THE ROLE OF EXECUTIVE ATTENTION IN HEALTHY OLDER ADULTS' CONCURRENT WALKING AND COUNTING

Linda McArthur Maclean

A Thesis Submitted for the Degree of PhD
at the
University of St Andrews

2013

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This thesis is submitted in partial fulfilment for the degree of PhD
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February 2013

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Acknowledgements

I am very grateful to all the participants who took part in the experiments described in this thesis. This research could not have been completed without their enthusiasm and patience.

I would like to thank Dr. Arlene Astell, my supervisor, for giving me the opportunity to undertake research in experimental psychology, especially with older adults, and for her guidance and advice along the way.

My thanks also go to my second supervisor, Dr Gerry Quinn, for his wisdom and kindness.

I am grateful to the technical staff at the University of St Andrews, Mr Ken Munro, Software Developer, and Mr Pete Wilcox, Mechatronics Technician, for their assistance in developing ‘Bigfoot’.

I am also grateful to the School of Psychology and Neuroscience at the University of St Andrews for the use of its facilities and to its academic and support staff for their support and friendship.

A special thank you to Mrs Janet Hoper for her expertise in the use of the comma.

I am grateful to the ESRC for providing the PhD studentship without which I could not have carried out this doctoral research.

And, finally, to my family: Harry, Margot and Ilona, thank you for giving me the time and space to realise a long-held ambition.

This thesis is dedicated to my father, who has always encouraged me to aspire, and especially to my mother who has supported me in all my endeavours.

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Abstract

Completing activities of daily life relies on using both cognitive and physical resources efficiently, but these are affected by age. This may be due either to an age-related reduction in the resources we have available for carrying out tasks or to a reduction in our ability to use these resources efficiently. These resources comprise a set of processes called executive functions (EF), which collectively allow us to plan, initiate and monitor our performance of activities. Control and allocation of these resources is attributed to a central mechanism, sometimes called the central executive or executive attention, but the parameters that determine how resources are allocated are not well understood. Even simple or apparently automatic activities, such as walking, require attention, meaning that when task demands increase, for example when walking and speaking on the phone, there is a loss of efficiency in both tasks. The dual-task (DT) paradigm is an empirical means of examining the way attentional resources are allocated between two tasks by comparing their performance together in relation to how well they are carried out singly. Asking people to perform a cognitive task, such as counting backwards or spelling, while walking provides a reasonably naturalistic way to examine how flexibly older adults can divide their attention between the two tasks. Manipulating the demands of the task, either by increasing the difficulty of the cognitive task or instructing the participants to focus on one task or the other (prioritisation) should illuminate the strategies they use to allocate their available attention between the two tasks ask task demands vary. To explore this hypothesis a cohort of physically and cognitively healthy community-dwelling older adults (mean age = 72.3 years) took part in three studies. In the first experiment, 72 participants completed 8 single and dual-task conditions with varying cognitive load (counting back in 3s and 7s) and attention prioritisation (no prioritisation, prioritising walking and prioritising counting). Instructing the participants to prioritise walking in the DT when counting back in 7s produced the best walking and counting performance and this was predicted their score on a standardised measure of cognitive flexibility. In second part of the study, 68 of the participants were tested 12 months later when there was improvement in both their single and dual-task performances. There was also decline in concurrent walking and counting performance, but *only* when attention was allocated to walking in preference to the cognitive task. Both the improvements and the decline in performance after the 12-month period were predicted by a standardised test for EF at T1. In the third study a separate group of older adults (73.2 years) was trained to walk rhythmically to music, to further investigate the external manipulation of resource-allocation during concurrent walking and counting. Their performances were compared to 2 control groups who did not receive the same intervention procedures. Overall findings from this doctoral research demonstrate that explicitly manipulating attention-allocation during concurrent walking and cognitive activity improved healthy older adults' walking and counting performance and this was strongly associated with better cognitive flexibility. After 12 months, subtle decline in ability to allocate attention to walking during the DT, when attentional-demands were high, was also predicted by cognitive flexibility in an EF task. Together, these findings illuminated the role of executive attention in a rapidly-changing complex task when the 'wrong' prioritisation could result in a fall. Observing healthy older adults' cognitive flexibility in allocating attention to walking, when required, revealed that executive attention was key to the future maintenance of their current functional well-being.

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List of Abbreviations

AAI – Attention Allocation Index

ACC – Anterior Cingulate Cortex

ANOVA – Analysis of Variance

BDI – Beck's Depression Inventory

BMI – Body Mass Index

CC – Corpus Callosum

CCR – Correct Cognitive Responses

CE – Central Executive

CET – Cognitive Estimation Test

CL – Cognitive Load

CV – Coefficient of Variation

D - Distance

D/TMT – Delta Trail Making Test

DR – Delayed Recall

DS/B – Digit Span/Backwards

DS/F – Digit Span/Forwards

DT – Dual Task

DTB – Dual-task Benefit

DTD – Dual-task Deficit

EA – Executive Attention

EF – Executive Functions

Est PMIQ – Estimate Pre-morbid Intelligence Quotient

GPS – Global Positioning System

IADL – Instrumental Activities of Daily Living

IR – Immediate Recall

M - Mean

m – metre(s)

m/s – Metres Per Second

MMSE – Mini Mental State Examination

Mob SU/SD – Mobility Stand-up/Sit-down

MP – Music Playing

ms – Milliseconds

MT – Musical Training

MTD – Mean of Time Delta

NANA – Novel Assessment of Nutrition and Ageing

NART – National Adult Reading Test

NHS – National Health Service

NM – No Music

NP – No Prioritisation

PA – Prioritising Attention

PASW – Predictive Analytics Software

PC – Prioritising Counting

PCA – Principal Component Analysis

PD – Parkinson's Disease

PFC – Prefrontal Cortex

PPC – Posterior Parietal Cortex

PW – Prioritising Walking

S - Speed

SAS – Supervisory Attentional System

SCR – Steps per Cognitive Response

SD – Standard Deviation

SDMT – Symbol Digits Modalities Test

secs - Seconds

SPSS – Statistical Package for the Social Sciences

ST – Single Task

T – Time

T1 – Time 1

T2 – Time 2

TD – Time Delta

TMT – A – Trail Making Test - A

TMT – B – Trail Making Test - B

TSP – Temporal-Spatial Parameters

TUG – Timed Up and Go

UTREC – University of St Andrews Teaching and Research Ethics Committee

V – Velocity

WM – Working Memory

Chapter 1: Introduction

1. 1 Research motivation

1.1.1 Healthy ageing

Successful ageing is observed in an older adult's ability to live independently, performing Instrumental Activities of Daily Living (IADLs) such as cooking a meal, managing their own finances, planning visits and taking public transport. Successful completion of IADLs depends on cognitive processes involved in planning and coordinating activity (Moritz, Kasl & Berkman, 1995; Njegovan, Man-Son-Hing, Mitchell & Molnar, et al., 2001). These higher-level cognitive processes, known as executive functions, also include allocating attention to the tasks to ensure there are sufficient resources for their successful completion. This applies to completing both complex IADLs and also 'simple' tasks such as walking and talking or walking and navigating a route (Sanders, Holtzer, Lipton, Hall & Verghese, 2008).

While some decline in functioning occurs naturally with age (Stuart-Hamilton, 2012), longitudinal studies indicate that there is a great deal of individual variability in maintenance and decline of cognitive function (see Verhaeghen, Steitz, Sliwinski & Cerella, 2011 for meta-analyses). Early lifestyle factors and opportunities such as education, nutrition and leisure activities may offer protection from cognitive decline (Stern, 2002) by building up a 'cognitive reserve'. This may be particularly seen in specific areas of cognition such as executive functioning (Salthouse et al., 2003) and mental speed (Salthouse, 1996). It has also been argued that this reserve 'buffers' not only age-related decline but may also be protective against the onset of neuropathological changes (Richards & Deary, 2005).

1.1.2. Working memory

Executive functions are coordinated and integrated through the working memory system, which oversees their actions and keeps track of performance. Several models of working memory have been described, with the most popular containing a central controlling system, the Central Executive (CE; Baddeley & Hitch, 1974). This 'manager' allows and inhibits information that helps individuals complete the tasks most efficiently (Baddeley & Hitch, 1974). In this model, it is the CE that controls the division of attention between multiple tasks. In later life, performance of more than one task at a time is commonly reduced from what it was in youth (Verhaeghen, Steitz, Sliwinksi, & Cerella, 2003).

Two lines of explanation have been proposed to explain less efficient performance in concurrent activities by older adults. These are that either they experience a reduction in their attentional resource capacity (Craik & Byrd, 1982; Salthouse, 1992) *or* a diminution in resource processing speed, possibly due to their failure to ignore irrelevant stimuli on which they then waste attention (Hasher & Zachs, 1988). A third possibility is that there is a decline in both skills combined (Luszcz, 2011). These reductions may be due either to a 'natural' ageing process or specific cognitive impairment. There is some evidence that age-related decline in working memory may be due to processing limitations rather than storage capacity but this is not conclusive as viewing the CE in action relies on proxy measures (Phillips & Hamilton; 2001; Stuart-Hamilton, 2012).

1.1.3 The dual-task paradigm

One method for investigating the impact of ageing on attentional capacity and processing speed is the dual task (DT; Della Sala, Baddeley, Papagno & Spinnler, 1995). The DT involves comparing the performance outcomes in two single tasks carried out separately with the performance outcomes when carrying out the two tasks concurrently. Invariably there is a dual task deficit (DTD) when two tasks are performed together although opinion is divided over whether this is age-related (Hartley & Little, 1999; Vanneste, 1999). The size and direction of a DTD (that is, whether one task is more affected by the concurrent activity than the other), provides a means of exploring how much attention is allocated to each task. Dual-task methodology has been widely used to examine the individual components of Baddeley and Hitch's (1974) working memory model in a range of cognitive tasks (Phillips & Hamilton, 2001). These include distinguishing between different messages in dichotomous listening tasks (Salthouse, 1985) or measuring reaction times (Pashler, 1994). Historically, significant DTDs did not appear to be present in normal ageing. In support, age effects in controls in recent DT experiments involving two cognitive tasks were not found to be as robust or consistent as those observed in AD patients (Logie, Della Sala, Cocchini & Baddeley, 2004). Using a naturalistic task, Lundin-Olsson and colleagues (1997) observed that some older adults stopped walking when they were talking, leading the researchers to propose that in some circumstances walking demanded too much attention for them to complete the two tasks simultaneously (Lundin-Olsson, Nyberg & Gustafson, 1997). This could be when the cognitive load was too great, either because the researcher made the cognitive task too demanding or the task difficulty was not too high but the older adult had cognitive impairment.

1.1.4 The relationship between gait and cognition

Findings from gait and cognitive DT studies suggest that the maintenance of gait while performing a cognitive task requires higher-level attentional resources (Woollacot & Shumway-Cook, 2002; Yogev-Seligmann, Hausdorff & Giladi, 2008). Gait and cognitive tasks are performed worse together than when each task is performed separately, and this is exacerbated with normal ageing (Lajoie, Teasdale, Bard & Fleury, 1996). Separately, maintenance of the two functions is important for successful ageing. Specifically, walking ability protects against fall-risk (Hausdorff, Rios & Edelberg, 2001; Montero-Odasso et al., 2005), and efficient cognitive ability is required for completion of IADLs (Peres, et al., 2008). While these two functions decline naturally through the ageing process, it is important to distinguish greater than usual decline as this may be an early sign of significant cognitive impairment such as dementia (Verghese et al., 2002) or other pathological diseases which might increase the risk of falls and lead to early death (van Iersel, Hoefsloot, Munneke, Bloem & Olde Rikkert, 2004). Therefore, explaining the interconnectedness of gait and cognitive function, in terms of demands on attentional resources, is important for distinguishing healthy ageing from early impairment in either domain (Montero-Odasso, Verghese, Beauchet & Hausdorff, 2012).

1.1.5 Prioritisation strategy

When two tasks (such as walking and counting) compete for the same attentional resources, people may prioritise one task over the other. It has been suggested that when no threat is posed to gait stability, young and cognitively healthy older adults subconsciously prioritise attention on the task (gait or cognitive) which is more important for the achievement of their personal goals. For example while walking along a flat, deserted street deep in discussion, people may consider that talking is more important but, when negotiating a busy crossing, walking may take preference over the conversation. However, when the cognitive task becomes too demanding, for example if the conversation takes place on a busy, cobbled street, their attention-allocation adapts to the threat imposed to gait security and they adopt a ‘posture-first’ strategy, whereby they unconsciously prioritise gait (walking) over the cognitive task (talking), presumably to avoid falling (Woollacott & Shumway-Cook, 2002).

Although appealing, this finding has not been consistently reported, with other studies showing that healthy older adults do not always prioritise gait over cognition (Verghese, et al., 2007; Yogev-Seligmann et al., 2010). This has led some to question the relevance of the 'posture first' hypothesis (Smulders et al, 2012). Amongst those who have not found evidence for the 'posture-first' strategy, it has been suggested that, on the one hand, if there is no threat to gait, healthy older adults will prioritise a more demanding cognitive task (Kelly, Janke & Shumway-Cooke, 2010; Li, Abbud, Fraser & DeMont, 2013). On the other hand, healthy older adults' inability to prioritise gait over cognition, in a demanding dual task, may be an indication of poor cognitive flexibility (Yogev-Seligmann, Rotem-Galili, Dickstein, Giladi & Hausdorff, 2012a). Investigating older adults' ability to adapt their prioritisation of attention may be a more useful tool with which to explore the mechanisms underlying attention-allocation in a dual task than focusing solely on the existence or not of a postural strategy.

Ability to flexibly prioritise attention relies on the integrity of cognition but, as yet, it is still unclear whether cognitive inflexibility or rigidity results from limited attentional resources or reduced processing (see 1.1.3). It has been possible to observe older adults' ability to flexibly allocate attention from one task (gait) to the other (cognitive) (Yogev-Seligmann et al., 2012a) by manipulating the instructions regarding which task should be prioritised. Additionally, poor cognitive flexibility, as indexed by task-switching and visual attention executive function tests, has been shown to predict altered attention-prioritisation in healthy older adults, although specific instructions for prioritisation were not evaluated in this study (Hobert et al., 2011).

1.1.6 The parameters of a gait and cognition dual task

Gait speed and gait variability (step or stride time and/or length) have been used to assess fall risk and other adverse events (Hausdorff, Yogev, Springer, Simon & Giladi, 2005; Montero-Odasso et al., 2005) as well as to predict longevity in older adults (Studenski, Perera & Patel, 2011). Until now, dual task gait and cognition studies have focused on the effect of an added secondary (cognitive) task on gait measures (Beauchet et al., 2011; Rosano, Brach, Studenski, Longstreth & Newman, 2007), but there have been relatively few studies investigating the DT effect on cognitive measures or, indeed, the role that cognitive flexibility plays in older adults' ability to carry out simultaneous walking and reasoning. Additionally, previous DT gait and cognitive research has focused largely on individuals with cognitive impairment; there has been little investigation of the impact of instructing healthy older adults to prioritise during a gait and cognition dual task to explore their gait, their cognitive function or the processes underlying their ability to carry out the two together.

1.1.7 Longitudinal study

Increasing cognitive load is a way to observe whether ability to concurrently walk and reason is influenced by attentional resource capacity (Priest, Salamon & Hollman, 2008). By comparing performances for prioritisation of attention on either walking or counting (no prioritisation, prioritising walking, prioritising counting), it is possible to observe the impact of attentional processing on performance outcomes (Verghese et al., 2007). However, there has been little research into the interaction between cognitive load and prioritisation. Previous research has tended to focus on separate research questions, either about the gait or cognition but none has focused on the cognitive function underlying the interplay between gait and cognition. In addition, studies in gait and cognitive dual tasks have used regression analyses to predict behavioural outcomes from underlying cognitive functioning (Hobert et al, 2011) but these have been carried out on cross-sectional studies which, when dealing with healthy older adults, can be misleading as behaviour which is identified at a particular time-point is often due to a 'cohort' effect. The cohort effect provides an explanation of varying performance outcomes in terms of generational, background and upbringing rather than on the normal ageing process itself (Stuart-Hamilton, 2012). The cohort effect will be maintained over time, unless a particular disease or external event intervenes and adversely affects well-being (Stuart-Hamilton, 2012), therefore longitudinal studies provide an ideal tool for exploring subtle changes that occur over time.

