent and incongruent conditions, the most challenging conditions, based on the behavioural analyses. As the ACC has been associated with detecting and resolving response conflict as well as being part of the limbic system (emotion system) (MacDonald, Cohen, Stenger, & Carter, 2000; Weissman, Gopalakrishnan,

Hazlett, & Woldorff, 2005), it is possible that, as part of the DMN, any deactivations present in this region could mean that distraction and conflict are associated with task-unrelated thoughts. This is likely to result in slower responding. In addition, the dorsal medial prefrontal cortex (DMPFC) region (BA32, 10, 9) is associated with monitoring together with BA24 (Provost et al., 2010). It is of interest here that BA 10 was active during slower responding in the global incongruent condition and BA9 and 10 were active during faster responding of this same condition. This indicates that although, overall, faster responding was associated with more DMN deactivations, the global incongruent condition (the most challenging) still indicated *some* failure of the DMN to deactivate in the ACC and DMPFC region even during faster responding. In previous research, attentional lapses and failure of the DMN has been associated with incongruent tasks requiring response conflict and of high cognitive (executive) demand (Christoff et al., 2009; Weissman et al., 2006). Considering that the regional location of the DMN regions, the ACC with the DMPFC overlap with those of executive control (Christoff et al., 2009) a regional conflict could result in slower responses. This can be explained by the suggestion that ACC activity conflicts with task-related activity and impairs task-related responses, particularly during the incongruent condition. However, a conflicting view suggests that mind wandering may evoke a 'unique mental state' which *allows* the opposing networks to cooperate and work together, at a cost to performance but enriching creativity and mental stimulation (Christoff et al., 2009). Furthermore, Hu et al. (2012) suggest that individuals with a high tendency to experience attentional lapses are actually less sensitive to irrelevant external stimuli, supporting the decoupling hypothesis of mind wandering whereby it is possible to effectively disengage attention from external distractions and respond automatically (Hu et al., 2012; Schooler et al., 2011; Smallwood, McSpadden, & Schooler, 2007).

Designed as a preliminary study, there was a limitation to the conclusions that could be drawn from the present results. The wide participant age range meant that variability neurovascular coupling and behavioural performance in the older participants may have been greater. Although, the study design set out to stratify participants according to age and compare younger versus older, the participants lost due to movement in the scanner meant that this was not possible.

To summarise and conclude, the focus of this study was on the neural correlates of response time variability in relation to the DMN and its association with the disruption of goal-related performance. It also considered the relationship between executive function, the DMN, attentional lapses and within-person variability. The findings suggest that attentional lapses and fluctuations in executive control may be linked to the failure of the DMN to deactivate and that these manifest behaviourally as intermittent slower responses. Importantly, the findings also suggest that a possible reason for the increased proportion of slower RTs that contribute to greater intraindividual variability in healthy old age, is a failure to deactivate the DMN. However, as attentional lapses were not measured empirically, this conclusion remains only tenuous. Specifically, the analysis focussed on the contrast between faster and slower responding, rather than on mapping the neural correlates against a direct measure of WP variability. This was therefore an indirect measurement of WP variability based on the relationship with attentional lapses, slower responses, the DMN and a common neurobiological region, the prefrontal cortex. In addition, also associated with executive control and inhibitory processes.

McVay and Kane (2010) argue that mind wandering represents a failure of executive control and not just a conflict or drain on executive resources. It can be seen therefore, as a dually determined active process between personal goal-related thoughts (DMN deactivations) and task-related performance (activations). The role of executive function is to buffer task-related performance against the former, a failure of which is detrimental to overall task-related performance.

General Discussion

The main objectives of this thesis were (1) to investigate factors that moderate cognitive performance in old age, (2) to compare outcome measures of mean RT and within-person (WP) variability, and (3) to explore evidence of dedifferentiation across cognitive domains. The moderating factors considered in this thesis were mental health, physical, social and intellectual activity, and aerobic fitness. Executive function was also investigated as a possible mediator and a summary of moderator and mediator findings across studies is presented in Table 6.1. Furthermore, this thesis explored the neurobiological origins of age-related cognitive decline, as indicated by slower responding, greater WP variability and fMRI evidence of a failure of the default mode network to deactivate.

Study 1 investigated whether executive function mediated age differences in cognitive function in other cognitive domains (psychomotor performance, visual search and recognition) following the guidelines of Baron and Kenny (1986). The investigation found that executive function mediated the effect of age on both mean RT and WP variability in visual search and recognition, and additionally, WP variability in psychomotor performance. Research suggests that executive function exhibits deficits in older age, with increased susceptibility to fluctuations in its efficiency (Banich, 2009; Treitz et al., 2007; West et al., 2002). Inhibition, an integral component of executive control, functions early in cognitive processing, preventing irrelevant information from gaining access to attentional focus (Lustig et al., 2007). Any disruption in this early processing will have a detrimental effect on cognitive performance, causing both slower mean RTs and increased WP variability. The present findings suggest that cognitive performance in older age *is* associated with the efficiency of executive control. The dissociation between the measures of mean RT and WP variability was of important theoretical interest, indicating a possible difference in the mechanisms supporting the two measures. This is consistent with existing research suggesting that WP variability may be particularly sensitive to early age-related neurobiological decline (Bunce et al., 2008a; Bunce et al., 2004; West et al., 2002). Additional evidence from this study provided little support for the 'dedifferentiation hypothesis', whereby the factor structure of cognition converges onto a single factor (Sims et al., 2009).

Table 6.1. Summary Table of Studies 1 to 4

Study	Summary of findings	Moderation effects	Mediation effects
1	No evidence of dedifferentiation between separate cognitive domains.	Not assessed in this study	Mediation by executive function for mean RT and WP variability in visual search and recognition. Additionally, for WP variability in psychomotor performance. Dissociation evident between mean RT and WP variability, increased mediation for WP variability.
2	Poor mental health (GHQ) has a negative effect on cognition in older age, associated with slower mean RTs and increased WP variability.	For mean RT in immediate recognition and for WP variability in SRT, simple visual search and immediate recognition. Dissociation evident between mean RT and WP variability with increased moderation effects for WP variabillity.	Mediation by executive funtion for WP variability in the interaction between age and recognition. Dissociation evident between mean RT and WP variability, increased mediation evident for WP variability.
3	Intellectual, social and physical activities (VLS questionnaire) selectively have a positive effect on cognition in older age selectively within individual VLS scales, associated with faster mean RTs and reduced WP variability.	*Physical Activity Scale* : for mean RT and WP variability in flanker arrows, Stroop word and immediate recognition. Additionally, for WP variability in 4-CRT and delayed recognition. Dissociation evident between mean RT and WP variability with increased moderation effects for WP variability. *Social Activity* : for mean RT and WP variability in Stroop arrow, Stroop word and simple visual search. Dissociation not evident between mean RT and WP variability. *Hobbies and home maintenance* : for mean RT and WP variability in flanker arrow, simple visual search and immediate recognition. Additionally, for mean RT in Stroop arrow. Slight dissociation between mean RT and WP variability.	Mediation by executive function for WP variability in the interaction between age and recognition. Dissociation evident between mean RT and WP variability, increased mediation evident for WP variability. No mediation evident. No mediation evident.
4	Aerobic fitness (VO_{2max}) has a positive effect on cognition in older age, associated with faster mean RTs and reduced WP variability.	For mean RT and WP variability in flanker arrows, Stroop Word, complex visual search and immediate recognition. Additionally, for mean RT in simple visual search and for WP variability in 4-CRT and Stroop arrow. Dissociation evident between mean RT and WP variability with increased moderation effects for WP variability.	Mediation by executive function for Mean RT and WP variability in the interaction between age and visual search. Additionally, for WP variability in the interaction between age and recognition. Dissociation evident between mean RT and WP variability, increased mediation evident for WP variability.

Notes: GHQ = General Health Questionnaire; VLS = Victoria Longitudinal Study

Instead, it was found that the factor structure was maintained, with the cognitive variables factoring onto the individual domains of psychomotor performance, executive function, visual search and recognition. This is contrary to existing research that suggests dedifferentiation ubiquitously occurs in older age (Babcock et al., 1997; Baltes & Lindenberger, 1997; Dennis & Cabeza, 2011) and may suggest that dedifferentiation is more characteristic of pathological ageing (Batterham et al., 2011; Salthouse, 2012; Sims et al., 2009). It is important to note that this sample population was healthy, with no sign of cognitive impairment, as measured by the mini-mental state examination (MMSE) (Folstein et al., 1975) and dedifferentiation was not evident. A recent research study also found no evidence of dedifferentiation, in a group of 1490 healthy adults aged 18 to 89 years (Salthouse, 2012). Together, these findings suggest that dedifferentiation is a feature of pathological ageing rather than healthy ageing as is likely in the present sample.

Study 2 was the first of three studies exploring moderators of cognition in older age. This investigation extended the research of Study 1 and examined mental health as a moderator of cognition using the same Baron and Kenny (1986) procedure as Study 1. The aim was to examine whether mental health, as measured by the General Health Questionnaire (Goldberg, 1978), moderated the relationship between age and cognition. Additionally, it also investigated whether moderation effects, where they were found, were mediated by executive function in a so-called mediated-moderation relationship. This is based on research that suggests poor mental health is associated with neurobiological deficits in the frontal regions that trigger the release of glucocorticoids, which may result in the disruption of cognitive processing (Sapolsky, 1999). As there is a high density of corticosteroid receptors in the frontal cortex, any additional stress response caused by anxiety or depression will have an effect on these receptors and may be detrimental to executive function which is supported by frontal regions (Bunce et al., 2008b; Channon & Green, 1999; Raz & Rodrigue, 2006). Poor mental health is also associated with reduced frontal neurotransmitter efficiency and increased white matter lesions (Bunce et al., 2007; Li et al., 2001) both of which have been associated with executive function. Taking into account the common neurobiological origin between executive function, the prefrontal cortex (PFC) and elements of mental health, it was of considerable interest to establish whether

executive function acted as a mediator of age-cognitive relations. As with Study 1, it also investigated whether the measures of mean RT and WP variability dissociated. The main findings of this study indicated that there *was* a significant interaction between age, mental health and cognition for both mean RT and WP variability, with a dissociation between the two measures, indicated by an increased number of significant interactions for WP variability. The moderating effect indicated that slower mean RT and greater WP variability were significantly associated with poorer mental health. It was also found that executive function mediated the effect of mental health on cognition for both mean RT and WP variability, suggesting a common underlying causal relationship with executive function.

Study 3 examined lifestyle factors as moderators of cognition. Using the Victoria Longitudinal Study lifestyle questionnaire (Hultsch et al., 1999) this study examined whether physical, social and intellectual activities moderated the relationship between age and cognition. The study was based on research that suggests an active lifestyle is associated with enhanced cognition and a delay in the onset of dementia (Hultsch et al., 1999; Larson et al., 2006). Additionally, as with Studies 1 and 2, it also investigated if the moderation affect where found, was mediated by executive function in a mediated-moderation relationship. This was based on research that suggests an active lifestyle is associated with delayed neurobiological decline (Dixon, 2011; Stine-Morrow & Basak, 2011) and as with Studies 1 and 2, taking into account the common neurobiological origin between executive function and the prefrontal cortex (PFC) it was of considerable interest to establish whether executive function acted as a mediator. As with Studies 1 and 2, it also investigated whether there was a dissociation between measures of mean RT and WP variability. The main findings of this study indicated that there were varying significant interactions between age, VLS scales and cognition for both mean RT and WP variability. Significant interactions were found for the physical, social and, hobbies and home maintenance VLS scales. This indicated that lifestyle activities were *selectively* moderating the effect of age on mean RT and WP variability, with lower VLS scale activity associated with slower mean RTs and greater WP variability. Additionally, this moderation effect was mediated by executive function for the physical activity scale and partially mediated for the social activity scale, suggesting a common underlying causal relationship with

executive function, as with mental health in Study 2. In sum, the findings of this study indicate that maintaining an active life style into older age has benefits for cognitive function.

Whereas the previous study used self-report measures of lifestyle activity, Study 4 explored the moderating effect of aerobic fitness on cognition, as measured by an objective measure of VO_{2max}. This study was based on existing research which suggests that aerobic fitness is associated with enhanced cognition, particularly executive function (Kramer et al., 2005; Weinstein et al., 2011). It is proposed that aerobic fitness affords cognitive enhancement through cardiovascular benefits and related neurobiological efficiency involving increased cerebral spinal fluid, and neurotransmission efficiency and grey matter atrophy may be attenuated (Bunce & Murden, 2006; Colcombe et al., 2006; Kramer et al., 2005). Additionally, as with Studies 1 to 3, the present study investigated whether the moderation effect was mediated by executive function. It is proposed that the positive association between aerobic fitness and executive function could be due to its beneficial effects on the PFC, as described in the Main Introduction. Here, there was evidence that aerobic fitness, as measured by VO_{2max}, moderated the association between age and cognition and that executive function mediated this effect. This finding is consistent with the view that aerobic fitness attenuates the underlying neurobiological decline that contributes to cognitive deficits in old age.

As a major interest in this thesis was moment-to-moment fluctuations in cognitive performance, Study 5 investigated the neural correlates of response time variability using brain imaging techniques. The previous studies explored whether executive function mediated age-related deficits in WP variability in other cognitive domains. An important issue was the association between executive function and WP variability and the common neural mechanisms between them. Functional magnetic resonance imaging (fMRI) was used to examine the neural substrates of response time variability using a global-local task. Specifically, faster behavioural responses were contrasted with slower behavioural responses to investigate whether the neural mechanism differed between them. The aim of the study was to investigate whether there was any evidence of differences in attentional or executive engagement for the two types of responses. This is based on research that suggests slower responding is associated with attentional lapses

(Bunce et al., 1993; Weissman et al., 2006). It was also found that there was an increased number of deactivations in the default mode network (DMN) during slow responses overall compared to during fast responses. This indicated that increased DMN deactivations were present during slow responding, associated with failure of the DMN to deactivate during a task-related activity. This finding is consistent with existing research suggesting that attentional lapses are associated with slower responding and greater variability in older age and that this, in turn, is associated with a failure of, or fluctuation in, executive control during task-related performance. As the role of executive function as a mediator of general cognition was explored in Studies 1 to 4, it was of considerable interest in this study to explore the relationship between executive function and the DMN. The rationale for this was that WP variability is associated with age-related neurobiological changes in the frontal regions of the brain which support both executive control and the DMN (Weissman et al., 2006). If attentional lapses suggest intermittent failure of executive control, it could be that failure of the DMN to deactivate is a major contributor to increased WP variability. The findings obtained in this study are consistent with suggestions that increased DMN activity may compete with the attentional or executive control mechanisms necessary for optimal task performance, resulting in slower responses. If DMN activity is associated with attentional lapses, it may reflect a failure of the executive control system to cope with the interference between attentional lapses and task performance (McVay & Kane, 2010). In this study, it was also found that there was a 'local precedence' effect with the global-local task, such that the local component was more easily identified than the global configuration. Existing research on global-local precedence is limited but one research study in this area found that 'global precedence', the ability to identify the global shape quicker than the local component shapes, diminishes with older age (Bruyer & Scailquin, 2000). The present behavioural findings are consistent with this emerging research. In sum, the main findings of the present study suggest that the intermittent slower responding associated with increased WP variability may be due to a failure of the DMN to disengage. It is important that further research explore this possibility as it is consistent with the view that age-related slowing may, in part, be due to a failure of inhibitory mechanisms.