1.1.8 Rhythmicity

In addition to exploring activity over time, another approach to illuminating the underlying cognitive processes is to look at the potential for intervention to change or improve behaviour. In the field of gait a range of interventions have been developed for people with specific impairment (for example those with Parkinson's disease (PD) with the aim of improving their attention-allocation when walking and carrying out a cognitive task. These have revealed that training older adults with PD to optimise their division of attention, by concentrating on the cognitive task, when walking and carrying out a cognitive activity, could benefit their gait (Yogev-Seligmann et al., 2012b; Schwenk, Zieschang, Oster & Hauer, 2010). Similarly musical training has been found to improve the gait of PD patients (Satoh &

Kazuhara, 2008). By combining these findings, it may be possible to identify a novel way of investigating attention-allocation in adults who do not have cognitive or gait impairment. If musical training steadies gait by making it ‘rhythmic’ and more ‘automatic’ then this might free up attention from walking which can then be transferred on to the demanding cognitive task, thus improving the cognitive performance in a DT.

1.1.9 Summary

Previous research suggests that gait and cognitive function are intimately linked in a relationship that has increasing importance as we age but it is challenging to explore the actual mechanisms that underlie performance of these activities, both separately and together. This thesis comprises a longitudinal study examining the effects of task (single and dual) x load (higher and lower cognitive demands) x prioritisation instructions (no prioritisation, prioritising walking and prioritising counting) on healthy older adults’ ability to allocate attention in a walking and counting dual task. The participants complete these conditions twice, twelve months apart to examine the impact of the natural ageing process on both their gait and cognitive performance. Additionally, a separate group of healthy older adults was trained to walk to music to explore the effect on their ability to flexibly allocate attention to both gait and cognitive performance.

1.2. Thesis overview

Chapter Two gives a comprehensive review of the literature relevant to the longitudinal study of older adults’ gait and cognition within the framework of the DT paradigm in a resource capacity working memory model. The background includes a discussion about methodologies used in this research field and their limitations. In addition, it describes very recent understanding of the interplay between gait and cognition and the gap in current research, which this thesis hopes to fill. **Chapter Three** describes two pilot studies carried out to validate new equipment and approaches to measurement developed for this thesis. **Chapter Four** describes two experiments at Time 1 (T1) and Time 2 (T2), 12 months apart, which investigated the attention allocation of a group of healthy older adults, under explicit instructions to prioritise either walking or cognition during a dual task, under varying cognitive loads (counting backwards, subtracting 3s and 7s) and prioritisation instructions (no prioritisation, prioritising walking and prioritising counting). The methodology is detailed in this chapter. **Chapter Five** contains analysis of the data at T2 compared to T1 and explores potential relationships between the outcome measures and participants' underlying cognitive processes, especially their executive functions. It focuses on healthy older adults' maintenance of cognitive function over time, while commenting on possible early warning signs of future cognitive impairment. **Chapter Six** contains a third study examining the effect of directly training older adults to walk rhythmically on both their gait and cognitive performance. This chapter investigates the idea that musical training will free attention from walking, which can be re-directed to a demanding concurrent cognitive task (counting backwards, subtracting 7s). **Chapter Seven** contains a comparison of two different gait measures (step-time variability and speed) using two different methodologies (video recording and 'DataGait' accelerometer technology) during an empirical study that investigated assessment measures of older adults' health. Finally, **Chapter Eight** contains a summary of the findings and suggestions for future research.

Chapter 2: Literature review

2.1 Healthy ageing

2.1.1 Cognitive ageing

People are living longer in the UK, especially in the category of the 'oldest old' (those aged 85 years and above). It is projected that this group will form 5% of the UK's population by 2034 and, by 2050, it is anticipated that 50% of our population will live beyond age 80 (Office for National Statistics, 2010, as cited in Stuart-Hamilton, 2012). But there may be a 'cost' to living longer in the loss of active life during those 'extra' years (Katz et al., 1983). Active life expectancy can be defined as the likely remaining time in which independently-living older adults retain functional well-being, in terms of activities of daily life (Katz et al., 1983). Successful ageing also relies heavily on efficient cognitive functioning (Rowe & Khan, 1987) with reduced efficiency linked to poorer survival rates (Duff, Mold & Gidron, 2008). In particular the cognitive processes involved in planning, co-ordinating and monitoring behaviour are critical to active independence. These higher-level or 'executive functions' (EF; Lezak, 1995) enable us to carry out instrumental activities of daily living (IADLs), such as banking, shopping, and cooking. Essentially, executive functioning oversees the allocation of resources such as attention to carry out a task, memory to store the information required to carry it out and monitoring to keep track of the activity in hand. If the effects of genetics, disease, illness, lifestyle and other external threats to survival are avoided then 'successful ageing' is heavily influenced by cognitive ageing (Richards & Deary, 2005).

2.1.2 Executive Functioning and Working Memory (WM) capacity

The term executive functioning is widely used to refer to the operation of cognitive processes at a notional high level of control and coordination of behaviour that largely operate outside of conscious awareness. The set of executive functions (EF) comprises the ability to inhibit irrelevant or distracting stimuli (*inhibition*), the ability to rapidly shift between items (*set-shifting*) the ability to initiate a task or activity (*initiation*), the ability to plan ahead to enable successful completion of the task (*planning*), the ability to monitor our performance to achieve completion (*monitoring*), the ability to regulate or modify performance if required (*regulating),* the ability to keep track of and update task demands in the light of new information, and keep the end-point in mind until the task is completed (*goal maintenance*;

McCabe, Roediger, McDaniel, Balota & Hambrick, 2010). Efficient activity of any type, be it cooking a meal, writing an email or driving a car, all rely on cognitive resources being available and allocated to the task in hand. Sometimes we may complete two or more activities at the same time, such as writing while listening to the radio or speaking on the telephone while watching the television. This is possible because we can flexibly allocate our cognitive resources between tasks, as the demands vary.

The process of allocating cognitive resources is attributed to the working memory system (Baddeley, 1996). Working memory (WM) is an integrated model of cognitive processing that oversees and manages EF and allocates resources to carry out the tasks we wish to accomplish. Resource allocation is partly determined by how much attention is required to carry out the activity. Tasks are thought to require either '*controlled*' or conscious processing, where demands on attention are heavy, have a limited capacity and responses are slow, or they require '*automatic*' or unconscious processing. These tasks do not demand attentional resources and are fast but inflexible (Schneider & Shiffrin, 1977). The process of allocating resources is commonly attributed to an overarching supervisory function within WM. Norman & Shallice (1980) referred to this as the Supervisory Attention System, described as a voluntary system of attentional control which responds to a variety of difficult problems using flexible (and novel) strategies. In contrast tasks that place low demands on attention were attributed to the actions of schema, stored action templates for processes that have become automatic (Norman & Shallice, 1980). Baddeley and Hitch's (1974) WM model has a comparable processor, termed the Central Executive (CE; Figure 2.1.).

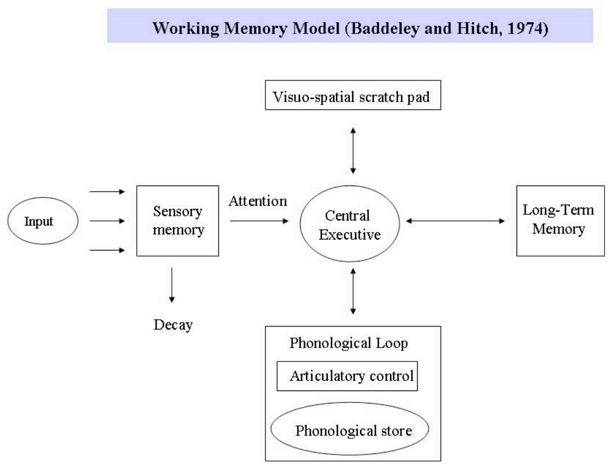

Figure 2.1. Adapted from *Baddeley and Hitch's (1974) Working Memory Model (http://secretgardenofthespotlessmind.tumblr.com/post/25579139714/working-memory-theory-by-baddeley-hitch-1974 accessed 8 February 2013)*

This is thought to be responsible for co-ordinating and controlling the allocation and flow of attention (Baddeley, 1996). These processes are directed by the CE to and from its two slave systems, the phonological loop and the visuo-spatial sketchpad, which store the incoming stimuli – either verbal or visual/spatial – for short periods. The central executive component of the working memory model is key in the control and allocation of attention to and from sensory input to allow selection, switching, inhibiting, scheduling and monitoring processes to take place so that some goal can be achieved (Baddeley, 1986). The Central Executive could also be considered as the controlling mechanism which McCabe and colleagues termed 'executive attention' (McCabe et al., 2010) and this term will be used throughout this thesis. Attentional processing is a function of working memory and diminishes with age (Phillips and Hamilton, 2001).

Executive control processes, such as those involved in IADLs, can be measured by how efficiently individuals process attentional demands emanating from different sources. Within a working memory (resource capacity) model (Baddeley, Baddeley, Bucks & Wilcock, 2001) attention has been situated in three main frameworks: limited resource/capacity, processing systems or multiple resource models. Recent understanding of working memory (Logie, 2011) describes it as multiple-component, multiple-resourced, multiple-domained and fractionated throughout different brain regions. In this model, attentional resources are chosen strategically, and used in concert to achieve the disparate goals of individuals who themselves employ different strategies for the ways in which they use these resources. Performance is not driven by overall capacity limitation but by the different capacity limitations for different component resources (Logie, 2011). Theoretically, the difference between individuals with good versus poor working memory is in the ability to control attention, either to achieve inhibition of irrelevant information or to combine storage and processing (Cowan, 2005).

Executive control is considered differently by experimental psychologists (who understand it as a component of working memory capacity) and by neuropsychologists (who view it as frontal lobe processing or executive functioning) (McCabe et al., 2010). Working memory and executive functioning were found to be very strongly associated in McCabe and colleagues' study and, to avoid confusion in terminology, the authors gave the overarching control mechanism found to be common to both, the term 'executive attention' (McCabe et al., 2010). Separate executive function tasks, disparate as they may appear, seem to share common ground in that they use resources from the frontal areas of the brain (McCabe et al., 2010), specifically the pre-frontal cortex (PFC). Although there is no agreement about the pattern of EF behaviour in older adults it is acknowledged that EF is generally preserved into old age, relative to memory, although some components, for example attentional capacity, do display subtle decline (McDowd & Shaw, 2000).

2.1.3 Traditional models of attention

Broadbent (1958) suggested that there was a limited capacity, single channel of information processing which held processes in sequence before appropriate responses to stimuli were made. Hypotheses were tested in a series of 'dichotic listening' experiments where participants were asked to listen to one message and shadow a different message. Information from one 'stream' was captured but, although the shadowed stream was heard, it was not remembered. These findings were explained by the 'bottleneck' theory which suggests that a bottleneck occurs when two different tasks, requiring two different processing streams, are attempted simultaneously. The two streams compete for limited attentional resources, and one task will take priority over another, leading to a decrement in the performance of the 'loser' of the competing streams. Completing two tasks, therefore, would take more time than completing one because attention would have to be switched between the two processing channels.

When considering this further, Kahneman (1973; illustrated below at Figure 2.2) suggested that the bottleneck was not due to the structure of the information processing system, but to the amount of processing capacity available. In his capacity-sharing model in which attention is allocated according to the demands of the task, attention capacity is limited and, therefore, when it has to be shared while performing two tasks, there will be a decrease in the performance of at least one of the tasks (Kahneman,1973). In the limited-capacity model, attention is a limited resource an individual must flexibly allocate, from moment to moment, according to the needs of the two tasks (Styles, 2006).

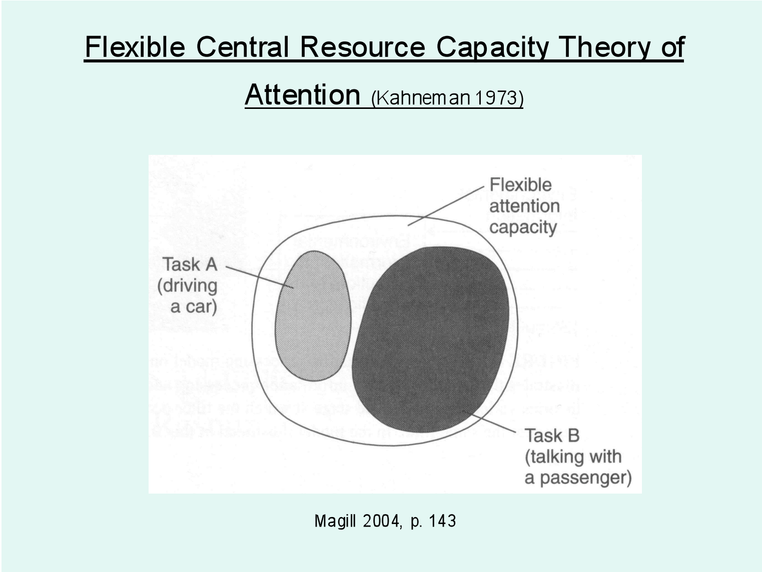

Figure 2.2. Kahneman's (1973) Resource Capacity Model

By contrast in a multiple resource model, as proposed by Allport et al. (1980), information processing has a number of resources, or modules, to complete the tasks, which are capacity-limited, and not centralised (Posner & di Girolamo, 2000). If the two tasks do not share the same common resources, then no interference should occur. For example, a visual task and an auditory task would elicit no change in performance (Fodor, 1983), whereas two concurrent counting tasks would result in a change in performance (Baddeley, 1996). The cross-talk theory challenges this by suggesting that two tasks from similar domains, for example, walking and finger-tapping, use the same neural networks but elicit no change in DT performance (Pashler, 1994). However, it could also be that the measurements used in the experimental tasks were not precise enough to detect differences in the DT.

Baddeley (1986) suggested that capacity and modular accounts of divided attention were complementary and not competitive, and his working memory model allows for processing to be carried out on different streams of information within a limited resource capacity. Posner & di Girolamo (2000) considered that individuals use 'attention' to carry out specific functions some of which related to specific cognitive processes. Implicit in their model of attention is the idea that attention has its own specific identity which interacts with a network of different sub-components located in different anatomical areas of the brain (fractionated), as and when required (Posner & di Girolamo, 2000).

Information processing during activities which use simple perception and attention-allocation operations do not appear to vary with age (Craik & Salthouse, 2000) but more complex operations, such as IADLs, which require multi-tasking, are age-related and act as a barometer for the maintenance of EF. In particular, successful shopping and meal preparation demand that attention be shared between several simultaneous subtasks. Looking at both attention-allocation and information processing during complex or multiple tasks, it should be possible to measure how much executive attention healthy older adults have, how efficiently they use it (under varying conditions) and the cognitive mechanism underlying their individual differences.

2.1.4 The dual-task paradigm

The dual-task paradigm is a convenient method with which to investigate how attention is divided between two or more tasks (Della Sala et al., 1995). The DT examines performance when people are carrying out two activities simultaneously (Baddeley & Hitch, 1974) and comparing this with their performance on the two single tasks (ST) carried out separately. By measuring the performance outcomes of STs and comparing the outcomes with those from the DTs, it is possible to see how much mental effort has been used to carry out two tasks as opposed to one; in other words, how much more or less attention has been required to divide attention between 2 tasks instead of one. There is almost always a 'cost' or dual-task deficit (DTD), no matter how 'simple' each task (Smith & Kosslyn, 2007). This 'cost' is the result of the 2 tasks competing for finite attentional resources and interfering with each other's performance. Baddeley (1996) suggested that the capacity to combine performance of two tasks is a necessary function of the central executive (CE), hence the DT paradigm provides an opportunity to see the CE in action, both in allocating-attention to the tasks and processing information whilst the tasks are being performed. Previous experimental methodology, in attention-allocation, has used the dual-task paradigm to measure reaction times and have not found this to be sensitive to age (Baddeley, 1986; Della Sala, et al., 1995; Hartley & Little, 1999; Pashler, 1994). But AD patients did display DTD in concurrent tasks, suggesting that an executive coordination function is required for divided attention or to allocate specialised resources to concurrent tasks in the healthy brain and that this is impaired in people with AD (Logie et al., 2004). Baddeley and colleagues' previous findings had already indicated that DT performance is a potentially useful marker for dysexecutive behaviour (Baddeley, Sala, Robbins & Baddeley, 1996). In other research using the DT paradigm, older adults perform worse in the DT than younger adults (Lindenberger, 2002), and especially when the older adults' cognition in impaired (Montero-Odasso et al., 2009). By measuring the performance deficit in a dual-task, one is measuring the amount of additional mental effort required to carry out two tasks together and those older adults who cannot carry out a dual-task successfully may be showing early signs of the kind of cognitive impairment which will affect their successful ageing.

2.2 The association between cognition and gait

2.2.1 Physical function

A longitudinal study of healthy, community-living older women suggested that those women with a greater physical activity level at baseline were less likely to experience cognitive decline in the following six to eight years (Yaffe, Barnes, Nevitt, Lui & Covinsky, 2001). Some research suggests that aerobic exercise and training intervention enhances brain plasticity that could reduce the amount of age-related cognitive decline (Voss et al., 2010). A more recent investigation of the effects of acute aerobic exercise on cognitive brain functions of healthy older adults suggested that, as people age, light or moderate exercise can not only maintain, but actually improve future cognitive function (Kamijo et al., 2009). These studies confirmed findings that engaging in physical activity at least twice a week in mid-life, is associated with a reduced risk of dementia in later life (Rovio et al., 2005). Long-term regular physical activity, including walking, has been associated with significantly better cognitive function and less cognitive decline in women aged 70-81 years (Weuve et al., 2004) and in very healthy older adults, faster-paced walking, appeared to be the most sensitive measure in assessing the relationship between gait and cognition (Fitzpatrick et al., 2007).

2.2.2 Executive Attention and gait

Walking was once considered to be a learned motor function which became 'automatic' early in life. Most theoretical descriptions of walking as an automatic motor function would describe it in terms such as 'autonomous', 'goal-driven' and 'unconscious' (Moors and De Houwer, 2006). However, recent reviews (Woollacott & Shumway-Cook, 2002; Hausdorff et al., 2005), suggest that, in healthy participants, even simple gait performance, requires a degree of attention and that the addition of a secondary cognitive task, puts demands on attention and gait is compromised. Evidence for the interconnectedness of gait and cognition in older adults appeared in a seminal study, which found that older people at risk of falls stopped walking when they started talking (Lundin-Olsson et al., 1997). It appeared that walking while talking demanded too much mental effort to be carried out concurrently by those older adults with cognitive impairment (who later went on to experience a fall).

Camicioli and colleagues (1997) suggested that cognitive and motor performances may be affected by the same neurological processes and Holtzer and colleagues (2011), in a study using a portable functional near-infrared spectroscope, posited that this commonality was located in the PFC (Camicioli, Howieson, Lehman & Kaye, 1997; Holtzer et al., 2011). It is evident that cognitive ability plays a key role in gait stability (Theill, Martin, Schumacher, Bridenbaugh & Kressig, 2011) and that good postural ability is associated with cognitive function, even in healthy older adults (Marquis et al., 2002). Recent studies in cognitive neuroscience have demonstrated the necessity of intact cognition, particularly executive function, for competent motor control (Sheridan, Solomont, Kowall & Hausdorff, 2003). Springer and colleagues found that DT deficits in gait were more pronounced in patient groups for example people with Alzheimer's disease (AD), Parkinson's disease (PD) and post-stroke patients who have difficulties in EF tests, specifically inhibition and divided attention (Springer et al., 2006). Performance outcomes, when walking and reasoning, are also sensitive to age, in that older adults show more DTD than younger adults (Beauchet, Dubost, Herrmann & Kressig, 2005; Hollman, Kovash, Kubik & Linbo, 2007), Concurrent gait and cognitive ability appears to tap into the control mechanism of both attentional resource-allocation and processing speed in healthy older adults and the dual-task is a convenient methodology with which to disentangle the two cognitive processes.

2.2.3 The neuropsychology of gait

Posner & Petersen (1990) proposed that 'top-down' voluntary control could be exerted over 'bottom-up' automatic brain systems. The primary motor cortex, located in the frontal lobe of the brain, projects directly onto the sub-cortical motor areas which are associated with walking (see Figure 2.3). But other motor-related areas of the brain exert secondary effects on walking via projections onto the primary motor area. These secondary effects come from the pre-motor cortex in the frontal lobe, which groups elementary movements into coordinated patterns, the basal ganglia, located in the forebrain, which transforms motivation into selected action and the cerebellum, located in the hindbrain, which calibrates the precision and the timing of movements (Kandel, Schwartz & Jessell, 2000) (Figure 2.4).

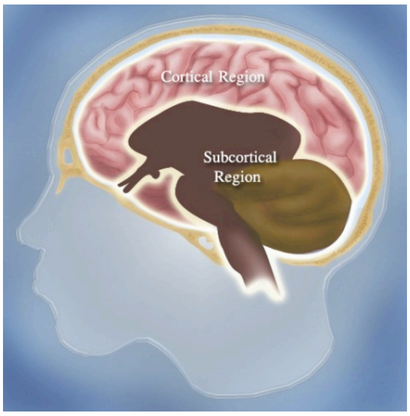

Figure 2.3. Cortical regions of the brain (ocdinformation.wordpress.com accessed 5/7/12)

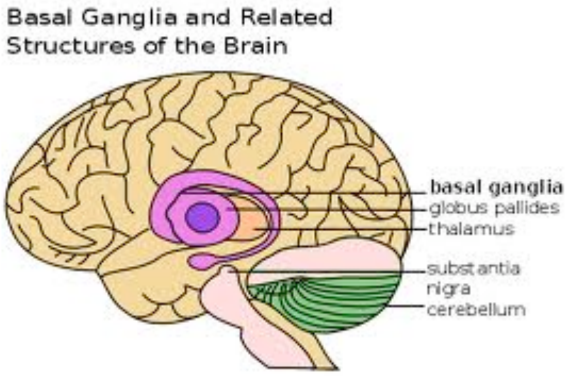

Figure 2.4. Basal ganglia and related structures of the brain *Biological/Evolutionary Approach to Gait. (www.stanford.edu accessed 5/7/12)*

There exists a strong interaction between motor control and cognitive behaviours, which use sensory information from shared systems in the anterior and posterior brain regions (Yogev-Seligmann et al., 2008). Executive attention is thought to be anatomically located in the PFC and is known to affect gait ability (Yaffe et al, 2009). However, neuroimaging studies investigating brain activity during EF tasks have produced inconsistent conclusions. It appears that, not only are the frontal and parietal areas of the brain (those associated with EF) activated when EF tasks are carried out, but that other areas, not usually associated with EF are also activated suggesting that higher-level cognitive processing is not domain-specific (Collette, Hogge, Salmon & Van der Linde, 2006). fMRI studies have shown that specific brain regions are activated during a task testing cognitive flexibility (Carter, 1999). These areas are the prefrontal cortex (PFC), the basal ganglia, the Anterior Cingulate Cortex (ACC) and the Posterior Parietal Cortex (PPC). More recently, neuroimaging (fNIRS) studies have indicated that attention is fractionated during a concurrent activity (Holtzer, et al., 2011).

White matter integrity is a factor which affects normal cognitive ageing (Deary & Gow, 2008). The corpus callosum (CC) is the main white matter tract connecting the two hemispheres of the brain. Atrophy of the CC occurs in normal ageing, as well in neurodegenerative disease. A longitudinal study over 3 years investigating the link between gait stability and the corpus callosum in a cognitively healthy group of older adults (mean age 74.2 years) with white matter atrophy, found that those with slow walking speed (timed over 4m) also had greatest atrophy of the CC areas. It was also found that the CC areas in those with the most gait difficulty were significantly smaller than in those without gait problems (Ryberg et al., 2007).

2.2.4 The gait and cognitive dual task

In order to understand physical and cognitive dynamics and the interplay between them, a dual-task can be used which can both measure and modify the attentional load placed on an older adult carrying out what can be described as a facsimile of an a everyday activity. The gait and cognitive performances in a DT appear to be more sensitive to changes over time in global cognition and EF (Marquis et al., 2002; Yaffe et al., 2001; Yogev-Seligmann et al., 2008). For example, Kelly and colleagues (2008) identified instability in gait, which was not detected in a single-task, but became apparent as the complexity of the walking task was increased due to a concurrent cognitive task, in this case verbal fluency (Kelly, Schrager, Price, Ferruci & Shumway-Cook, 2008). Exactly how and why this happens is debatable, as the wide variety of measures used to assess gait and cognitive tasks separately and concurrently have produced inconsistent findings regarding DT deficits or benefits to either gait or cognitive outcomes. It is essential, therefore, that a suitable secondary cognitive task is chosen which is sensitive enough to measure the dual-task deficit/benefit produced from the gait and cognitive task association. The importance of the secondary task is highlighted by a recent study by Holmann et al., (2007) in which the variability in stride velocity was compared with performance on a cognitive task of spelling a 5-letter word backwards in 3 groups of adults (young, mean age = 20, middle-aged, mean age = 48 and old, mean age = 80). Greater variability in stride velocity in older adults was strongly associated with a decrease in their ability to carry out the cognitive task at the same time, whereas this was not the case with the two younger groups (Holmann et al., 2007).

2.3 Gait Measures

2.3.1 Spatial and temporal parameters

An individual's walking ability is contingent on both their cognitive functioning and their mood, during the planning and performance stage of the walk *and* on the cognitive and motor demands which are influenced by real-time external (environmental) events (Giladi, 2007). In order to assess how, and by how much gait can vary, several different aspects of gait must be considered. Temporal parameters correspond to the time taken to walk from point A to point

B, whereas spatial ones correspond to the distances covered in that time (temporal-spatial parameters or TSPs). Gait is often measured in cycles or strides. A gait cycle is from the heel-strike of one foot to the next heel-strike of the same foot. A gait step or stride is from the heel-strike of one foot to the next heel-strike of a different foot. There are 2 gait strides/steps in one gait cycle but they are not necessarily equal (see Figure 2.5). The measurement of gait speed and the length and timing of step/stride, and the variability between the steps/strides may serve as good indicators of overall locomotion performance, that is self-propulsion from one place to another (Ayyappa, 1997a; Barker, Craik, Herrmann & Hillstrom, 2006). Older adults with cognitive impairment generally have shorter steps, reduced gait speeds, lower cadence, and greater gait variability than those whose cognition is intact (Beauchet, Dubost, Herrmann & Kressig, 2005), although healthy older adults also show significant variations in their stride times. Variability in the different gait measures provides a sensitive and clinically relevant parameter in the evaluation of mobility and fall risk and greater stride time variability in gait is specifically related to EF (Hausdorff, 2005).

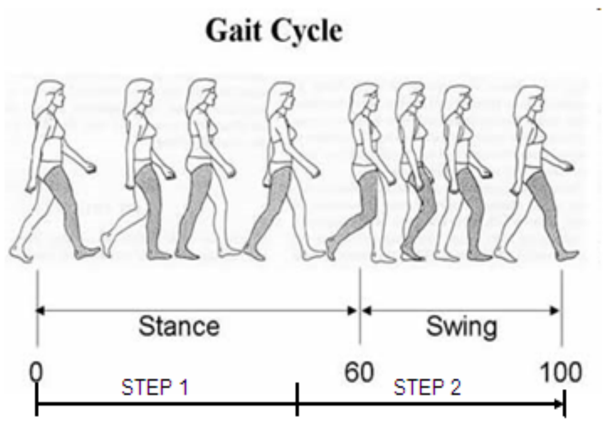

Figure 2.5. *Gait Cycle showing stance, swing, stride and step concepts*

2.3.2 Gait measurement

A recent review of the interrelationship between gait and cognition highlighted the different roles of gait velocity versus gait variability (Montero-Odasso et al., 2012). They concluded that results from velocity and variability outcomes are not mutually exclusive but can provide the researcher with different types of information (Montero-Odasso et al., 2012). Gait velocity is an easy measure to observe and gives valuable information about the general physical function of older adults (Montero-Odasso et al., 2005; Studenski et al., 2011). Variability in gait may serve as a sensitive and clinically relevant parameter in the evaluation of mobility and fall risk, and could form part of an intervention therapy for older adults at risk of these adverse physical outcomes of ageing (Hausdorff, 2005). It has been the generally accepted approach to measure variability of gait through one of its parameters by calculating the coefficient of variability (CV) which is the percentage of Standard Deviation (SD) over the Mean (M) or average of values obtained from a participant's gait trials, or 100% x SD/M (Hausdorff et al., 2001).

2.3.3 Tools of gait measurement

The simplest quantitative method for measuring participants' gait TSPs, is by timing it (for example using a stop watch) over a known distance, while counting the number of steps (Barker et al., 2006). The TSP approach allows the researcher to calculate the mean values of the following gait parameters: step length and time; cadence (total number of steps with respect to time); and gait speed (total distance divided by total time). This approach is practical, inexpensive, and easy. However, timing with a stop-watch is open to human error and risks inaccuracy in the collection of data (Dickens & Smith, 2006).

Other tools used for quantitative gait analysis that offer the measurement of TSPs include instrumented walkways ('virtual foot-printing') that have pressure switches or force sensors embedded in a mat placed on the floor that detect, record and analyse footfalls. The GAITRite® system is an example of a gait mat (2 feet x 12 feet) which is in wide use in gait research laboratories. The main drawback of such devices is the relative expense and the limited steps they can measure, due to the size of the mats (Bilney, Morris & Webster, 2003). Foot-switches, 3D motion analysis systems, motion sensors, pedometers, and Global Positioning System (GPS) are also employed by gait analysts to measure specific aspects of gait (Hausdorff, 2005).

Dual-task studies of gait and cognition have also made use of a range of measures from gait speed timed with a stopwatch (Beauchet et al., 2008) to gait variability using the GAITRite® walking mat in a gait analysis laboratory (van Iersel, Kessels, Bloem, Verbeek, & Olde Rikkert, 2008). Some studies have measured gait simply by counting the time and number of steps taken to walk a short distance, for example 8 feet (Alfaro-Acha, Raji, Markedes &

Ottenbacker, 2007), whilst others have asked for multiple trials over longer distances, for example 10 metres (Cho et al., 2008) or even along an 8 metre figure-of-eight (Laessoe et al., 2008). There is currently no consensus regarding the optimal distance over which to measure gait, although it has been suggested that this is between 18 – 30 feet for gait speed (Montero-Odasso, 2006) and 20 strides (Hollman et al., 2010), 50 steps (Sheridan et al., 2003), and 2 minutes' continuous walking (Galna, Lord & Rochester, 2013) for step-length and step-time variability.

Across these methods significant performance deficits have consistently been found in gait and cognition dual-tasks. While gait measurement is now well established, there is scope for further exploration of the secondary cognitive task, in terms of the type, sensitivity and reliability. Manipulating the cognitive demands during a gait and cognition dual task appears to hold the key to the sensitivity of the gait and cognitive task measures in dual-task performance deficit in older adults (see Beauchet et al., 2005).

Gait performance data have been correlated with as few variables as simply the global cognition scores from the Mini-Mental State Examination (MMSE; Folstein, Folstein & McHugh, 1975) to the scores on a cognitive test battery covering a range of cognitive domains, including executive function (Sanders, Holtzer, Lipton, Hall & Verghese, 2008), memory (Marquis et al., 2002) and attention (Inzitari et al., 2007). In DT studies, gait measures are always discussed in conjunction with cognitive measures, although the analysis of the secondary (cognitive) task has not always been carried out or its importance evaluated.