Implications of the Research

One of the theoretical considerations of this thesis was the dedifferentiation of cognition in older age. The findings of Study 1 were contrary to previous research which suggests dedifferentiation is an inevitable process of cognitive decline in older age (Babcock et al., 1997; Baltes & Lindenberger, 1997; Dennis & Cabeza, 2011). In this study, the factor structure of cognition was maintained and cognitive performance did not converge onto a single factor model as suggested by the dedifferentiation hypothesis, indicating a differential cognitive decline across the cognitive domains examined with this healthy group of participants.

In Study 1, it was evident that executive function mediated the effect of age on cognition for mean RT and WP variability in visual search and recognition and additionally, WP variability in psychomotor performance. This mediating effect suggests that the efficiency of executive function influenced cognitive performance in these domains for both measures. This is consistent with the 'frontal lobe hypothesis' where cognitive function associated with this region (executive control) declines earlier than other functions possibly due to early neurobiological decline (Banich, 2009; Treitz et al., 2007; West, 2000; West et al., 2002; West, 1996). This neurobiological decline has deleterious effects on executive function (the mediator here) with consequences for wider aspects of cognition (Raz et al., 2005).

In addition to the above findings, the fMRI results suggested that failure of the default mode network (DMN) to deactivate was associated with slower responding. This is consistent with previous research where failure of the DMN to deactivate during task-related activity resulted in both slower responding and greater variability (Weissman et al., 2006). From the perspective of this thesis, it is of note that the DMN and executive function are associated with similar overlapping neurobiological substrates in areas of the PFC (see Table 5.1.). Existing research and the fMRI results obtained here indicate that certain regions of the PFC are activated during tasks of high cognitive demand. Existing research has also found that failure of the DMN is more prevalent with older age and that lower executive control is exhibited during the slowest responses, also associated with an increase in behavioural variability (Unsworth et al., 2010), attentional lapses and failure of executive control (Weissman et al., 2006). It is possible,

therefore, that a failure of the DMN to disengage may contribute to age-related deficits in cognitive performance. These findings are consistent with work elsewhere in younger adults (Weissman et al., 2006), and additionally suggest that DMN activity in conditions of greater task demands may compete with the attentional or executive control mechanisms necessary for optimal task performance. Importantly, during faster RTs there was little evidence of the failure of the DMN to deactivate whereas for slower responses such failures were in greater evidence. Indication of some DMN activity during faster responding could have been attributed to the age of the participants whereby even during fast responses, the DMN does show some activity (failure to deactivate) in regions (BA9, 10 and 21), however, as discussed in Study 5, regions BA9 and 10 are the PFC regions overlapping with executive function and task-related activations. Weissman et al. (2006) focused on *pre*-response activity and found a reduction in PFC activity associated with attentional lapses with his younger age group (18 to 35), here, during slow responses, there was a reduction in PFC activity, when compared to during fast responses (BA9 and 10). Although this study did not directly measure activations associated with WP variability, it was a preliminary study exploring the neural correlates of response time variability with the associative relationship between the DMN, attentional lapses and age-related neurobiological decline, particularly in the PFC region.

Another major objective of this thesis was to investigate factors that moderated cognitive deficits in old age. Study 2 investigated the influence of mental health on cognition and Studies 3 and 4 investigated active lifestyle and aerobic fitness. It was found that in agreement with existing research (Bunce et al., 2008a; Bunce et al., 2008b; Sapolsky, 1999; Sliwinski et al., 2006) poorer mental health was associated with slower mean RTs and greater WP variability. The findings were consistent with research suggesting that age and anxiety or depression-related task interference compete for the resources available for attentional focus, specifically those for executive control, with a consequent deleterious impact on cognitive performance (Bunce et al., 2008a; Bunce et al., 2008b).

In addition to mental health, there was also statistical evidence of an active lifestyle moderating age differences in cognition. Specifically, the subscales of physical and social activity, and hobbies and home maintenance. An active lifestyle

has been shown to have a beneficial effect on the PFC, with new neuronal connections being formed in response to stimulation provided by novel situations (van Praag et al., 2000). This indicates that participation in lifestyle activities, particularly novel activities may have a positive effect on the neurobiology of the PFC, moderating the rate of age-related decline. Importantly, physical activity as a self-reported measure of the VLS questionnaire was shown to be positively associated with faster mean RTs and reduced WP variability. Physical activity is associated with increased cardiovascular activity, which has a positive effect on cerebral blood flow, neurotransmission efficiency and neurodegeneration (Bunce & Murden, 2006; Colcombe & Kramer, 2003; Colcombe et al., 2006; Colcombe, Kramer, Erickson, et al., 2004; Kramer & Erickson, 2007b; Larson et al., 2006; van Praag, 2009). This was expanded on, in Study 4, in which an objective measure of VO_{2max} confirmed the findings obtained from the self reported measure of the VLS questionnaire. In Study 4, not only was aerobic fitness significantly associated with faster mean RTs and reduced WP variability, the effect was mediated by executive function. This suggests that aerobic fitness could be having a significant effect on mechanisms supporting executive function in the PFC. The theoretical implication of this is that aerobic fitness significantly moderates the effect of age on cognition with a higher level of aerobic fitness associated with increased cognition due to the neurobiological benefits on the PFC (Erickson & Kramer, 2009).

Dissociation of Cognitive Measures

The possible dissociation of the measures of mean RT and WP variability was an additional focus of this thesis. As increased WP variability has been associated with mild neuropathology (Bunce et al., 2008a; Bunce et al., 2008b; Burton et al., 2006; de Frias, Dixon, Fisher, & Camicioli, 2007), it was of interest here whether this would be evident in this healthy group of participants. Although the group was healthy, they were all above the age of 50 years, unlike many studies which include a younger age range, for example, 18-89 years (Salthouse, 2012). The extent of the dissociation between the two measures varied across the studies. In Study 1, there was increased mediation by executive function for WP variability. For both mean RT and WP variability, executive function mediated in visual search and

recognition but also in psychomotor performance for WP variability, as previously mentioned. In Study 2 there were a larger number of significant interactions between age, mental health and WP variability relative to mean RT. For WP variability, these were for SRT, simple visual search and immediate recognition and for mean RT, only immediate recognition. This indicates that WP variability may be a more sensitive measure of the association between mental health and cognition and also, in agreement with work previously cited in Bunce et al., (2004) and mentioned in Study 1, the psychomotor task was particularly a sensitive measure of WP variability. There was also dissociation evident between mean RT and WP variability in Study 4 where there were a greater number of interactions between age, aerobic fitness and WP variability than for mean RT. For WP variability, these were for; 4-CRT, all the executive function tasks, complex visual search and immediate recognition. For mean RT, they were flanker arrows, Stroop word, both visual search tasks and immediate recognition. Although the dissociation in Study 4 was only slightly evident, this was of interest due to the neurobiological benefits that aerobic fitness affords and the association of WP variability and early neurobiological decline. Also, that all of the executive function tasks exhibited significant interactions is of additional interest here due to the neurobiological region associated with executive function (prefrontal cortex), the neurodegeneration of which, is associated with greater WP variability (Jackson et al., 2012; MacDonald, Li, et al., 2009). To summarize, dissociations were evident to varying degrees across the studies with increases interaction effects found for WP variability, indicating that WP variability could be a more sensitive measure of neurocognitive decline, even in this group of healthy older adults with no obvious cognitive impairment.

Future Directions

A future longitudinal study would enhance validity and allow causal inferences to be made in relation to the study objectives. In addition, considering the significant moderator results obtained for mental health, future research could differentiate between anxiety and depression to ascertain the main contributing factor of poor mental health, as measured here by the GHQ. Furthermore, extending the age range of this population downwards to 40 years could be considered as there is accumulating evidence that lifestyle factors in middle age are particularly important when considering risk and protective factors for health and well-being in later life. A future direction for the fMRI study (Study 5) would be to recruit more participants in the present age range (60 to 80 years) and stratifying the sample into "young-old" and "old-old". This would provide important insights into the role of the DMN in cognitive performance in later life.

Main Conclusions

It is evident from the results obtained that although older age is associated with cognitive deficits as indicated in both increased mean RT and greater WP variability, there are moderators such as an active lifestyle and aerobic fitness that may attenuate such deficits and help protect cognition. In addition, the theoretical implications drawn from the mediation role of executive function suggests that neurobiological structures, and specifically the PFC, are key to age-related variation in cognitive performance. The findings underline the importance of promoting good mental health, continued participation in stimulating lifestyle activities, and maintaining aerobic fitness into old age in order to protect and perhaps enhance neurobiological structures. With the expanding older population, these findings highlight the need for public health policy to promote healthy and active lifestyles, not only amongst older adults, but also among persons of all ages.

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Appendices

Appendix I

Advertisement for participant recruitment

Volunteers Wanted!

Aged 50 to 80 years old?

Can you walk 1 mile?

Do you want to participate in an important study about lifestyle and brain function?





I will be investigating the influence of lifestyle on brain function and I am looking for 300+ volunteers to participate in a study for my doctoral research. I am assessing how social, mental and physical activities affect brain function during normal ageing.

You will be asked to complete a questionnaire about your activities (hobbies and social activities), do some fun activities on a computer (good computer skills not needed!), walk one mile on a treadmill, and complete a few details about yourself.

Locations will be at gyms and fitness clubs in Hook and Basingstoke.

If you are interested in taking part, please take a contact card. It will take just an hour or so of your time, will be fun and give you the satisfaction of knowing that you contributed to this important research.

Hope to hear from you soon, via email or telephone. Please tell a friend!

Sarah Bauermeister
Research Student - Cognitive Ageing

Centre for Cognition and Neuroimaging (CCNI)
Brunel University, West London

Please call Sarah Bauermeister on 07092 121165 or
e-mail: sarah.bauermeister@brunel.ac.uk

Please take a contact card and one for a friend too!
Feel free to contact me for more information.

Appendix II

Biographical questionnaire

BIOGRAPHICAL QUESTIONNAIRE **Participant:**

Please answer the following questions.

(Answers to the following questions will be treated in the strictest of confidence, and seen by the researchers only)

1) Please state your **AGE** in years _____

2) Please tick as appropriate: **male** ☐ **female** ☐

3) Please indicate your marital status by ticking the appropriate box:

Single	☐
Married/cohabiting with partner	☐
Separated	☐
Divorced	☐
Widowed	☐
Never married	☐

4) Please state the **number of years** you have spent in **full-time education** _____

5) Please circle the letter next to your **highest qualification**:

a) None
b) GCSE / 'O' level or equivalent
c) 'A' Level or equivalent
d) BSc / BA or equivalent
e) MSc / MA or equivalent
f) PhD
g) other _____

Participant:

6) If applicable, please state your **job title** _____

Please state you **job grade/level** _____

7) Do you suffer from colour blindness? Yes ☐ No ☐

8) How would you rate your **general health relative to others your age**?

Extremely Unhealthy 1 2 3 4 5 6 7 8 9 10 extremely healthy

9) Do you take **regular physical exercise**? Yes ☐ No ☐

If yes:
What sort of exercise? _____
(generally)

_____

for how many hours each week? _____
(roughly)

10) Have you ever suffered any major health conditions (e.g. heart, neurological, mental health etc)? Please give brief details_____

11) Are you taking any regular **medication** Yes No

If yes, please state the **medication name and the reason for taking it**

(e.g. hypertension, high cholesterol, diabetes)

12) Are you happy to be contacted for further participation in this and related studies in the future? Yes ☐ No ☐

13) Ethnicity (Statistical purposes only): Please tick

White: English ☐ Irish ☐ Scottish ☐ Welsh ☐ Other White ☐

Black: Black British, Black English, Black Scottish or Black Welsh ☐

Caribbean ☐ African ☐ Other Black background ☐

Asian: Asian British, Asian English, Asian Scottish or Asian Welsh ☐ Indian ☐

Pakistani ☐ Bangladeshi ☐ Other Asian background ☐

Chinese: Chinese British, Chinese English, Chinese Scottish or Chinese Welsh ☐
Chinese ☐

Mixed: White and Black Caribbean ☐ White and Black African ☐
White and Asian ☐

Other mixed background ☐

Other ethnic background: ☐

Participant:

14) **Full Name:** _____

15) **Participation Number:** _____

16) **Home address**: _____
_____
_____
_____

Home Tel No: _____

Mobile Tel No: _____

Work Tel No: _____

Home email .....@.....

Work email .....@.....

*Please mark most used contact email address with *.*

* * * * *

Thank you for your participation!

Official Use:

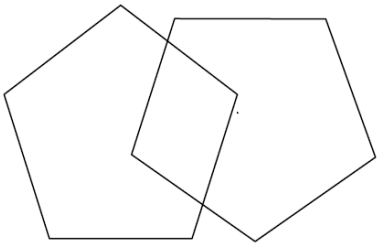
Height			
Weight		BMI:	
Pulse: Resting			
Pulse: Post Exercise			
Pulse: Post Exercise + 1 minute			
FEV			
FVC			
MMSE			
NART: Raw			
NART: FSIQ			

Appendix III

Mini-Mental-State-Examination (MMSE)

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

MMSE **Participant:**

Orientation	Date		
	Day		
	Month		
	Year		
	Season		
	Country		
	County		
	Village/Town		
	Building		
	Room		
		*******	*******
Registration - Memory	Toothbrush		
	Key		
	Torch		
		*******	*******
Attention – Calculation 100/world	93 d		
	86 l		
	79 r		
	72 o		
	65 w		
		*******	*******
Recall	Toothbrush		
	Key		
	Torch		
		*******	*******
Language	What is this? (wrist watch)		
	What is this? (pencil)		
	Repeat 'No ifs, and or buts'		
	Follow 'Take a paper in your hand'		
	'Fold it in half'		
	'and put it on the floor'		
	Read the sign and do it 'Close your eyes'		
	Please write a sentence 'subject/verb/sensible'		
	Copy design: 		
		*******	*******
Total			

Appendix IV

National Adult Reading Test (NART)

Nelson, H. (1982). *The National Adult Reading Test (NART)*. Windsor, England: Nfer-Nelson.

NART **Participant:**

Ache Debt Psalm Depot Chord		Superfluous Radix Assignate Gist Hiatus	
Simile Rarefy Cellist Zealot Abstemious		Gouge Placebo Facade Aver Leviathan	
Bouquet Deny Capon Heir Aisle		Aeon Détente Gauche Drachm Idyll	
Subtle Nausea Equivocal Naïve Thyme		Beatify Banal Sidereal Puerperal Topiary	
Courteous Gaoled Procreate Quadruped Catacomb		Demesne Campanile Labile Syncope Prelate	

Appendix V

Information sheet for behavioural study

The association between mental, social, physical fitness and cognitive behaviour in older people

RESEARCH PARTICIPANT INFORMATION SHEET

Thank you for taking part in this research. Recent research into the study of brain ageing suggests that individuals who continue to take part in mental, social, and physical activities well into old age may maintain their cognitive abilities (brain function) better than those who do not. This study investigates this issue using a multi-methodological approach in at least 300 participants, aged from 50 to 80 years old, you are one of these participants.

The tasks on the computer were designed to investigate response time and accuracy in a number of different cognitive domains including memory, attention and spatial skills. The treadmill task evaluated fitness level and the questionnaire was designed to assess social and mental activity levels.

These measures will enable us to investigate:

- The relationship between physical fitness level and cognitive function.
- The relationship between social activity level (social fitness) and cognitive function.
- The relationship between mental activity (mental fitness) level and cognitive function.
- The relationship between age and mental/social/physical fitness level.

The findings from the study will form part of my dissertation for my PhD research at Brunel University, West London.

I hope that this experience was fun, interesting and enjoyable. Thank you again for your interest and/or taking part in this study. All data collected will be kept confidentially in a secure location. Participants will be anonymous in the research outputs, e.g, reports, presentations.