2.4 Standardised cognitive measures

2.4.1 Global cognition

One of the best-known cognitive tests for global cognition is the Mini-Mental State Examination (MMSE; Folstein et al., 1975), which is used as a clinical screen for the diagnosis of dementia. MMSE is often used to provide a baseline global cognition measure against which performance measures of tests on separate variables (such as memory) are compared. Folstein and colleagues (1975) stated that older adults with no dementia or other cognitive impairment should score 27 or above (out of 30) in this 10-minute test. One longitudinal study of the relationship between gait (walking time) and baseline cognition over 7 years used the MMSE as the only measure of cognition (Alfaro-Acha et al., 2007) and found that walking time over 8 feet was a non-cognitive marker of future cognitive decline.

2.4.2 *Standardised executive function measures*

Hausdorff (2005) used the MMSE score of ≥ 27as a measure of global cognition but found that there was a stronger association between walking stride-time variability and higher-level cognitive processes, in general, and with specific EF tests, in particular. In a recent review of the role of attention in gait (Yogev-Seligmann et al, 2008), the authors proposed that more evidence is needed for a causal relationship to be established between changes in gait and changes in EF, and in particular attention. Looking at the relationship between gait and specific aspects of cognition rather than just a global measure, should benefit this. Traditionally, researchers have chosen neuropsychological tests specific tests to measure specific executive functions, in the assumption that they were separate and distinguishable. However, it has also been suggested that individual EF tests might measure multiple EFs. Therefore, it is important that each test used in any study describes the aspects of cognition, be it executive functions or other domains such as memory, that it measures (McCabe et al., 2010). Cognitive test batteries are constructed to ensure that a range of cognitive domains are tested. Their purpose is to include measures of the cognitive domains of interest, for example, EF, but within the context of the level of participants' performance in other domains. This is to facilitate identification of domain-specific problems or general cognitive problems. Since the purpose of this longitudinal study was to investigate attention-allocation within the framework of a resource capacity/resource processing model of working memory, a battery of standardised cognitive tests was chosen to test specific executive functions, including attention, set-shifting, perceptual speed and judgement in the context of performance in general cognition and memory. In healthy older adults, performance should be consistent across cognitive function, that is it should be within normal ranges. Variation in performance would be expected where there is some impairment in cognition and this can be function specific, for example, memory might be impaired but not vocabulary.

2.4.3 *Cognitive load*

Varying the cognitive load of the secondary task is a factor in the differences between results in the same performance measures. Investigating this hypothesis, Lovedon and colleagues (2008) manipulated the attentional load of healthy young and older adults. Participants were asked to walk on a treadmill while carrying out a numerical memory task (the *n*-back), where they had to remember the position of a particular number (1 to 4 places back) in a list of numerals they had heard previously. When attentional load was increased in each trial (from 1 place to 4 places back in the list), they found no dual-task performance cost for the cognitive task but gait stride-time and stride-length variability increased, (worsened) as the working memory load became greater (Lovedon, Schaefer, Pohlmeyer & Lindenberger, 2008). However, the researchers acknowledged that, at some point, the cognitive demands may have become too much for their older participants and that this may have adversely affected their dual-task cognitive scores (Lovedon et al., 2008). Varying the load or demands of the cognitive task in a DT condition is the key to improving sensitivity in a gait and cognitive dual-task performance. Too much load on the secondary task may make it too difficult, resulting in a 'floor' effect. However, if the cognitive task does not demand sufficient attention, it may have little effect on gait at all. To determine where attention is being directed in a dual-task gait and cognitive dual task, it has been proposed that, by manipulating the cognitive load (task difficulty), the expected dual-task costs, might reveal which task receives the most attention by seeing which is most affected (Hausdorff, 2005; Yogev-Seligmann et al., 2008). In other words, seeing if attention is directed to maintaining gait or executing the cognitive task should illuminate the underlying process of attention allocation.

2.4.4 Choice of secondary tasks

It is a similar story with the choice of the concurrent cognitive task. It is thought that disordered and disinhibited behaviour of the type found in frontal lobe syndrome is associated with difficulty in distributing attention (Smith & Kosslyn, 2007). Any secondary task that specifically uses attentional processing, then, might be a better measure of executive function than, for example, the more widely-used verbal fluency tests which may draw more on memory function (Baddeley, 1996). In a study investigating two different but recognised EF secondary tasks, Beauchet and colleagues (2005) used compared cognitive performance in both arithmetic and a verbal fluency tests with gait stride time and stride-time variability in frail participants (MMSE < 16). They found that there was a significant increase in mean stride time only with the arithmetic task. Other cognitive tasks used with gait in a DT experiment include arithmetic tasks such as simply counting backwards in 1s (Allali, Assal, Kressig, Dubost, Herrmann, & Beauchet, 2008), complex arithmetic such as counting backwards in 7s (Laessoe, Hoeck, Simonsen, Voigt et al., 2008), verbal fluency, such as enunciating girls' and boys' names (Camicioli et al., 1997), auditory Stroop tests (Siu, Chou, Mayr, van Donkelaar & Woollacott, 2008; Siu, Chou, Mayr, van Donkelaar & Woollacott, 2009). Whilst there is still no agreement about the most appropriate choice of a cognitive task in DT gait and cognitive task studies, the most recent literature has used Serial 7s (Hobert et al., 2012; Springer et al., 2006; Srygley et al., 2009; van Iersal et al., 2008; Yogev et al., 2005).

2.5 Attention allocation in a gait and cognitive dual task

2.5.1 Cognitive flexibility

It has been suggested that cognitive demands can strongly affect our ability to prioritise attention on gait when required, and that this ability is age-related (Yogev-Seligmann et al., 2010). It is thought that cognitively healthy participants unconsciously adopt a 'posture first' approach during a DT, in order to preserve their postural stability; that is, they have prioritised gait over cognition, presumably to avoid falling (Shumway-Cook, Woollacott, Kerns, & Baldwin, 1997). In contrast, older adults with PD did not favour the 'posture first' strategy in a gait and cognition DT (Bloem, Grimbergen, van Dijk, & Munneke, 2006). Instead, they opted for the 'posture second' strategy, treating both the gait and cognitive elements of a DT with equal priority. Bloem et al (2006) concluded that, in daily life, adopting this strategy could threaten posture control and lead to falls. The idea of 'posture-second' has support from a study where reduced ability to allocate attention appropriately between two concurrent tasks explained decreased dual-task performance in older adults with existing balance impairments (Siu et al., 2008). In this study, which compared younger and older adults' performance in a gait and simultaneous verbal working memory task (verbal Stroop), the older adults displayed an inability to adopt the 'posture-first' strategy and switch their attention allocation to gait in order to ensure gait stability in the DT. There have been relatively few studies examining the impact of attentional load on walking in healthy older adults and how this affects their postural strategies.

There is evidence that some older adults who unconsciously prioritise the cognitive task may adversely affect their gait stability. Beauchet and colleagues (2007) found that 'old' adults (aged 75 to 100 years) with an MMSE score > 24, who counted faster in the dual-task condition than in the single task, were actually at greater risk of falling (Beauchet et al., 2007). This again calls into question whether those at risk of falling were able to allocate their attention efficiently during the dual-task. The cost of allocating attention to concurrent tasks can be measured in the dual-task deficit, but researchers can only establish how efficiently attention has been allocated between the 2 tasks by comparing performance outcomes after explicit instructions have been given to prioritise either gait or the cognitive task. Explicit prioritisation in gait and cognitive dual tasks in healthy older adults has been the subject of few studies (de Bruin & Schmidt, 2010; Hobert et al., 2011 Kelly et al., 2010; Yogev-Seligmann et al., 2010; Verghese et al., 2007) and, to my knowledge, none has been longitudinal.

2.5.2 Rhythmicity

In a sample of 100 cognitively healthy older adults (aged 69.8 ± 0.07 years and MMSE > 28), 20% of participants' DT performance in both the gait and the cognitive task was better than in the ST (Beauchet et al., 2010). This improved DT performance was only observed in participants with the highest initial gait stride-time variability. Participants with an irregular gait stride, and therefore a greater risk of falls, were identified by measuring gait and cognitive performances, in this case walking and counting backwards. Beauchet and colleagues (2010) attributed this improvement in the DT cognitive responses to 'the magnet effect' which is the tendency of biological oscillators to attract each other (see Ebersbach & Poewe, 1995 for analysis). Improved DT cognitive responses had also been found in other studies (Beauchet et al., 2007; Yogev-Seligmann et al., 2010). Because walking and counting both have strong rhythmic components, if performed simultaneously, Beauchet and colleagues (2007) concluded that the counting backwards acted like a metronome, regulating the irregular walking rhythm of the participants with most unsteady gait, leading to an improvement in performance when doing them both together.

The walking difficulties experienced by people with PD have been attributed to impairment in motor-timing or rhythmicity. Findings have suggested that external cues, such as walking to the regulated beat of a metronome (adjusted to the preferred walking pace of the participant) can have a positive effect on participants with PD because they may have adopted a compensatory cognitive strategy (steadier gait) that reduces fall risk. (Rochester, Burn, Woods, Godwin, & Nieuwboer, 2009). Rochester and colleagues (2009) suggested that auditory cues that regulate gait reduce the interference between DT gait and cognitive performances, leading to decreased variability in gait step and double-limb support time (increased steadiness) in participants with mild cognitive impairment. Their results suggest that gait improved because of better use of attentional resources and/or better task prioritisation. Rochester and colleagues (2009) did acknowledge that cues, such as walking to the beat of a metronome, could increase the attentional load during a DT and this attentional burden might lead to greater gait instability in those who were already at risk of falls. A similar study, hypothesising that gait disturbances are improved using auditory cues, trained participants with PD to walk while singing in their heads. Gait time and number of steps significantly improved after just one training session, suggesting that there is potential for improvement in the gait of participants with PD when they walk while mentally singing (Satoh & Kuzuhara, 2008). However, in neither of these studies, was the secondary cognitive task scored and so it was not possible for the researchers to observe and measure attention allocation and, therefore, to comment on the effects of explicitly manipulating attention on performance.

2.5.3 Prioritisation of attention

The allocation of attention during the performance of concurrent tasks depends on many factors including the nature of both the cognitive and gait task, the participants' goals and the nature of the instructions given to them (Shumway-Cook et al., 1997). Being able to observe and measure how well older adults prioritise and allocate attention, when increasing mental effort is demanded, could be an effective way for researchers of observing executive attention in action. In one study, researchers concluded that, when older adults prioritised different aspects of performance (walking or talking) during same gait and cognitive tasks, the effect of prioritisation could be observed on gait outcomes but not on cognitive responses (Verghese et al., 2007).

More recently, the effect of a secondary cognitive task on gait measures was strongly influenced by the explicit prioritisation of attention on either the walking or the cognitive task (or on neither, in particular) (Yogev-Seligmann et al, 2010). Healthy young and older adults were asked to walk and perform a category verbal fluency cognitive task under ST and DT conditions. In this study, during the DT, participants were instructed to prioritise walking, to prioritise the cognitive task or given no specific prioritisation instructions. Yogev-Seligmann and colleagues (2010) found that the effect of the secondary cognitive task on gait speed was strongly influenced by explicit prioritisation instructions, even among young adults, but the effect was statistically significant in older adults. Moreover, in both age groups gait speed in the no-prioritisation condition was similar to the condition where they focused attention on cognition rather than when they were prioritising walking (Yogev-Seligmann, et al., 2010).This suggests that measuring the difference in performance between a ‘no prioritisation’ condition and those where prioritisation has been explicitly instructed is an observable, and therefore measureable way of assessing participants’ efficiency in allocating attention to concurrent gait and cognitive tasks.

2.6 Conclusion

The goal for individuals as they age is to maintain physical and cognitive function for as long as possible and early detection of how well this is being achieved may be possible through measuring how well healthy older adults control their ability to allocate attention. This can be seen in their ability to prioritise attention and how flexibly they can adapt to different conditions. As people age, carrying out complex tasks requires them not only to use the attentional resources available to them, but also to adapt their prioritisation strategies so that they can flexibly prioritise one task over the other, as necessary. Using the DT paradigm, in a concurrent gait and cognitive task, will make it possible for researchers to disentangle the effects of cognitive load from the effects of processing ability in a complex task, and to relate DT performances to underlying cognitive ability, such as specific executive functioning. This may provide a simple way to identify the indicators of independence and functional well-being in later life.

2.6.1 Aims of the study

This thesis contains two main studies – a longitudinal study over 12 months, with data collected at two time points and an intervention study using rhythmical training. The longitudinal study has the following aims:

1. To investigate the effect of manipulating cognitive load on the dual-task performance of healthy older adults (in DT vs. ST gait cognitive performance outcomes) as a means of assessing attention resource capacity.
2. To investigate the effect of explicitly instructing participants to prioritize their allocation of attention to walking or counting (no prioritization, prioritizing walking and prioritizing counting) as a means of assessing attentional processing.
3. To look for evidence of the ‘posture first’ strategy in healthy older adults by comparing gait and cognition outcomes under different attention-prioritising conditions.

4. To assess the relationship between healthy older adults' executive attention, as indexed by their cognitive flexibility (how efficiently they can adapt their concurrent gait and cognitive performances under varying loads and prioritization instructions) and their performance on standardized tests of EF, in order to identify potential markers or predictors of successful ageing.

2.6.2 Outline of empirical chapters in the longitudinal study

Chapter 4 describes the first phase (T1) of a longitudinal study. T1 is a within participants design, investigating the mechanisms underlying executive attention by measuring attentional capacity and processing speed in a DT with two levels of cognitive task – counting backwards in 3s and 7s.. The experiment measured the effect of cognitive load and prioritisation instructions on the gait and cognitive performance of 72 healthy older adults in single and dual tasks. They also completed a battery of standardized cognitive tests and completed a demographic questionnaire to investigate markers or predictors of the maintenance of cognitive function in older age. In addition, the experiment used comparisons of the performance outcomes in the prioritising conditions to assess whether healthy older adults do adopt the 'posture-first' strategy and whether such as strategy is a plausible means of assessing attention-allocation to a DT gait and cognitive task. **Chapter 5** compares the participants' performance at T1 and T2, on all measures. This chapter considers the implications of the findings for our understanding of the mechanism underlying our ability to carry out two tasks at once and the role that flexible attention-allocation (cognitive flexibility) has in healthy ageing. Evidence is presented for a possible predictor of the maintenance or decline of this higher-level (executive) function. The chapter ends with a proposed model of executive attention which might sit within a recent integrated model of concurrent gait and cognitive task and their association with ageing. **Chapter 6** investigates the relationship between the rhythmicity or automaticity of gait and cognitive ability. It describes a between-participants experiment in which a musical training intervention is given to one group and compared with a group who just hear music playing and a third group who have no training or music. The aim of the musical training is to make their gait more automatic and therefore require less mental effort, to see if this has an impact on either gait or cognition or both.

Chapter 3: Validation of gait analysis methods

A variety of methods have been developed to collect gait and cognition data during dual task studies (Section 2.3, Chapter 2). In brief these need to be sensitive, reliable and efficient, whilst being as non-invasive as possible. Two methods were selected for comparison in this research, the first for its ease and simplicity and the second in order to obtain more complex outcome measures automatically`. The first was to video record participants carrying out all single and dual task conditions. This would provide timings of task completion, observational data on the walking and audio data on the cognitive performance. The second was a footswitch system that could be attached to the shoe to record gait data, nicknamed 'Bigfoot'. Each of these methods was piloted to clarify their reliability and suitability for the proposed longitudinal study.

3.1 Video-recorder pilot study

3.1.1 Introduction

In order to test the feasibility of conducting dual-task gait and cognition research in a laboratory setting, I completed a short pilot study of two single tasks (walking at own pace and, separately, counting backwards in 7s) and one dual-task condition (simultaneously walking and counting backwards in 7s). The method of measuring experimental outcomes was by video- recording participants as they carried out the single (ST) and dual tasks (DT). This provided permanent visual and sound data on both gait and cognitive performance. These data were then processed manually to calculate gait time, speed and step-time variability. While gait speed and time taken to walk are less sensitive gait measures than step-time variability, they have both been used previously to describe gait locomotion (Fitzpatrick et al., 2007; Montero-Odasso et al, 2005; 2012).
A second set of timings was also taken using an automatic stop clock to validate the manually analysed gait measures from video recordings.