For further information, please contact:

Sarah Bauermeister
Research Student
CCNI
Brunel University
Uxbridge
UB8 3PH
sarah.bauermeister@brunel.ac.uk

Appendix VI

Consent form for behavioural study

PARTICIPANT CONSENT FORM **Participant:**

Please read the following carefully and then sign below.

The research study that you have been invited to take part in forms part my PhD research at Brunel University, supervised by Professor David Bunce of the Centre for Cognition and Neuroimaging (CCNI) investigating mental, social, physical activities and cognitive brain function, in older people.

The study will involve some physical fitness measures (pulse, body weight, lung function) and also a lifestyle questionnaire, a 1-mile treadmill walk and performance on a variety of cognitive tasks (e.g. memory, response speed) on a computer. The session will last for about two hours and if you wish to take a short break at any time, simply inform the researcher.

Participation is voluntary, and you may withdraw from the study at any time. Data will be held in the strictest of confidence. The eventual results of the study will be presented in aggregate terms across all participants (over 200 - 300 people), in my PhD degree and research reports. No data will be attributed to any one individual.

Declaration

I have read the above and am willing to take part in the research as a volunteer. I broadly understand the procedures involved, and what the objectives of the research are. I also acknowledge that I am taking part entirely at my own risk and I do not hold either the researchers or facility owners responsible for any consequences from my participation.

NAME (Please print).....

SIGNATURE.....DATE……

If you have any questions, please ask at any time.

Thank you very much for participating in this study and contributing to my research.
Sarah Bauermeister (Researcher)

Appendix VII

Debrief of behavioural study

The association between mental, social, physical fitness and cognitive behaviour in older people

PARTICIPANT DEBRIEF

Thank you for taking part in this research. Recent research into the study of brain ageing suggests that individuals who continue to take part in mental, social, and physical activities well into old age may maintain their cognitive abilities (brain function) better than those who do not. This study investigates this issue using a multi-methodological approach in at least 300 participants, aged from 50 to 80 years old, you are one of these participants.

The tasks on the computer were designed to investigate response time and accuracy in a number of different cognitive domains including memory, attention and spatial skills. The treadmill task evaluated fitness level and the questionnaire was designed to assess social and mental activity levels.

These measures will enable us to investigate:

- The relationship between physical fitness level and cognitive function.
- The relationship between social activity level (social fitness) and cognitive function.
- The relationship between mental activity (mental fitness) level and cognitive function.
- The relationship between age and mental/social/physical fitness level.

The findings from the study will form part of my dissertation for my PhD research at Brunel University, West London.

I hope that this experience was fun, interesting and enjoyable. Thank you again for your interest and/or taking part in this study. All data collected will be kept confidentially in a secure location. Participants will be anonymous in the research outputs, e.g, reports, presentations.

For further information, please contact:

Sarah Bauermeister
Research Student
CCNI
Brunel University
Uxbridge
UB8 3PH
sarah.bauermeister@brunel.ac.uk

Appendix VIII

Ethical approval for behavioural study

→ David Bunce

SCHOOL OF SOCIAL SCIENCE RESEARCH ETHICS CHECKLIST (Effective 1 Oct 2007)

If the ethics submission relates to staff research for which an application to an external funding agency will be/has been made, then please complete and submit the full University ethics submission form.

Section I: Project Details

1. Project title. **The effects of mental, social and physical fitness on brain function and cognitive behaviour in an ageing population**

Section II: Applicant Details

2. Name of researcher (applicant). **Sarah Bauermeister**
3. Status (please circle): /**Postgrad Student**
4. Discipline (please circle): /**Psy/**
5. Email address: **sarah.bauermeister@brunel.ac.uk**
6. Telephone number **07854916136**

Section III: For Students Only

7. Module name and number: **PhD Research (Psychology)**
8. Brunel supervisor's or module leader's name: **Professor David Bunce**
9. Brunel supervisor's email address: **david.bunce@brunel.ac.uk**

Supervisor: Please tick the appropriate boxes. The study should not begin until all boxes are ticked:

- ☑ The student states that he or she has read the Brunel University Code of Research Ethics.
- ☑ The topic merits further research.
- ☑ The student will possess the skills to carry out the research by the time that he or she starts any work which could affect the well-being of other people. He or she will be deemed to have acquired such skills on passing the relevant research skills module.
- ☑ The participant information sheet or leaflet is appropriate.
- ☑ The procedures for recruitment and obtaining informed consent are appropriate.

Please confirm the professional research ethics code that will guide the research (please circle)

ASA/BPS/BSA/Other (please state) _____

David B — 30/10/07

Supervisor's signature — Date

Section IV: Research Checklist

Please answer each question by ticking the appropriate box:

	YES	NO
1. Does the study involve participants who may be particularly vulnerable and/or unable to give informed consent, thus requiring the consent of parents or guardians? (e.g. children under the age of 16; people with certain learning disabilities)	☐	No
2a. Will the study require the co-operation of a gatekeeper for initial access to the groups or individuals to be recruited?	☐	No
2b. If the answer to Question 2a is Yes, then will the study involve people who could be deemed in any way to be vulnerable by virtue of their status within particular institutional settings? (e.g. students at school; disabled people; members of a self-help group; residents of a nursing home, prison, or any other institution where individuals cannot come and go freely)	☐	☐
3. Does the research involve observational/ethnographic methods?	☐	No
4. Will the study involve discussion by or with respondents or interviewees of their own involvement in activities such as sexual behaviour or drug use, where they have not given prior consent to such discussion?	☐	No
5. Are drugs, placebos or other substances (e.g. food substances, vitamins) to be administered to the study participants or will the study involve invasive, intrusive or potentially harmful procedures of any kind?	☐	No
6. Will blood or tissue samples be obtained from participants?	☐	No
7. Is pain or more than mild discomfort likely to result from the study?	☐	No
8. Could the study induce psychological stress or anxiety or cause harm or negative consequences beyond the risks encountered in normal life?	☐	No
9. Will the study involve prolonged or repetitive testing?	☐	No
10. Will financial inducements (other than reasonable expenses and compensation for time) be offered to participants?	☐	No
11. Will the study involve recruitment of patients or staff through the NHS?	☐	No
12a. Have you undertaken this study as part of your work placement?	☐	No
12b. If your answer to Question 12a is Yes, then have the employers at your work placement conducted their own research ethics review?	☐	☐
13. Does the research involve MRI, MEG, or EEG methods?	Yes	☐

Give a brief description of participants and procedure (methods, tests used etc) in up to 150 words

Research Methodology: This study will use multi-methodological tools:

- The Mini Mental State Examination (MMSE) and National Adult Reading Test (NART) will be administered, and biographical information collected
- Cognitive behavioural tasks will be administered via computer-based programs.
- For a subsample, neuroimaging will be used to investigate cognitive function while controlling for fitness, age and social/mental variables.
- Physical Fitness tests will include the Rockport Walking Test which will determine a VO2 Max level for each participant, placing them in a fitness category. This is a submaximal measures of VO2 max, and is appropriate for use in older populations.
- Questionnaires will be used to ascertain social/mental activity levels of the participants.

Participants:

The participants will be recruited via advertisements in gyms, fitness clubs, post offices, shopping centres and other social recreational points such as Bingo Halls and Recreation Halls. A minimum number of 210 participants will be recruited.

Please note, the MRI element of the is covered by the generic ethics clearance granted for MRI methodology in healthy populations by UREC.

Name of Principal Investigator at Brunel University (please print): **Sarah Bauermeister**

Signature of Principal Investigator at Brunel University: _____

E-Mail Address: **sarah.bauermeister@brunel.ac.uk**

Date: _____

This request for expedited review has been: (1) Approved (no additional ethics form is necessary)
~~(2) Declined (full University ethics form is necessary)~~

Signature of School Research Ethics Officer: _____

Date: 9/11/07

Appendix IX

The General Health Questionnaire (GHQ)

GHQ12 **Participant:**

Please read this carefully.