Aims

- To investigate the feasibility of collecting standard outcome measures by conducting a single and dual-task gait and cognition experiment in the School of Psychology and Neuroscience, University of St Andrews.

- To validate data collected by manual analysis of video recording against a mechanical stop-clock.

3.1.2 Methods

Design

The design was 2 x 2 repeated measures, within participants. The independent variables were task type (single vs. dual) and means of recording (manual vs. automatic) and the dependent variables were mean time, in seconds, gait step-time variability, expressed as the percentage coefficient of variation (% CV), number of steps taken to walk 16m and number of responses in the secondary (cognitive) task.

Participants

An opportunistic sample of six graduate students, aged 24 to 37 years, (4 female and 2 male), mean age 27.3 years, from the School of Psychology and Neuroscience at the University of St Andrews, volunteered to participate in the experiment.

Materials

A video camera, measuring tape, stop clock and white tape were procured from the technical department of the School of Psychology. A 16-foot walkway was measured out and marked at each end with white tape. As described in Chapter 2, studies in gait and cognitive dual-tasks have measured gait over distances as short as 8 feet. Gait mats such as the GAITRite® system measure footfalls over 12 feet but it has been suggested that gait should only be analysed over distances between 18 – 30 feet (Montero-Odasso, 2006). The distance in this pilot study was to compare methodologies and 16 feet was the longest flat, indoor facility available for research purposes at that time. The video camera was set up on a tripod to video record the participants' steps along the entire 16 foot walkway. The stop clock was used to time each task, as was the timer on the video camera.

Procedure

The participants were tested separately. The experimental conditions were explained individually to each participant, using the same instructions, at the beginning of each experimental session as follows:

Thank you for agreeing to take part in this pilot study. My aim today is to test the reliability of this video camera which I intend to use in a larger research project. You will be asked to carry out 3 tasks today. A walking task, a counting task and a simultaneous walking and counting task. The walking task starts from the first white marker and ends back at that same white marker. You should aim to start your walk with either foot touching the first white marker. You should then walk at your own comfortable pace until you cross the second white marker, at the other end of this room. I would like you to turn in the space provided and walk back, again at your own comfortable pace, the same way you came, aiming to touch the second white marker with either of your feet, as you start the walk back. I will say '3, 2, 1, Go' and you should start walking in your own time after the word 'Go'. You can now practise walking to the second white marker and back again. The counting task will be counting backwards in 7s from a given number. I will say 'Ready, steady….' and then give you the number you should start counting backwards from. Please do not repeat the number I give you, but start to count backwards from it, and please count out loud. If you make a mistake, you can correct it or just carry on. You can now practise this. 'Ready, steady... 250.' For the dual-task, I will ask you to walk, in the same way as you did for the single task, but this time I will also give you a number and you should count backwards at the same time as walking. The number I will give you will be different from the number you have just practised. Remember to count aloud - backwards in 7s from the number I give you. You will not be allowed to practise this task. I will be videoing all three tasks and timing them with a stopwatch. Do you have any questions? That is the end of the pilot study. Have you any further questions? Thank you for taking part.

In the single task walking (ST-W), on the researcher's instruction, the participants walked from the white tape, at one end of the walkway to the white tape 16 feet away at the other end. They turned round and walked back along the same walkway. Before they started the researcher demonstrated the walking test and each participant carried out a practice walk.
In the second condition, the single-task counting (ST-C), the participants were told to count backwards from a given three digit number in 7s and allowed to practise with a starting number of 250. The researcher included the starting number in the starting instructions, for example 'ready, steady, 250'. In the actual single-task trial, the starting number was 199.
The final condition, the dual-task walking and counting backwards task (DT), the participants were not allowed to practise before the trial began and the starting number was 175. The

dual-task commenced, therefore, with the instruction ‘ready, steady, 175’. The single counting task used different numbers to avoid practice effects.

Participants were filmed completing the entire 16-foot walk and the return journey. The DT was carried out before the ST-C. This was because it was important to ensure that each participant was given the same amount of time on the counting task in the single condition as they had taken in the dual-task, to ensure parity between conditions. The single-task counting was completed at the end of the experiment. All participants performed the three conditions in the same order. The video recordings also provided a record of participants’ verbal responses in the counting task, including pauses or hesitations. The experiment lasted approximately 5-7 minutes in total.

Scoring

The dependent outcomes were gait time, speed, step-time variability and correct cognitive responses. The gait step-time variability was calculated from timing each step manually from the playback of the video recorder, using a Nokia 7210 stopwatch. The step-time variability was quantified as the percentage of coefficient of variation (CV) across the outward and returning walk (16ft) collected from the single and dual-task walking trials. CV is determined by the equation:

CV = (SD/M) x 100, where SD is the standard deviation and M is mean of the step-time variability between each step. Gait speed was also recorded from the manual stop-clock. The number of correct cognitive responses was calculated by subtracting the number of mistakes from the total number of responses made by each participant.

Statistical Analysis

The means % CV for the single and dual-task performance was compared using a paired samples t-test. The confidence intervals were 95% with a p value of 0.05 considered to be statistically significant. All statistical analyses were carried out using PASW, version 17.0.

3.1.3 Results

Participant background characteristics and descriptive statistics for the performance outcomes of single and dual tasks are given at Table 3.1. The average speed for completing the walk on its own was: video timer M = 11.01, range = 9.1 – 12.0 and stop clock M = 11.42, range 9.0 - 13.0 (see Table 3.1). When it was carried out whilst counting backwards the walk was slower on average using both recording methods (video M = 12.5 seconds and stop clock M = 12.5 seconds) (see Table 3.1). Paired-sample *t*-tests revealed there were no differences between the video recording and the stop-clock methods in either the walk in the single task t (5) = -1.55, p = 0.182, r = -.57 or in the dual-task t (5) = 0.00, p = 1.00 (where the means were identical; see Table 3.1).

In order to assess if performing a dual task would affect these young adults' step-time variability or their cognitive responses, their ST and DT performance measures were compared for significant differences. There was no significant difference between the % CV gait step-time variability in the single walking task and the % CV gait step-time variability on the dual-task, t (5) = 0.30, p= 0.977. There was also no significant difference between the cognitive responses in the single and dual-tasks, t (5) = 0.00, p=1.00 (where the means were identical; Table 3.1).

Table 3.1

Background characteristics and descriptive statistics for ST and DT

ID	Age	Sex	ST Time (secs) Video	ST Time (secs) Clock	ST Cognitive responses	DT Time (secs) Video	DT Time (secs) Clock	DT Cognitive responses	ST Step-time (SD)	DT step-time (SD)	ST Step-time variability (% CV)	DT Step-time variability (% CV)
1	30	F	10.09	11	5	11	11	4	.473 (.090)	.510 (.086)	18.97	16.82
2	24	F	9.12	9	4	10	10	3	.523 (.078)	.605 (.143)	14.84	23.63
3	25	M	11.87	12	2	14	14	3	.623 (.101)	.715 (.089)	16.26	12.49
4	24	M	11.04	12	5	12	11	6	.588 (.064)	.609 (.077)	10.97	12.67
5	24	F	11.97	13	5	12	13	5	.531 (.139)	.580 (.079)	24.8	13.56
6	37	F	11.97	11.5	4	16	16	4	.558 (.064)	.708 (.125)	11.47	17.6
Mean	**27.3**		**11.01**	**11.42**	**4.16**	**12.5**	**12.5**	**4.16**	**.549 (.089)**	**.621 (.099)**	**16.21**	**16.12**

ST - Single counting backwards from 199
DT - Dual-task counting backwards from 175

Responses – total number of answers minus number of mistakes

Step-time = mean of time for each step

CV% = SD/M x 100

3.1.4 Discussion

This Pilot Study was carried out to test the utility of the video camera as a means of collecting data for calculating step time variability. In addition, the video camera was assessed as a useful means of recording the number of responses and errors on the cognitive task. There were no differences between the gait speed and time to walk 16m whether measured by video-recording or stop-clock. There was also no difference between ST and DT results for both gait step-time variability and cognitive responses. In other words, there was no cost to the walking or to the counting task of carrying out both tasks concurrently, compared to performing them singly for these healthy young adults. This last result is consistent with other studies (Hollman et al., 2007; Laessoe et al., 2008) and supports the suggestion that manual analyses of video-recorded data could be used to measure gait parameters.

In addition to testing the validity of video recording for gait analysis, the Pilot Study provided a means of identifying potential problems with the design and methodology of the main study. Firstly, the raw data revealed that each participant took one or two steps to settle into the walk as the step-time variability of their gait was larger at the beginning of each walk. Therefore, it was decided to allow participants to take two to three steps to steady their gait, before starting the data collection in the main study. Secondly, a separate recording device should also be employed to record participants' responses to take account of decreases in volume as participants walked away from the camera. Thirdly, since one of the participants started the backwards task counting in their head rather than out loud, all participants should be instructed, in future, to give their responses to the counting task out loud. Fourthly, one participant actually stopped walking, momentarily, during the dual-task, raising the question of how to deal with this occurrence. It was decided to record all instances of people stopping to determine what they contribute to furthering understanding of the underlying physical and cognitive processes at work. Lastly, the 'Bigfoot' device (see 3.2 below) records the time of each step, even if a participant has stopped walking. Therefore, stopping in the middle of a trial should be recorded as the gait time of that particular step, no matter how long the pause is. The video recording, as an additional asset, would provide a means to verify at which point of the cognitive task the participant stopped walking.

3.1.5 Summary

A comparison was made between the data collected by video recorder and by manual analysis of timing by stop-clock. The results suggested that the video camera is a valid measure with which to collect data during a gait and cognition dual-task study. However it is costly in terms of time required to conduct the manual analysis of gait and cognitive responses. There is also potential for human error. It was therefore decided to assess the video recording method as a potential 'back-up' measure for the 'Bigfoot' system, which was developed specifically for this research project.

3.2 'Bigfoot' pilot study

3.2.1 Introduction

Although gait speed has been successfully timed with a stop watch (Beauchet et al., 2008), the inherent 'variability' of people's individual step-times is recognised as a more sensitive gait measure for DT gait and cognitive research (Montero-Odasso et al, 2012). In order to measure both speed and step-time variability a reliable mechanical system that could automatically measure individuals' mean step-time was required. Using previously published research (Bilney et al., 2003) a design brief was produced for 'Bigfoot', a simple piece of equipment that could be attached to the shoe. This was produced in the technical workshop of the School of Psychology and Neuroscience, University of St. Andrews. This comprised two footswitches that would collect gait data as the participants walked up and down a designated walkway. A second pilot study was conducted to validate the Bigfoot footswitches as the principal gait performance measure in future research and to assess whether gait measures using video-recording could be used as a back-up system to Bigfoot, in case of mechanical failure.

Aim

To validate the 'Bigfoot' gait analysis system, as method of recording and analysing gait time, speed and step-time variability, against the manual analysis of data from video-recordings of the same experiment.

3.2.2 Methods

Participants

An opportunistic sample of six older adults (all female), with a mean age of 75 years (range 66 - 91 years) was recruited. Since the walkway used in the previous pilot study was unavailable, another, undisturbed, flat corridor was identified, already set up for a 15m walk with one metre at either end for acceleration and deceleration. Therefore, the walks described in this pilot study were performed over 15m (35 feet).

Equipment

The technical workshop produced two ultrasound footswitches that measured the step-time taken between each foot stride. The system (Bigfoot; see Appendix A) comprised a laptop computer with associated software, 2 footswitches (attached to the participants' heels) and 2 wires from the footswitches leading to an interface box, clipped to the participants' waistband or belt. The wearable step detector generated ultra-sound pulses when the participants took a step, which were detected by an ultra-sound microphone connected to the interface box. The box translated the pulses to 'sounds' which could be detected by the computer's microphone. The software was designed to work with Microsoft Windows, XP, Vista and Windows 7. Each trial was started and terminated by pressing the space bar on the laptop. The 'Bigfoot' system measured, analysed and recorded the results of each individual's separate walks and gave an automatic read-out of the results in terms of the date/time of the trial, the participant's ID, gender and the distance to be walked. The walk measures recorded were participants' gait performance (each separate step-time in milliseconds) expressed as Time Delta (TD), the mean (M) of TD, the standard deviation (SD) of MTD, the coefficient of variation (CV) of MTD (calculated as SD divided by M), the velocity of each walk in seconds and the overall time of each walk in milliseconds. From the recorded data, it was also possible to count the number of steps taken in each 15m walk.

A Sony Cybershot 7.2 video camera, an Olympus Digital Voice Recorder (WS-450S) and Nokia 7210 stop watch were also used to measure participants' gait and cognitive responses. Since the 'Bigfoot' footswitches emit a 'click' on every heel-strike, it was possible to manually record the time of each 'click' and to manually calculate the same measures as the automatic 'Bigfoot' system.

Procedure

The participants each walked along a 15m flat corridor, wearing flat comfortable shoes, at their preferred pace. The mean gait time, speed and step-time were recorded and gait measures, such as gait velocity, step-time variability (CV) and number of steps were calculated using 'Bigfoot', video camera and the digital voice recorder. Participants were also video recorded and timed using a stop watch.

Statistical Analysis

The 'Bigfoot' and video-recorded step-time variability was quantified as the coefficient of variation (CV) as determined by the equation:

CV = (SD/M)

where SD is the standard deviation and M is mean of the individual step-times taken in one 15m walk at the participants' preferred pace. In addition to gait step-time variability of each participant in each trial, overall gait speed was also recorded, to the nearest hundredth of a second, from the video-recordings by the researcher using a stopwatch on lap-timing. The time of each walk was also recorded by the video camera.

Variability in gait measures is, by its very nature, 'variable'. That is, individual steps vary from one to the other and from person to person and it is likely that the results of mean step-times will not be normally distributed. This was the case with these data and, therefore, the means of CV from the 'Bigfoot' system and the video-recordings were compared using non-parametric statistical analysis (Wilcoxon Signed Rank Test). The mean gait speeds were normally distributed and were compared using a paired sample *t*-test. The confidence intervals were 95% with a *p* value of .05 considered to be statistically significant. All statistical analyses were carried out using PASW, version 17.0.

3.2.3 Results

A paired-sample *t*-test revealed that there was no difference between the time taken to walk 15m with the 'Bigfoot' system (M = 13.59) and the video-recording (M = 14.90) t(5)=-0.186, *p* = .743, *r* = .256 and between the walking speed recorded by the 'Bigfoot' system (M=1.13) and the video-recording (M = 1.09) t(5) = - 0.757, *p* = .483, *r* = -.321. Similarly, there was no difference between the Bigfoot system (Mdn = 0.069) and the manual analysis from video-recording (Mdn = 0.070) for step-time variability (CV), T = 9, *p* = .753, *r* = -.091 (Table 3.2).

Table 3.2
Time taken to walk 15m at preferred pace

P ID	'Bigfoot' Time	Video Time	'Bigfoot' Speed	Video Speed	'Bigfoot' Step-time*	Video Step-time*	'Bigfoot' CV	Video CV
1	16.297	16.300	0.920	0.920	0.615 (± .045)	0.618 (±0.051)	0.073	0.189
2	10.45	18.80	1.431	1.138	0.475 (±.031)	0.483 (±0.030)	0.065	0.148
3	13.47	13.26	1.114	1.131	0.531 (±.011)	0.055 (±0.031)	0.204	0.163
4	14.81	15.05	1.013	0.997	0.052 (±.027)	0.518 (±0.041)	0.052	0.110
5	11.25	10.80	1.333	1.389	0.488 (±.011)	0.494 (±0.036)	0.374	0.025
6	15.26	15.24	0.983	0.984	0.568 (±.022)	0.567 (±0.038)	0.039	0.114
*Means	13.59	14.90	1.13	1.09	0.455	0.456	0.135	0.162

*Values are means (± SD), other values are actual times and speeds
P ID – Participant Identification

3.2.4 Summary

This second pilot study demonstrated that the Bigfoot gait analysis system could be used for recording and analysing gait. Additionally, as there was no difference between the video-recording and the stop-clock timings in the previous pilot study, it was decided that video recordings of participants' performances could be used as a 'back-up' system to the 'Bigfoot'. Since some of the verbal responses were 'lost' as the participants walked away from the video-recorded, it was decided that a separate voice-recorder should also be used in future experiments. These methods were used in the studies described in the following chapters.

Chapter 4: Investigating executive attention using the DT paradigm: Experiment 1 (T1)

4.1 Introduction

Ageing is a process where the end result is obvious but the mechanism remains obstinately obscure (Kirkwood, 1988). Chapter 2 outlined the ways in which aspects of mental ability generally deteriorate with increasing age, although the course of such change is not uniform. It is possible to identify older adults who are ageing 'successfully' with respect to cognition, in relation to their peers and those who are not. This is the result of interplay between genetics and environment, including education, occupation and psychosocial health, some of which are modifiable (Deary, 2009). With an ageing population, prolonging cognitive vitality into later life is increasingly important. While cross-sectional studies are a popular approach to assessing cognition, longitudinal data provide the opportunity to look for subtle changes over time in the same individuals (Deary, 2009; Stuart-Hamilton, 2012).

4.1.1 Longitudinal studies

Studying participants over a period of time permits exploration of the mechanisms underlying any changes (improvement or decline) or lack of change (maintenance) in their performance. It also allows for investigation of differences between aspects of behaviour, to see if some change whilst others remain constant. While looking at a combination of behaviours is more complex in an experimental setting, it is also more reflective of the way we operate in the real world. A longitudinal design has many advantages for researchers; assessments can be repeated after a specified interval to gain information about the rate and extent of any changes (improvement or deterioration) and to examine the relative rate of change between abilities, functions and performances (Lezak, 1995).

There are, however, also several disadvantages to conducting longitudinal research, particularly with older adults. It does, by its very nature, take time and, there may be higher attrition among older adults due to illness, death, or loss of interest. Attrition rates between 26% and 92% have been reported in ageing studies (Salthouse, 2010), although the latter figure suggests there may have been an issue with the design in that particular study that made continued participation unappealing. For these reasons an 'attrition' rate of 7 participants was allocated to the initial requirement of 65 (based on the power calculation). From the initial set of 72 participants, four did not wish to continue the study at T2 giving an attrition rate of 5.5%. One reason the attrition rate is low may be due to the selection of baseline cognitive and physical tests, which were selected to discourage the participants from thinking of the research as a ‘competition’ with ‘pass’ or ‘fail’ results. In addition, tests with an obvious pattern of ‘decline’ were avoided. The overall experiment had to be difficult enough to stretch the physical and cognitive abilities of the participants but not put them off returning for a second time.

In longitudinal research there is also the potential problem of ‘practice effect’, which would result in participants improving over time, due to remembering the tests and how to perform well on them, and mask the rate of decline. This is addressed by selecting tests that have parallel versions. However, it is also possible that on second or subsequent visits, participants are more relaxed with the research and the researcher, know what is required of them and are more motivated to respond positively (Stuart-Hamilton, 2012), which could lead to improved performance.

This present longitudinal study investigated if ability to flexibly allocate attention in a gait and cognition dual task is a marker for healthy ageing. The important outcomes were the changes over one year in the participants’ ability to manipulate their attention efficiently as required in a range of changing situations. The method of assessing how well healthy older adults were maintaining their ability to flexibly allocate attention was to measure change in both gait and cognitive performance separately and together. The dual-task paradigm was used to observe the underlying mechanisms whereby attention is divided when concurrent tasks compete for it. When no instruction to prioritise walking or counting were given (NP) it was assumed that participants would allocate attention to the two tasks in the DT in the most expedient way. By comparing this condition with the conditions when explicit instructions were given to either prioritise walking (PW) or counting (PC), it was possible to observe where participants’ attention was directed as the cognitive load was varied (that is either counting backwards in 3s or 7s). Changes in performance in the different walking and counting conditions, over time, were examined in relation to baseline measures of cognition and background characteristics to look for markers of predictors of healthy ageing.

This longitudinal study was carried out over 12 months. This chapter describes the first phase (at T1) and Chapter 5 contains comparison with the data collected at T2.

4.2 Methods

4.2.1 Participants

Seventy-two physically and cognitively healthy adults (43 women and 29 men) mean age [SD] = 72.8 [5.7] were recruited from the local community by means of leaflets, posters, talks and media advertisements. The inclusion criteria were: healthy adults aged over 65 years old, living independently, able to walk unassisted and with English as their first language. Participants were excluded if, after adjusting for age and education, they scored less than 27 in the Mini-Mental State Examination (MMSE) and/or they had chronic physical or mental illness which might adversely affect their gait or cognitive function. All participants were given details of the study prior to participation, and had the opportunity to raise any questions about the study before providing signed consent to take part (Appendix B). A G-power analysis, with a small effect size, was carried out, for all proposed quantitative approaches and the highest number of participants (65) at a power of 9 was selected (Figure 4.1). An attrition rate was built into the recruitment process, with 72 finally taking part.

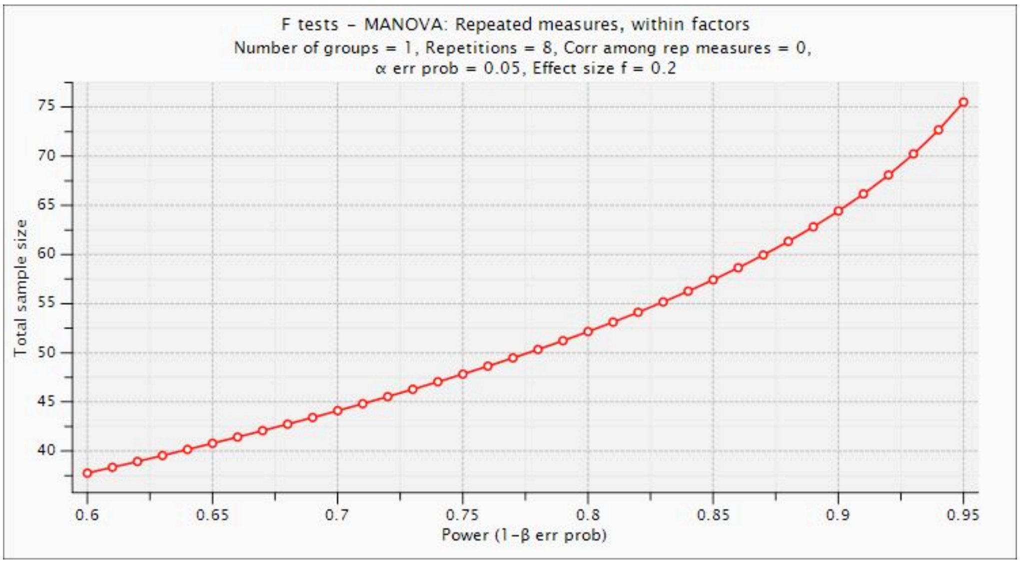

Figure 4.1. Plot of G-Power Analysis for Proposed Research Project

4.2.2. Ethics

The Study was approved by the University of St Andrews Teaching and Research Ethics Committee (UTREC). All participants received a Participation Information Sheet prior to participation (T1), and had the opportunity to raise any questions about the study before providing signed consent to take part.

4.2.3 Design

This study is T1 of a longitudinal study using a within participants 2 x 2 x 3 factorial design. The independent variables were:

1. Task type (single and dual)
2. Cognitive Load (Serial 3s and Serial 7s)
3. Explicit Prioritisation of Attention (no prioritisation, prioritising walking and prioritising counting)

The dependent variables were:

1. Gait: step-time variability, expressed as Coefficient of Variation (CV), velocity and number of steps taken to walk 15m.
2. Cognition: correct cognitive responses per second (CCR) and number of steps taken per cognitive response (SCR).

The dependent variable outcomes were recorded under 10 conditions as shown in Table 4.1.

Table 4.1
Experimental conditions

SINGLE TASK	DUAL-TASK	OUTCOME
Walking 15m at normal pace		CV, velocity
Walking 15m at brisk pace		CV, velocity
Serial 3s	Walking 15m at own pace + (Serial 3s) with no prioritisation (NP)	CV, velocity, number of CCR and SCR
	Walking 15m at own pace + (Serial 3s) prioritising walking (PW)	CV, velocity, number of CCR and SCR
	Walking 15m at own pace + (Serial 3s) prioritising counting (PC)	CV, velocity, number of CCR and SCR
Serial 7s	Walking 15m at own pace + (Serial 7s with no prioritisation (NP)	CV, velocity, number of CCR and SCR
	Walking 15m at own pace + (Serial 7s) – prioritising walking (PW)	CV, velocity, number of CCR and SCR
	Walking 15m at own pace + (Serial 7s) – prioritising counting (PC)	CV, velocity, number of CCR and SCR

4.2.4 Materials

Gait was recorded and analysed using the ‘Bigfoot’ footswitch system developed at the University of St Andrews (see Chapter 3 and Figure 4.2). A 15 metre course was marked along a corridor with a white tape at the start and end of the course. One metre was added to the start and end of the course for acceleration and deceleration. All of the gait conditions were video-recorded by the researcher. If necessary, the video data was later analysed manually and used as a back-up for missing Bigfoot data, or to verify data collected electronically. (See pilot study in Chapter 3 for details).

Figure 4.2. 'Bigfoot' gait analysis system

4.2.5 Baseline measures

The following data were collected using a questionnaire (Appendix C) and measurement at the first appointment:

- Age
- Level of education (total years in education)
- Number of IADL functions (ability to shop for food and clothes, manage finances, prepare meals, travel on public transport) carried out weekly
- BMI (Body Mass Index from height and weight)
- Weekly exercise, including walking regime
- Weekly cognitive activity
- Alcohol levels (number of units per week)
- Smoking status (current, in the past, never)
- Number of falls in the previous year
- Existing chronic medical conditions
- Number of medications taken regularly
- Hospitalisation in the previous year

- Visual impairment (need to wear spectacles for reading)
- Hearing impairment
- Satisfaction with health status

Cognitive Tests

Participants also performed a baseline battery of standardised tests to assess their global cognition and estimated pre-morbid IQ, as well as separate baseline cognitive tests to assess a variety of cognitive functions (see Table 4.2).

<u>Mini Mental State Examination</u> (MMSE: Folstein et al., 1975)

The MMSE was used to obtain a measure of global cognition. The test was developed to quantify the cognitive abilities of older adults with dementia and/or delirium (Hodges, 2000) and is now used as a screening measure of gross cognitive impairment. It assesses orientation, attention, memory, visuo-spatial ability and language and is quick and easy to administer, with a high rate of inter-rater reliability. A score of 27 or above is considered cognitively 'normal', although this can be adjusted for age and education levels (Folstein et al, 1975).

Immediate and Delayed Story Recall (Wechsler, 1987)

Immediate and delayed story recall provides a measure of short- and long-term memory in the form of a story with 25 different memory items. Participants are read a story and immediately asked to recall as much as they can. Twenty minutes later (after completing other cognitive tests) they are asked to recall the story without any prompting. The story recall score for this study is the percentage of items correctly remembered in the delay stage as a percentage of the immediate recall stage.

<u>National Adult Reading Test</u> (NART; Nelson & O'Connell, 1982),

Although age can detrimentally affect many skills, an individual's intelligence level remains constant in relation to his/her age group (Grant & Adams, 1996). Because reading vocabulary is IQ-related, the NART can provide an estimate of pre-morbid IQ. Participants read out 50 words in English, which became increasingly uncommon. The number of correctly pronounced words is used to calculate an estimated IQ score.

Executive Function tests

<u>Trail Making Test</u> (TMT; Reitan & Wolfson, 1993)

TMT involves motor-speed and attention-processing functions in 2 visual scanning and visuo-motor tracking tasks (A and B) both of which are sensitive to pathological progressive cognitive decline (Lezak, 1995). The tests reflect a wide variety of cognitive processes including attention, visual search and scanning, sequencing and shifting, psychomotor speed, abstraction, flexibility, ability to execute and modify a plan of action and ability to maintain two trains of thought simultaneously (Salthouse, 2011). Participants have to join 25 circles in the fastest possible time, without lifting the pen from the paper. In TMT- A, the circles are numbered 1-25 and must be connected in ascending order, whereas in TMT- B, the 25 circles contain numbers and letters which must be connected alternately from 1-A, 2-B to 13. TMT-B has been found to involve processing speed and fluid cognitive ability (Salthouse 2011) and to predict quality of life (Grant & Adams, 1996).

Digit span Forwards (DS/F; Wechsler, 1987)

DS/F is a measure of verbal working memory capacity and involves auditory attention and rehearsal. Participants are asked to repeat different strings of numbers (starting at 2 digits long), delivered at one-second intervals by the researcher, which become progressively longer. The test requires only the capacity to briefly hold several bits of information in short-term memory (Grant & Adams, 1996).

Digit span Backwards (DS/B; Wechsler, 1987)

DS/B is the same task except that the sets of numbers are repeated backwards. The memory span is calculated based on the longest string of digits successfully repeated. This test makes far greater demands on working memory, requires some cognitive processing of the information and is more sensitive to brain dysfunction than DS/F, although the combined DS/F and DS/B test predicted AD 7 or more years in advance of the clinical onset of the disease (Grant & Adams, 1996).

Symbol Digit Modalities Test (SDMT; Smith, 1982)

SDMT assesses complex scanning, visual tracking and perceptual/ processing speed. Participants are presented with a key containing digits from 1-9, each of which is matched with a symbol. The task is to put the relevant symbol into rows of empty boxes underneath rows of digits as rapidly as possible. The score is the correct responses given within 90 seconds. The test reflects fluid cognitive ability (a novel or abstract problem solving capability) and has been found to be a significant predictor of the subsequent development of dementia (Grant & Admas, 1996).

Cognitive Estimate Test (CET; Shallice & Evan, 1978)

Distinguishing reasoning ability between healthy older adults and patients with frontal lobe impairment requires tests which demand relatively novel strategies. The CET assesses problem-solving ability involving deduction and judgement and sometimes even a single answer can give a definite diagnosis of frontal-lobe (executive) dysfunction (Grant & Adams, 1996). In this current study, participants were asked 5 questions which they could not answer from general knowledge (such as ‘how many camels are there in Holland?’). Their answers were scored from 0 – 3 for ‘bizarreness’. A score of 0 was considered to be within given normative data and a score of 3 was given for the most ‘bizarre’ answer. Therefore, if a participant answered ‘no camels’ this would score 1 and if they answered 1000 camels they would score 3, but if they answered 10 camels, they would score 0 as this was thought to take into consideration the possibility that there was more than one camel located in Dutch zoos or animal parks.

Table 4.2
Cognitive test battery

Test	Cognitive function	Scoring
Mini Mental-State Examination (MMSE; Folstein et al., 1975)	Global cognitive function	30-point scale – scores between 27-30 are considered as cognitively unimpaired
Immediate Story Recall and Delayed Story Recall (Wechsler, 1987)	Logical memory	IR = correctly recalled out of 25 items DRPIR = % of IR correctly recalled after 20 minutes
National Adult Reading Test (NART; Nelson, 1982)	Estimated pre-morbid intelligence	Number of errors (out of 50) converted to IQ score
Trail Making Test A and B (TMT A and TMT B: AITB, 1944; Reitan, 1993,)	Visual attention and task-switching	Speed in seconds to complete TMT B and TMT A (Delta TMT = B minus A)
Digit Span Forwards (DS/F) and Backwards (DS/B; Thorndike et al., 1987)	Verbal working memory capacity (DS/F) and cognitive processing (DS/B)	Number of full strings of digits remembered without error
Symbol Digit Modalities Test (SDMT; Smith, 1982)	Perceptual/processing speed and fluid cognitive ability	Number of correct responses in 90 seconds
Cognitive Estimate Test (Shallice & Evans, 1978)	Executive Function (frontal lobe function/judgement)	0 – 3 for bizarre answers, 0 = within norms

4.2.6 Other baseline measures

Beck Depression Inventory-II (BDI; Beck, Steer & Brown, 1996)

The BDI-II is a self-report test used to screen for depression. The BDI-II contains 21 statements, and participants endorse one of four responses in relation to how they have felt over the past two weeks. For example: *Sadness*: 0 – I do not feel sad; 1 – I feel sad much of the time; 2 – I am sad all the time; 3 – I am so sad or unhappy that I can't stand it. The cutoffs are: 0–13: minimal evidence of depression; 14–19: mild depression; 20–28: moderate depression; and 29–63: severe depression.