I would like to ask about how you have been feeling over the last few weeks. Please answer ALL the questions simply by underlining the answer which you think best applies to you. Remember that we want to know about present and recent thoughts and feeling, not those you've had in the past.

It is important that you try to answer ALL the questions.

Thank you for your participation!

Have you recently……..

been able to concentrate on whatever you're doing?	Better than usual	Same as usual	Less than usual	Much less than usual
lost much sleep over worry?	Not at all	No more than usual	Rather more than usual	Much more than usual
felt that you are playing a useful part in things?	More so than usual	Same as usual	Less useful than usual	Much less useful
felt capable of making decisions about things?	More so than usual	Same as usual	Less so than usual	Much less than usual
felt constantly under strain?	Not at all	No more than usual	Rather more than usual	Much more than usual
felt you couldn't overcome your difficulties?	Not at all	No more than usual	Rather more than usual	Much more than usual
been able to enjoy your normal day-to-day activities?	More so than usual	Same as usual	Less so than usual	Much less than usual
been able to face up to your problems?	More so Than usual	Same as usual	Less so than usual	Much less able
been feeling unhappy and depressed?	Not At all	No more than usual	Rather more than usual	Much more than usual
been losing confidence in yourself?	Not At all	No more than usual	Rather more than usual	Much more than usual
been thinking of yourself as a worthless person?	Not At all	No more than usual	Rather more than usual	Much more than usual
been feeling reasonably happy, all things considered?	More so than usual	About same as usual	Less so than usual	Much less than usual

Appendix X

Victoria Longitudinal Study (VLS) Lifestyle Questionnaire

(modified)

Activities Questionnaire	**Participant:**
Please circle the letter that MOST NEARLY describes the frequency with which you have done the activity in the last two years. PLEASE DO NOT HESITATE TO ASK IF YOU DO NOT UNDERSTAND THE QUESTION!	

Answer Key			
a	Never	e	About once a month
b	Less than once a year	f	2 or 3 times a month
c	About once a year	g	About once a week
d	2 or 3 times a year	h	2 or 3 times a week
		i	Daily

Question	Response								
1. I prepare a meal	a	b	c	d	e	f	g	h	i
2. I do housework (dishes, laundry, vacuuming etc.)	a	b	c	d	e	f	g	h	i
3. I go food shopping	a	b	c	d	e	f	g	h	i
4. I go shopping at a centre or town	a	b	c	d	e	f	g	h	i
5. I drive a car	a	b	c	d	e	f	g	h	i
6. I take a bus	a	b	c	d	e	f	g	h	i
7. I take care of someone in my family (invalid/disabled)	a	b	c	d	e	f	g	h	i
8. I take care of one or more pets	a	b	c	d	e	f	g	h	i
9. I do household repairs (painting, leaking gutters etc.)	a	b	c	d	e	f	g	h	i
10. I repair a car, lawn mower or other machine	a	b	c	d	e	f	g	h	i

Question	Response								
11. I purchase a new item requiring set-up or assembly	a	b	c	d	e	f	g	h	i
12. I do woodworking, carpentry or furniture refinishing	a	b	c	d	e	f	g	h	i
13. I play a musical instrument	a	b	c	d	e	f	g	h	i
14. I engage in creative writing, writing poems, articles etc.	a	b	c	d	e	f	g	h	i
15. I engage in photography	a	b	c	d	e	f	g	h	i
16. I collect stamps, coins, dolls, or other memorabilia	a	b	c	d	e	f	g	h	i
17. I engage in sewing, knitting, or needlework	a	b	c	d	e	f	g	h	i
18. I engage in painting, sculpting, ceramics, drawing etc.	a	b	c	d	e	f	g	h	i
19. I participate in theatrical activity	a	b	c	d	e	f	g	h	i
20. I sing in a choir	a	b	c	d	e	f	g	h	i

Question	Response								
21. I garden indoors or outdoors	a	b	c	d	e	f	g	h	i
22. I engage in exercises such as jog/swim/cycle/run	a	b	c	d	e	f	g	h	i
23. I engage in outdoor activities such as sail/fish/backpack	a	b	c	d	e	f	g	h	i
24. I engage in recreation sports such as tennis/golf/bowls	a	b	c	d	e	f	g	h	i
25. I do crossword puzzles, sudoku, or anagrams	a	b	c	d	e	f	g	h	i
26. I play card games such as bridge/whist/poker	a	b	c	d	e	f	g	h	i
27. I do jigsaw puzzles	a	b	c	d	e	f	g	h	i
28. I play board games such as chess/draughts	a	b	c	d	e	f	g	h	i
29. I play knowledge games such as Trivial Pursuit	a	b	c	d	e	f	g	h	i
30. I play word games such as Scrabble	a	b	c	d	e	f	g	h	i

Question	Response								
31. I read newspapers	a	b	c	d	e	f	g	h	i
32. I read books or magazines for leisure	a	b	c	d	e	f	g	h	i
33. I read books or magazines as part of my job/career	a	b	c	d	e	f	g	h	i
34. I go to the library	a	b	c	d	e	f	g	h	i
35. I watch news programs on TV (television)	a	b	c	d	e	f	g	h	i
36. I watch documentary or educational programs on TV	a	b	c	d	e	f	g	h	i
37. I watch quiz game shows such as Countdown on TV	a	b	c	d	e	f	g	h	i
38. I watch comedy or adventure programs on TV	a	b	c	d	e	f	g	h	i
39. I watch continuing dramas on TV	a	b	c	d	e	f	g	h	i
40. I listen to radio programs	a	b	c	d	e	f	g	h	i

Question	Response								
41. I write a letter (friend/relative/business etc.)	a	b	c	d	e	f	g	h	i
42. I program software for a personal computer (PC)	a	b	c	d	e	f	g	h	i
43. I use pre-programmed software on a PC	a	b	c	d	e	f	g	h	i
44. I use an electronic calculator	a	b	c	d	e	f	g	h	i
45. I balance a cheque book	a	b	c	d	e	f	g	h	i
46. I prepare my own tax return	a	b	c	d	e	f	g	h	i
47. I prepare someone else's tax return	a	b	c	d	e	f	g	h	i
48. I do arithmetic or mathematical calculations	a	b	c	d	e	f	g	h	i
49. I attend films (travel films/commercial films)	a	b	c	d	e	f	g	h	i
50. I attend a concert or play	a	b	c	d	e	f	g	h	i

Question	Response								
51. I attend a public lecture or talk	a	b	c	d	e	f	g	h	i
52. I attend sports events such as rugby/football/cricket	a	b	c	d	e	f	g	h	i
53. I eat out at a restaurant	a	b	c	d	e	f	g	h	i
54. I visit a medical physician such as doctor/dentist/other	a	b	c	d	e	f	g	h	i
55. I visit relatives, friends or neighbours	a	b	c	d	e	f	g	h	i
56. I give a dinner or a party for friends	a	b	c	d	e	f	g	h	i
57. I attend a religious service of any faith	a	b	c	d	e	f	g	h	i
58. I engage in prayer, meditation or philosophical thought	a	b	c	d	e	f	g	h	i
59. I attend meetings of services such as Lions/Rotary etc.	a	b	c	d	e	f	g	h	i
60. I attend meetings of clubs such as hobbies/book/talks	a	b	c	d	e	f	g	h	i

Question	Response								
61. I give a public talk or lecture to club/service etc.	a	b	c	d	e	f	g	h	i
62. I do volunteer work for hospital/school/political party	a	b	c	d	e	f	g	h	i
63. I engage in business activities (stocks/investments)	a	b	c	d	e	f	g	h	i
64. I engage in an on-the-job training program	a	b	c	d	e	f	g	h	i
65. I enrol in a course at college or university	a	b	c	d	e	f	g	h	i
66. I enrol in a correspondence course	a	b	c	d	e	f	g	h	i
67. I study or practice a foreign language	a	b	c	d	e	f	g	h	i
68. I travel away from my home in the UK	a	b	c	d	e	f	g	h	i
69. I travel outside Hampshire in the UK	a	b	c	d	e	f	g	h	i
70. I travel to a foreign country	a	b	c	d	e	f	g	h	i

Thank you for completing this questionnaire, your participation is valued!