Mobility measures

Three baseline mobility tests were completed: 1. number of stand-ups from a sitting position, without the use of assistance, within 30 seconds; 2. balancing on one leg (participant's choice) for up to 30 seconds; 3. time taken to walk toe-to-heel along a 15m indoor, straight track, without assistance. These three tests were chosen from previous literature to give 3 separate indications of specific mobility function, flexibility, balance and centre of gravity control (Berg K, Wood-Dauphinee, Williams & Maki, 1992; Inzitari et al., 2006).

4.3 Procedure

4.3.1 Gait and cognitive STs and DTs

Prior to the start of each condition, the footswitches were attached to the participant's heels. The participants were allowed to practise walking with the footswitches on before the experiment commenced. This procedure allowed them to get used to wearing the footswitches and allowed the researcher to ensure that the footswitches were recording.

The order of conditions was randomized by the Bigfoot computer program. The researcher started each trial with the words 'ready, steady – go'. All of the gait measures recorded (mean delta step-times, time to walk 15m, number of steps taken) were included in the calculation of CV, velocity correct cognitive responses and number of steps per correct cognitive response, and are reported as separate measures.

Participants were asked to perform 3 single tasks (ST): 2 cognitive tasks lasting one minute each (counting backward in 3s and 7s), whilst they were seated, and 1 walking (15m walk at their own pace). No practice time was given for these conditions, since the participants had already practised Serial 7s in the MMSE and, since the ST was counter-balanced, half of them would have also performed them several times in the DT. A 'brisk pace' 15m walk was included as ST requiring conscious 'mental effort'. Walking at brisk pace was only assessed at baseline, to determine any difference in attentional demands on gait performance between own and brisk pace walking, as a means of assessing the existence of 'mental effort' between simple walking and walking with intent but no secondary cognitive task.

Participants completed 6 gait and cognitive dual-tasks (DT); walking and counting backwards in 3s with no prioritisation (DT3sNP), prioritising walking (DT3sPW) and prioritising counting (DT3sPC). They were also required to do the same for Serial 7s (DT7sNP, DT7sPW, and DT7sPC). The start number for each DT trial was randomly chosen using 3 digits from 102 – 298 and was different for each trial (for example, 249, 165, 237, 186, 204 and 138) and for each visit (T1 and T2). The same number was used for each participant in each condition, e.g. '204' was always the starting number for DT7sPW. The researcher started the dual-task condition with, for example, 'Ready, steady - 199'. There were no specific instructions given to the participants regarding stopping walking or making mistakes in the cognitive task. All of the walking conditions were randomised. The following data were recorded: overall time of walk, total responses, total errors and total correct responses. The cognitive responses were counted and scored as total verbal responses as a proportion of time taken to complete each particular walking condition and then in relation to the correct total number of responses, thus giving the number of correct verbal responses per second (correct cognitive response; CCR). In the case of the single counting tasks (ST), the number of correct verbal responses (CCR) was scored as the correct number of responses in relation to the walking time in the NP walking condition. If a participant had made a mistake in their subtraction, this was scored as an error and subsequent responses were scored in relation to the 'error'. This ensured that the participant was only penalised once per mistake. In the case of the DT, each DT performance was adjusted to reflect the individual's level of ability as performed in that particular walking condition. In addition, the total number of steps taken in each walk was calculated in relation to the total number of cognitive responses uttered during the walk (steps per cognitive response; SCR) to give a measure of 'pace' of response.

By comparing the DT and ST performance measures - step-time variability, walking velocity, number of correct responses - to the counting task and number of steps taken per cognitive response, the dual-task deficit (DTD) or 'cost' or 'benefit' (DTB) of simultaneously walking and counting was found.

4.3.2 Statistical analyses

Descriptive statistics were used to assess the normality and homogeneity of the data. Since the descriptive analyses of the gait (CV) outcomes showed that the data were non-parametric, these data were transformed, using a Log_{10} transformation equation and then treated as parametric data. A one-way, repeated measures ANOVA was used to assess any effects within the participants across the experimental conditions. Where main effects were found, *post-hoc* analyses were performed using paired *t*-tests, to examine changes within conditions. Pearson's correlations were used to look for relationships between variables. Principle Component Analysis was used to examine variables that clustered on the same general component and Regression Analyses to investigate possible predictors or markers of future behaviour. Where appropriate, Mauchley's test of sphericity and the Bonferroni adjustment for multiple comparisons were used. Based on the estimated marginal means, all mean differences detected were significant at the .05 level. Two-tailed Pearson's correlation co-efficients were used to assess the significance of relationships between independent and dependent variables.

All data were analysed using the PASW version 18. 0 for Windows (2010) software package. Effect size (partial-eta square, η_p^2) and power (β) values for ANOVAs were calculated by SPSS, effect size (*r)* was calculated manually and power for *t*-tests were calculated with G*Power Version 3.0.8.

4.3.3 Attention-allocation index (AAI)

In order to evaluate how flexibly older adults can allocate attention, Yogev-Seligmann and colleagues (2012a) devised an attention-allocation index (AAI) calculated by the following equation: PW minus PC divided by NP. Values of the AAI can range between 1.0 to -1.0, where 0.0 represents a complete inability to shift attention to either the walking or the cognitive task and ± 1 represents a total ability to flexibly allocate attention to either gait or the cognitive task. Yogev-Seligmann and colleagues (2012a) suggested that this index represents the ability to change attention from one task to another, during a DT. So that the participants' flexibility in allocating attention between the prioritisation conditions could be compared between the two cognitive loads, AAIs were produced for each DT performance outcome at the end of the T1 experiment.

4.4 Results

In order to assess whether the group of participants was a representative cohort of physically healthy community-dwelling older adults, their background characteristics were reported as a percentage of total number of participants, where this was more appropriate. Participants' self-reported health, mood and lifestyle characteristics at T1 are summarized at Table 4.3. Eighty-six percent of the participants were satisfied with their health status; 62.5% took fewer than 3 medications and 88.9% had stayed overnight in hospital less than once in the previous twelve months. Although 53.5% of participants were overweight or obese, this was comparable with the national average (NHS Lifestyle Statistics, 2012). In contrast, 95.9% reported that they walked for exercise at least three times per week, 97.3% did not smoke, 66.7% reported a low level of alcohol intake (less than 7 units of alcohol per week) and 93.1% had experienced one or no falls in the previous year. Ninety-seven percent reported taking part in cognitive activities more than 3 times a week and 73.6% undertook some form of physical activity more than 3 times a week (Table 4.3). The group mean total years of education (15.32 years) was above the average number (13 years) spent in high school education (Spreen & Strauss, 1998) and the group Pre-morbid IQ of 116 (as estimated using the NART – Table 4.3) was also above average (Lezak, 1995). Taken together, these results indicate that the 72 participants were a physically healthy group of independently-living older adults.

Table 4.3
Demographic and health characteristics

Variable	Mean	SD	Range	%	Comments
Gender (M/F)				40/60	29 Males, 43 Females
n = 72					
Age	72.75	±5.71	65-91		
Total years of Education	15.32	±3.77	3-22		
Estimated Premorbid IQ	116	±9.08	86-29		
Body Mass Index	26.35	±4.57	18.4-42	53.5	Overweight or obese = BMI > 25
5/6 IADLs carried out on a weekly basis				90.3	Shopping for food, preparing meal, taking public transport, managing finances, planning a trip, using IT.
Regular exercise – 3 or more times per week				73.6	Walking, golf, yoga, dancing, gardening, housework, swimming, riding, Pilates, tai-chi, DIY, aerobics, cycling, dancing, tennis, badminton, table-tennis, skiing
Walking regularly (more than 3 times per week)				95.9	
Cognitive activities – 3 or more times per week				97.3	Cross-words, Sudoku, card-games, reading, scrabble, bridge, learning musical instrument, writing, planning, committees, computer, tapestry, puzzles, quizzes, genealogy, dressmaking, cooking, U3A, finances
More than 7 units per week of alcohol				33.3	
Current smokers				2.7	

More than 1 fall in last year	6.9
Taking 3 or more medications	37.5
At least one night in hospital in last year	11.1
Using spectacles	100
Using hearing aid	20.8
Satisfied with own health	86

In order to confirm if the group was also cognitively healthy, a series of standardised tests for cognition were administered (Table 4.4). The oldest participant (aged 91 years) scored 24/30 in the MMSE, but, after adjusting for age and education, this was considered within the test norms (Crum, 1993). All other participants scored 27 or more out of 30. Their EF, as measured by specific executive functioning tests and their pre-morbid IQs suggested they were an above average sample (Table 4.4). None was suffering from depression as measured by the BDI-II. For the purposes of the experiment, all participants were assumed to be cognitively and physically healthy older adults.

Table 4.4
*Participant standardised test results**

Variable	(*n* = 72)	Range	Within Norms?
MMSE (global cognition)	28.4 ± (1.33)	24 - 30	Yes**
BDI-II score	5.19 ± (4.35)	0 - 17	Yes
Symbol Digit Modalities score (right)	43.9 ± (9.95)	16 - 66	Yes
TMT – A (seconds)	32.00 ± (9.28)	20.57 – 67.23	Yes
TMT – B (seconds)	69.84 ± (28.10)	28.73 - 162	Yes
Delta TMT (B - A in seconds)	38.94 ± (24.29)	9.90 – 132.64	N/A
Digit Span Forwards	6.56 ±(1.14)	5 - 8	Yes
Digit Span Backwards	5.23 ± (1.05)	3 - 7	Yes
Story Recall – Immediate (score)	11.14 ±(3.94)	2.5 – 18.5	Yes
Story Recall – Delayed (as % of Immediate Recall)	84.41 ± (24.57)	14.3 - 180	Yes
Cognitive Estimation Test	2.46 ± (2.28)	0 - 9	Yes
Mobility 1 SUSD (number of completed stand-up/sit-downs)	11.24 ± (2.45)	7 – 19.5	N/A
Mobility 2 Balance (seconds)	16.4 ± (11.07)	0.5 - 30	N/A
Mobility 3 Tandem Walk (82% completed test)	57.48 ± (24.46)	27.26 - 120	N/A

*Values denote mean ± SD
** Scores adjusted for age and education

4.4.1 Main effects between Serial 3s and Serial 7s tasks

To investigate the effect of task difficulty on how well participants concurrently walked and counted, their performance counting backwards in 3s and 7s was compared (Table 4.5). The participants' gait was significantly more unsteady ($p < .05$), they walked more slowly ($p < .05$), gave fewer correct verbal responses ($p < .001$) and took more steps per verbal response ($p < .001$) when counting backwards, subtracting 7s than they did when they counted back in 3s. These results revealed that Serial 7s demanded more attention than Serial 3s, suggesting that Serial 7s might be a more sensitive measure of resource capacity under dual-task conditions. In one condition – prioritising walking - there was no difference between counting back in 3s and 7s in step-time variability ($p > .05$; Table 4.5 and Figure 4.3). That is when their attention was prioritised on walking, the participants walked just as steadily whether they counted backwards in 3s or 7s.

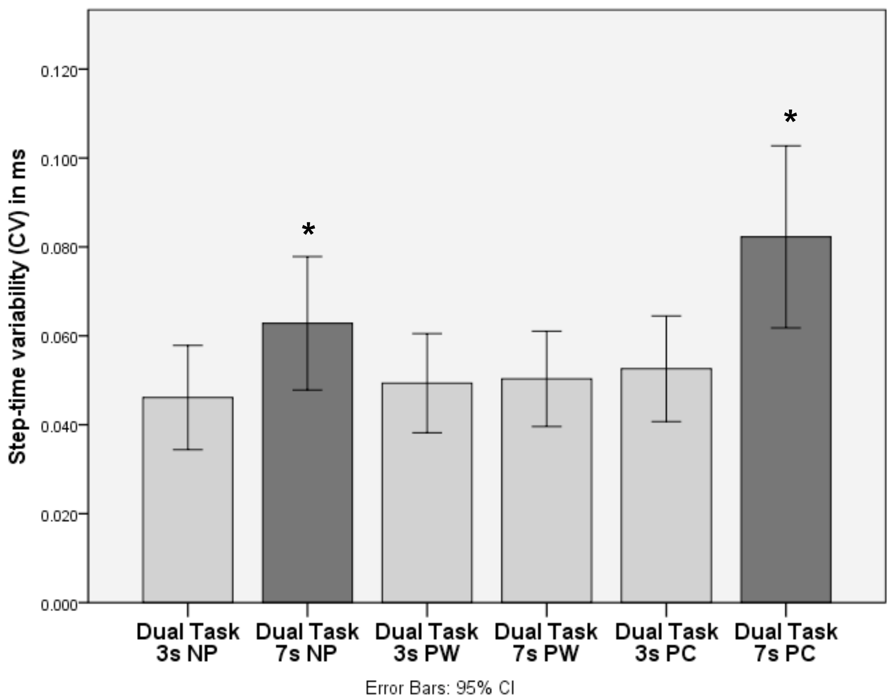

Figure 4.3. Significant differences between mean step-time variability (CV) in the DT conditions (NP, PW and PC) of the Serial 3s and Serial 7s tasks
**Post-hoc* tests are significant at the $p < .001$ level

Table 4.5
Significant differences between Serial 3s and Serial 7s performance outcomes

Performance Outcome	**Dual-task Condition**	**Mean ± SD Serial 3s**	**Mean ± SD Serial 7s**	***t***	**df**	***p < .05 **p < .001**	***r***
Step-time variability (CV)	DTNP	0.046 ± (0.048)	0.062 ± (0.063)	-3.24	70	*	-.38
	DTPW	0.046 ± (0.048)	0.051 ± (0.049)	-.359	70	ns	-.04
	DTPC	0.052 ± (0.049)	0.085 ± (0.88)	-3.357	71	*	-.37
Velocity	DTNP	1.02 ± (0.25)	0.971 ± (0.31)	2.582	68	*	.29
	DTPW	1.07 ± (0.26)	1.09 ± (0.29)	2.273	69	*	.26
	DTPC	0.99 ± (0.28)	0.897 ± (0.28)	3.398	69	*	.38
Correct Cognitive Responses (CCR)	ST	0.445 ± (.175)	0.293 ± (.149)	9.703	70	**	.76
	DTNP	0.503 ± (.182)	0.295 ± (.157)	14.085	70	**	.86
	DTPW	0.470 ± (.151)	0.334 # ± (.153)	7.875	68	**	.69

	DTPC	0.535 ± (.179)	0.270 ± (.166)	12.913	71	**	.97
Performance Outcome	**Dual-task Condition**	**Mean ± SD Serial 3s**	**Mean ± SD Serial 7s**	***t***	**df**	***p < .05 **p < .001**	***r***
Steps/ cognitive response (SCR)	DTNP	3.53 ± (2.85)	5.62 ± (3.74)	-4.613	70	**	-.52
	DTPW	3.56 ± (1.56)	4.60 ± (1.92)	-5.393	68	**	-.55
	DTPC	3.09 ± (1.22)	6.75 ± (6.13)	-5.828	71	**	.57

ST – Single task
DTNP – Dual task (no prioritisation)
DTPW – Dual-task (prioritising walking)
DTPC – Dual-task (prioritising counting)

4.4.2 *Main effects of prioritisation and interactions*

To assess the main effects on load and prioritisation, repeated-measures ANOVAs were performed. There was a significant main effect of attention prioritisation (NP, PW or PC) on step-time variability (p < .001), velocity, (p < .001), CCRs (p < .05) and SCRs (p < .05) (Table 4.6). These effects were then analysed further by *post hoc* t-tests (see Tables 4.8 and 4.9). To determine if the participants' performances differed not only with different cognitive loads, but also by where they were instructed to prioritise their attention, interactions between load and prioritisation were explored. There was a significant interaction between cognitive load and prioritisation direction for step-time variability (p < .05), velocity (p < .05), CCRs (p < .001) and SCRs (p < .001) indicating that the difficulty of the cognitive task affected the efficient prioritisation of attention on gait (Table 4.6).