Appendix XI

Ethical approval for functional magnetic resonance imaging (fMRI)

28/5/08

SCHOOL OF SOCIAL SCIENCE RESEARCH ETHICS CHECKLIST (Effective 1 Oct 2007)

If the ethics submission relates to staff research for which an application to an external funding agency will be/has been made, then please complete and submit the full University ethics submission form.

Section I: Project Details

1. Project title: Lifestyle, fitness, and cognition in adults aged 50 to 85 years: An fMRI study

Section II: Applicant Details

2. Name of researcher (applicant): Sarah Bauermeister

3. Status (please circle): /Postgrad Student

4. Discipline (please circle): /Psy/

5. Email address: sarah.bauermeister@brunel.ac.uk

6. Telephone number 07525031161

Section III: For Students Only

7. Module name and number: PhD research

8. Brunel supervisor's or module leader's name: Professor David Bunce

9. Brunel supervisor's email address: david.bunce@brunel.ac.uk

Supervisor: Please tick the appropriate boxes. The study should not begin until all boxes are ticked:

☒ The student states that he or she has read the Brunel University Code of Research Ethics.

☒ The topic merits further research.

☒ The student will possess the skills to carry out the research by the time that he or she starts any work which could affect the well-being of other people. He or she will be deemed to have acquired such skills on passing the relevant research skills module.

☒ The participant information sheet or leaflet is appropriate.

☒ The procedures for recruitment and obtaining informed consent are appropriate.

'X' denotes 'yes' to the above

Please confirm the professional research ethics code that will guide the research (please circle)

BPS/(please state) _____

*See attached email

_____ _____

Supervisor's signature Date

Section IV: Research Checklist

Please answer each question by ticking the appropriate box:

	YES	NO
1. Does the study involve participants who may be particularly vulnerable and/or unable to give informed consent, thus requiring the consent of parents or guardians? (e.g. children under the age of 16; people with certain learning disabilities)	☐	No
2a. Will the study require the co-operation of a gatekeeper for initial access to the groups or individuals to be recruited?	☐	No
2b. If the answer to Question 2a is Yes, then will the study involve people who could be deemed in any way to be vulnerable by virtue of their status within particular institutional settings? (e.g. students at school; disabled people; members of a self-help group; residents of a nursing home, prison, or any other institution where individuals cannot come and go freely)	☐	No
3. Does the research involve observational/ethnographic methods?	☐	No
4. Will the study involve discussion by or with respondents or interviewees of their own involvement in activities such as sexual behaviour or drug use, where they have not given prior consent to such discussion?	☐	No
5. Are drugs, placebos or other substances (e.g. food substances, vitamins) to be administered to the study participants or will the study involve invasive, intrusive or potentially harmful procedures of any kind?	☐	No
6. Will blood or tissue samples be obtained from participants?	☐	No
7. Is pain or more than mild discomfort likely to result from the study?	☐	No
8. Could the study induce psychological stress or anxiety or cause harm or negative consequences beyond the risks encountered in normal life?	☐	No
9. Will the study involve prolonged or repetitive testing?	☐	No
10. Will financial inducements (other than reasonable expenses and compensation for time) be offered to participants?	☐	No
11. Will the study involve recruitment of patients or staff through the NHS?	☐	No
12a. Have you undertaken this study as part of your work placement?	☐	No
12b. If your answer to Question 12a is Yes, then have the employers at your work placement conducted their own research ethics review?	☐	No
13. Does the research involve MRI, MEG, or EEG methods?	Yes	☐

Give a brief description of participants and procedure (methods, tests used etc) in up to 150 words

I will be administering 3 short behavioural tasks to approx 30 healthy participants aged 50-85 years old. These behavioural tasks will be measuring:

- Visual processing (choice reaction time to visual stimuli)
- Inhibitory control (a 'global-local' Stroop-type response task requiring responses to 4 types of stimuli)
- Word recognition (words will be presented for learning, and then following one of the tasks above, will be presented with foil words requiring a 'yes'-'no' response.

These tasks will be administered during an fMRI session at Royal Holloway. Generic clearance for the MRI procedure has already been granted, so this application relates purely to the behavioural aspect of the study.

Participants will be recruited from an ongoing behavioural study that has already received ethics approval.

Name of Principal Investigator at Brunel University (please print): Sarah Bauermeister (with David Bunce and Adrian Williams as supervisors)

Signature of Principal Investigator at Brunel University: _____

E-Mail Address: sarah.bauermeister@brunel.ac.uk

Date: 28/05/08

This request for expedited review has been: (1) Approved (no additional ethics form is necessary)
~~(2) Declined (full University ethics form is necessary)~~

Signature of School Research Ethics Officer: _____

Date: 30/05/08

Devinder Saggi

From: David Bunce
Sent: 28 May 2008 13:38
To: Devinder Saggi
Cc: Sarah Bauermeister; Adrian Williams
Subject: Ethics submission
Attachments: Bauermeister fMRI ethics.doc

Hi Devinder,

Apologies for not submitting hardcopy, but I'm away at the moment. Please find attached an ethics submission from my PhD student Sarah Bauermeister, relating to a coming study. I would appreciate it if you could enter it into the Psych system. Please accept this email in lieu of my signature.

Many thanks

David

David Bunce PhD
Professor of Psychology
Centre for Cognition and Neuroimaging
Brunel University
Uxbridge, UB8 3PH
UK
Tel: ++44 (0)1895 267242
Fax: ++44 (0)1895 237573
email: david.bunce@brunel.ac.uk
Webpage: http://www.brunel.ac.uk/about/acad/sss/depts/psychology/psychstaff/davidbunce

28/05/2008

Appendix XII

fMRI information sheet

Brunel UNIVERSITY WEST LONDON

Combined Universities Brain Imaging Centre, Royal Holloway, Egham, Surrey

INFORMATION SHEET

These notes give some information about an fMRI study in which you are invited to take part.

FMRI is a method for producing images of the activity in the brain as people carry out various mental tasks. It involves placing the participant inside a large, powerful magnet which forms part of the brain scanner. When particular regions of the brain are active, they require more oxygen, which comes from red corpuscles in the blood. As a result, the flow of blood increases. This can be detected as changes in the echoes from brief pulses of radio waves. These changes can then converted by a computer into 3D images. This enables us to determine which parts of the brain are active during different tasks.

As far as we know, this procedure poses no direct health risks. However, the Department of Health advises that certain people should be NOT be scanned. Because the scanner magnet is very powerful, it can interfere with heart pacemakers and clips or other metal items which have been implanted into the body by a surgeon, or with body-piercing items. If you have had surgery which may have involved the use of metal items you should NOT take part. You will be asked to remove metal from your pockets (coins, keys), remove articles of clothing which have metal fasteners (belts, bras, etc), as well as most jewellery. Alternative clothing will be provided as necessary. Watches and credit cards should not be taken into the scanner since it can interfere with their operation. You will already have been asked to complete a questionnaire (the Initial Screening Form) which asks about these and other matters to determine whether it is safe for you to be scanned. In addition, you are asked to give the name and address of your Family Doctor. This is because there is a very small chance that the scan would reveal something which required investigation by a doctor. If that happened, we would contact your doctor directly. By signing the consent form, you authorise us to do this. You will also be asked to complete a second, shorter, screening form immediately before the scan.

To be scanned, you would lie on your back on a narrow bed on runners, on which you would be moved until your head was inside the magnet. This is rather like having your head put inside the drum of a very large front-loading washing machine. The scanning process itself creates intermittent loud noises, and you would wear ear-plugs or sound-attenuating headphones. We would be able to talk to you while you are in the scanner through an intercom. If you are likely to become very uneasy in this relatively confined space (suffer from claustrophobia), you should NOT take part in the study. If you do take part and this happens, you will be able to alert the experimenters by squeezing a 'panic button' and will be removed from the scanner quickly. It is important that you keep your head as still as possible during the scan, and to help you with this, your head will be partially restrained with padded headrests. We shall ask you to relax your head and keep it still for a period that depends on the experiment but may be more than one hour, which may require some effort on your part. If this becomes difficult, you may ask to be removed from the scanner.

You will be asked to look at the centre of a screen through a small mirror (or other optical device) placed just above your eyes. You may be asked to make judgements about what you see or asked to perform some other kind of mental task. Details of the specific experiment in which you are invited to participate will either be appended to this sheet or else given to you verbally by the experimenter. Detailed instructions will be given just before the scan, and from time to time during it.

The whole procedure will typically take about 1 hour, plus another 15 minutes to discuss with you the purposes of the study and answer any questions about it which you may raise. You would be able to say that you wished to stop the testing and leave at any time without giving a reason. This would not affect your relationship with the experimenters in any way. The study will not benefit you directly, and does not form part of any medical diagnosis or treatment. If you agree to participate you will be asked to sign the initial screening form that accompanies this information sheet, in the presence of the experimenter (or other witness, who should countersign the form giving their name and address, if this is not practical). It is perfectly in order for you to take time to consider whether to participate, or discuss the study with other people, before signing. After signing, you will still have the right to withdraw at any time before or during the experiment, without giving a reason.

The images of your brain will be held securely and you will not be identified by name in any publications that might arise from the study. The information in the two screening forms will also be treated as strictly confidential and the forms will be held securely until eventually destroyed.

Further information about the specific study in which you are invited to participate may have been appended overleaf, if the experimenter has felt that this would be helpful. Otherwise, he/she will already have told you about the study and will give full instructions prior to the scan. Please feel free to ask any questions about any aspect of the study or the scanning procedure before completing the initial screening form.

Centre for Cognition and Neuroimaging Brunel University Uxbridge UB8 3PH ccni@brunel.ac.uk

Appendix XIII

Initial screening form (fMRI)

Brunel UNIVERSITY WEST LONDON

Combined Universities Brain Imaging Centre, Royal Holloway, Egham, Surrey

INITIAL SCREENING FORM

NAME OF PARTICIPANT ..... Sex: M / F

Date of birth..... Approximate weight in kg..... (1 stone is 6.3 kg)

Email address..... Telephone number.....

Please read the following questions CAREFULLY and provide answers. For a very small number of individuals, being scanned can endanger comfort, health or even life. The purpose of these questions is to make sure that you are not such a person.

You have the right to withdraw from the screening and subsequent scanning if you find the questions unacceptably intrusive. The information you provide will be treated as strictly confidential and will he held in secure conditions.

	Delete as appropriate
1. Have you been fitted with a pacemaker or artificial heart valve?	YES/NO
2. Have you any aneurysm clips, shunts, or stents in your body, or a cochlear implant?	YES/NO
3. Have you ever had any metal fragments in your eyes?	YES/NO
4. Have you ever had any metal fragments, e.g. shrapnel in any other part of your body?	YES/NO
5. Have you any surgically implanted metal in any part of your body, other than dental fillings and crowns (e.g. joint replacement or bone reconstruction)	YES/NO
6. Have you ever had any surgery that might have involved metal implants of which you are not aware? If yes, please give details:	YES/NO
7. Do you wear a denture plate or brace with metal in it?	YES/NO
8. Do you wear a hearing aid?	YES/NO
9. Have you ever suffered from any of: epilepsy, diabetes or thermoregulatory problems?	YES/NO
10. Have you ever suffered from any heart disease?	YES/NO
11. Is there any possibility that you might be pregnant?	YES/NO
12. Have you been sterilised using clips?	YES/NO
13. Do you have a contraceptive coil (IUD) installed?	YES/NO
14. Are you currently breast-feeding an infant?	YES/NO

I have read and understood the questions above and have answered them correctly.

.

SIGNED..... DATE.....

In the presence of ..... (name) .....(signature)

Address of witness, if not the experimenter:.....

.....

Please enter here the name and address of your doctor (general practitioner):.....

.....

Data Protection Act. Your name, email address and phone number will be stored electronically for the purposes of contacting you with regard to scanning. The information will be passed to no other party and will be accessed only by Brunel University staff who are also authorised users of the CUBIC facility.

Centre for Cognition and Neuroimaging Brunel University Uxbridge UB8 3PH ccni@brunel.ac.uk

Appendix XIV

Consent form (fMRI)

Rev. 2009

ROYAL HOLLOWAY, UNIVERSITY OF LONDON

MAGNETIC RESONANCE IMAGING UNIT

CONSENT FORM

NAME OF PARTICIPANT……

Please read the following statement carefully and then add your signature. If you have any questions, please ask the person who gave you this form. You are under no pressure to give your consent and you are free to withdraw from the MRI examination at any time.

I agree to participate in an MRI examination conducted for research purposes by

…… (name of operator) on ……

…… (name of project).

I understand that the examination is not part of any medical treatment. I have completed two screening forms and I have been given an opportunity to discuss any issues arising from it. The nature of the examination has been explained to me and I have had an opportunity to ask questions about it. I consent to my general practitioner being contacted in the unlikely event that the scan reveals any suspected abnormality**.** I understand that the scans will be done solely for research purposes, and that the Investigators are not experts in MRI diagnosis and cannot provide a 'clean bill of health'.

Signature …… Date……

FOR STAFF USE:

Statement by a witness, who must be either an authorised person or a scientific collaborator who is familiar with the experimental procedure and is able to answer questions about it.

I certify that the above participant signed this form in my presence. I am satisfied that the participant fully understands the statement made and I certify that he/she had adequate opportunity to ask questions about the procedure before signing.

Signature…… Date……

Name ……..

Address of witness (if not an Authorised Person):

Appendix XV

Second screening form (fMRI)

ROYAL HOLLOWAY, UNIVERSITY OF LONDON - MAGNETIC RESONANCE IMAGING UNIT

SECOND SCREENING FORM

This form should be completed and signed immediately before your scan, after removal of any jewellery or other metal objects and (if required by the operator) changing your clothes.

NAME OF PARTICIPANT ……

Date of birth……. Sex: M / F

Please read the following questions CAREFULLY and provide answers. For a very small number of individuals, being scanned can endanger comfort, health or even life. The purpose of these questions is to make sure that you are not such a person.

You have the right to withdraw from the screening and subsequent scanning if you find the questions unacceptably intrusive. The information you provide will be treated as strictly confidential and will he held in secure conditions.

BEFORE YOU ARE TAKEN THROUGH FOR YOUR SCAN IT IS ESSENTIAL THAT YOU REMOVE **ALL METAL OBJECTS** INCLUDING:-WATCHES, PENS, LOOSE CHANGE, KEYS, HAIR CLIPS, ALL JEWELLERY, BRASSIERES WITH METAL FASTNERS, METALLIC COSMETICS, CHEQUE/CASH POINT CARDS.

	Delete as appropriate
1. Are you wearing or carrying any metal items such as those listed above?	YES/NO
2. Have your answers to any of the questions in the initial screening form changed? (The initial screening form must be shown to you before you answer this question.)	YES/NO
Specifically, please confirm:	
3. Have you been fitted with a pacemaker, artificial heart valve or cochlear implant?	YES/NO
4. Are you wearing a trans-dermal drug patch?	YES/NO
5. Is there any possibility that you might be pregnant?	YES/NO

I have read and understood the questions above and have answered them correctly.

SIGNATURE…… DATE……

FOR STAFF USE:

I certify that the initial screening form and the consent form have been completed by the person named above and I have attached them to this form. The volunteer has been given the standard information sheet about MRI experiments, together with any necessary study-specific information, and has been given an opportunity to ask questions. I am satisfied that the volunteer is adequately informed and understands the content of the consent form. I have taken adequate steps to ensure that the volunteer has no ferro-magnetic metal in or on his/her person and I am satisfied that the scan can proceed.