Table 4.6
Effects of cognitive load and prioritisation on gait and cognition measures during dual-task conditions (NP, PW, PC)

Variable		F - Value	Significance	Effect Size η_p^2	Interaction	Significance *p<.05 level **p < .001 level	Effect Size η_p^2
Gait CV (ms)	CL	F(1, 69) = 20.12	**	.226	F(3,207) = 5.41	*	.073
	PA	F(3,207) = 13.32	* *	.162			
Gait Velocity (seconds)	CL	F(1,66) = 23.56	**	.263	F(3,198) = 4.15	*	.059
	PA	F(3,198) = 4.58	**	.387			
CCR	CL	F (1,67) = 406.73	**	.859	F(3, 201) = 75.9	**	.531
	PA	F(3,201) = 2.675	*	.038			
SCR	CL	F(1.67) = 51.74	**	.436	F(3,201) = 13.326	**	.166
	PA	F(2,134) = 3.29	*	.047			

CL = Cognitive Load, PA = Prioritising Attention (NP, PW or PC)
CV = Difference in step-time expressed as SD/M, CCR = Correct cognitive responses in relation to walk time

4.4.3 Cognitive load, prioritisation and step-time variability

The effect of cognitive load on ST and DT step-time variability was investigated to measure the ‘mental effort’ (attention) used in each condition. There were dual-task deficits (DTDs) across both loads and all prioritising conditions (see Table 4.7). In other words, as task difficulty increased and put additional demands on the participants’ attentional resources, step-time variability also increased (gait became more unsteady), no matter where attention was prioritised (either on gait or cognition, or on neither; see Table 4.8 for specific *t*-test results).

Table 4.7.

Performance outcome measures (CV, Velocity, CCR and SCR) between ST and DT and between DT conditions (NP, PW, PC)

Condition	Cognitive Load	Step-time variability (CV)	Velocity	CCR	SCR	% Data calculated manually
Single Task Walking (Own Pace)	N/A	0.035 ± (0.030)	1.191 ± (0.24)	N/A	N/A	2.8
				N/A	N/A	
Single Task Counting (adjusted to NP time)	Serial 3s	N/A	N/A	0.445 ± (.175)	N/A	0
	Serial 7s	N/A	N/A	0.293 ± (.149)	N/A	0
Single Task Brisk Pace	N/A	0.042 ± (0.041)	**1.500##** ± (0.27)	N/A	N/A	0
				N/A	N/A	N/A
No Prioritisation	Serial 3s	**0.046 *** ± (0.048)	**1.02**** ± (0.25)	**0.503##** ± (.182)	3.53 ± (2.85)	0
	Serial 7s	**0.062 **** ± (0.063)	**0.971**** ± (0.31)	0.295 ± (.157)	5.62 ± (3.74)	1.4
Prioritising Walking	Serial 3s	**0.049*** ± (0.047)	**1.07**** ± (0.26)	0.470 ± (.151)	3.56 ± (1.56)	1.4
	Serial 7s	**0.051*** ± (0.049)	**1.09**** ± (0.29)	**0.334 #** ± (.153)	4.60 ± (1.92)	0
Prioritising Counting	Serial 3s	**0.052*** ± (0.049)	**0.99**** ± (0.28)	**0.535##** ± (.179)	3.09 ± (1.22)	0
	Serial 7s	**0.085**** ± (0.88)	**0.897**** ± (0.28)	0.270 ± (.166)	6.76 ± (6.13)	1.4

Values denote mean (Transformed) ± (SD)

ST = Single Task, **DT** = Dual Task, **DTNP** = Dual Task No Prioritisation, **DTPW** = Dual Task Prioritising Walking, **DTPC** = Dual Task Prioritising Counting

* Dual-task deficit (DTD). *Post-hoc* tests are significant at the $p < .05$ level

** Dual-task deficit (DTD). *Post-hoc* tests are significant at the $p < .001$ level

Dual-task benefit (DTB). *Post-hoc* tests are significant at the $p < .05$ level

Dual-task benefit (DTB). *Post-hoc* tests are significant at the $p < .001$ level

Table 4.8. *Significant differences in step time variability (CV) between single and dual- task performance and between dual-task conditions for Serial 3s and Serial 7s*

Measure/Conditions	**Serial 3s**				**Serial 7s**			
Step-time variability (CV)	*t*	df	**p*<.05 ***p*<.001	*r*	*t*	df	**p*<.05 ***p*<.001	*r*
ST/DTNP	-2.03	71	*	-.23	-4.37	70	**	-.46
ST/DTPW	-2.60	70	*	-.29	-3.33	71	*	-.37
ST/DTPC	-3.05	71	*	-.34	-5.53	70	**	-.55
DTPW/DTPC	-	-	-	-	-3.39	71	**	-.37

ST/DTNP – Single task and dual task, no prioritisation
ST/DTPW – Single task and dual task prioritising walking
ST/DTPC – Single task and dual task prioritising counting
DTPW/DTPC – Dual task prioritising walking and dual task prioritising counting

Compared to the ST, when the participants walked and counted backwards, their gait became significantly less steady, incrementally, as cognitive load increased (see Figure 4.4). That is, step-time variability (CV) was significantly higher (slower and more unsteady) when performing Serial 7s than Serial 3s, except when the participants counted back in 7s and prioritised walking, $t(70) = -0.359$, $p > .05$, $r = .043$. When they walked and subtracted 7s ($M = 0.051$), it had the same effect on their gait stability as when they walked and subtracted 3s ($M = 0.049$) (Table 4.7 and Figure 4.3). There were no significant differences between the ST and Brisk Pace (BP) walking condition and the BP and any other of the DT performances in either the Serial 3s or in the Serial 7s prioritisation conditions (Figure 4.4). These findings confirm that gait steadiness is not affected by increased gait speed (see Figure 4.4).

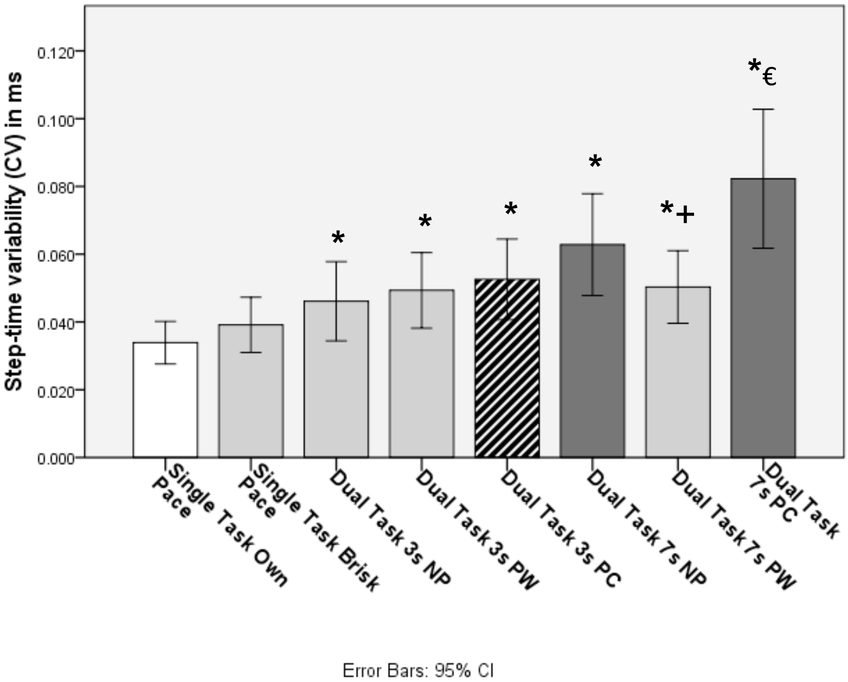

Figure 4.4. Step-time variability outcomes for all ST and DT conditions
*DTD, *Post-hoc* tests are significant at the $p < .05$ level
+ PW significantly different from PC condition, $p < .001$
€ PC significantly different from NP condition, $p < .05$

Since cognitive load appeared to have affected dual-task step-time variability in the same way in all conditions, in the Serial 3s task, prioritisation of attention was investigated for more subtle performance effects. There was no significant difference between any of the DT conditions in the Serial 3s task (that is between NP and PW and PC or between PW and PC) . In other words, participants walked just as steadily, when counting backwards in 3s, no matter where their attention was implicitly or explicitly directed.

In the more cognitively-demanding task (Serial 7s), the only significant difference between the dual-task conditions was between PW (M = 0.051) and PC (M = 0.085), $p < .001$, (Table 4.8 and Figure 4.4). Here the participants walked significantly more steadily when they prioritised walking than when they prioritised counting, which was to be expected.

4.4.4 Cognitive load, prioritisation and velocity

Participants' gait speed was analysed for evidence of dual task deficits (DTD). As expected they walked significantly more slowly (in terms of m/s) in all of the DT conditions than in the ST (M = 1.191), $p < .001$, irrespective of whether they were counting back in 3s, NP (M = 1.02), PW (M = 1.07), PC (M = 0.99) or 7s NP (M = 0.971), $p < .001$, PW (M = 1.09), $p < .001$,PC (M = 0.897), $p < .001$ (Table 4.7 and Table 4.9 for specific *t*-tests results). When instructed to walk at a self-regulated 'brisk' pace (BP) there was a significant increase in speed (M = 1.5), in relation to the ST 'own' pace (OP), (M = 1.19), $p < .05$, which was to be expected, and reflects the greater amount of 'conscious' mental effort required when participants are instructed to walk more quickly.

Table 4.9 *Significant differences in velocity between single and dual-task performance and between dual-task conditions for Serial 3s and Serial 7s*

Measure/Conditions			**Serial 3s**				**Serial 7s**	
Velocity	*t*	df	**p*< .05 ***p*<.01 ****p*<.001	*r*	*t*	df	**p* < .05 ***p*< .01	*r*
STOP/BP	-11.96	69	***	-.82	-11.96	69	***	-.82
ST/DTNP	5.45	69	***	.55	6.71	68	***	.63
ST/DTPW	6.05	68	***	.59	7.10	68	***	.65
ST/DTPC	8.56	69	***	.72	8.56	69	***	.72

ST/BP – Single task own pace and brisk pace

ST/DTNP – Single task and dual task, no prioritisation

ST/DTPW – Single task and dual task prioritising walking

ST/DTPC – Single task and dual task prioritising counting

DTPW/DTPC – Dual task prioritising walking and dual task prioritising counting

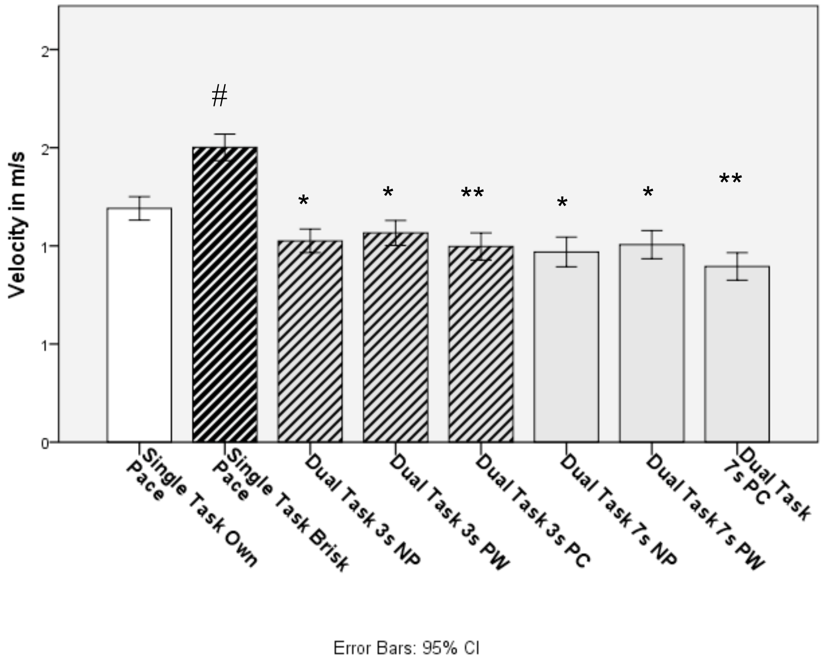

Figure 4.5. Velocity outcomes for all ST and DT conditions

Dual-task Benefit (DTB), *Post-hoc* tests are significant at the $p < .05$ level

** Dual-task Deficit (DTD), *Post-hoc* tests are significant at the $p < .05$ level

+ PC significantly different from PW condition, $p < .01$

€ PC significantly different from NP condition, $p < .01$

The participants' speed when no prioritisation instructions were given was compared with the outcomes when explicit instructions were given to prioritise either walking or counting to examine their ability to prioritise attention (Figure 4.5). When counting back in 3s (M = 0.99) participants walked significantly slower than when they were instructed to pay attention to walking (1.06), t (69) = 2.546, $p < .001$, $r = .29$ (see Table 4.9). This result was mirrored in the Serial 7s task. The participants walked more significantly more slowly when they prioritised counting (M = 0.897) than when they prioritised walking (M = 1.06), t (70) = 3.792, $p < .01$, $r = .66$. In addition the participants' speed was also slower in the Serial 7s task, when they prioritised counting, than when they were given no explicit prioritisation instructions (t (68) = 2.707, $p < .01$, $r = .32$).

4.4.5 Cognitive load, prioritisation and correct cognitive responses

In the DT conditions it is expected that performance in the DT will decline relative to the ST as this is the cost of performing 2 tasks together. Observing the decline in gait measures in this study, it was possible that the gait performance might bear all the 'cost' and the cognitive performance might be maintained. However, the number of correct cognitive responses (CCRs) actually increased in some of the DT conditions in relation to the ST performance, for both Serial 3s and Serial 7s, (see Table 4.7). In other words, as opposed to a dual task deficit, there was a dual task benefit (DTB) when counting back in 3s with no specific prioritisation instructions (M = 0.503) compared to the ST (M = 0.445; t (71) = -3.43, $p <$ .001, $r = -.38$)..Similarly, there was a DTB when prioritising counting (PC) (M = 0.535) relative to the ST counting (t (70) = -13.15, $p < .001$, $r = -.85$, whereas there was no significant increase in CCRs when prioritising walking (PW) (M = 0.470) (see Figure 4.6).

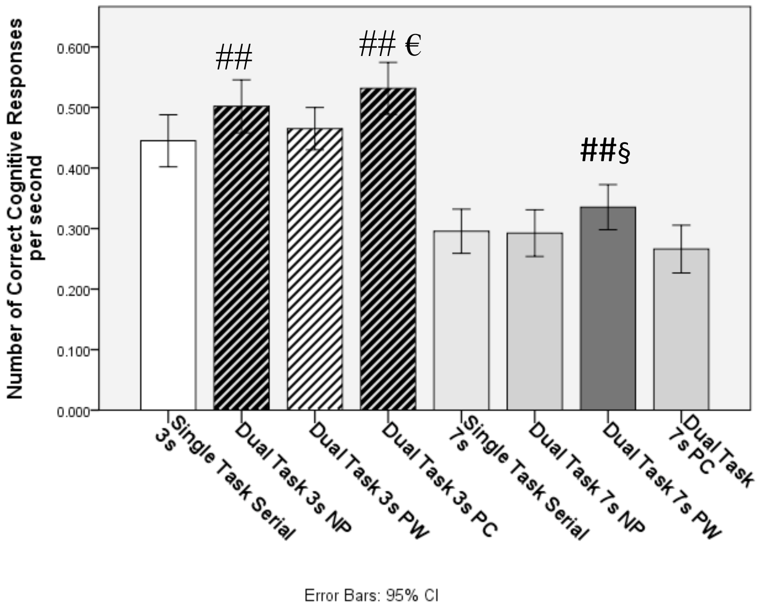

Figure 4.6. Correct cognitive responses ST and DT outcomes for cognitive load and different prioritising conditions

Dual-task Benefit significant at the $p < .001$ level

§ PW condition significantly better than PC condition, $p < .05$

€ PC condition significantly better than PW condition, $p < .001$

In the Serial 7s task, another DTB was produced. When instructed to prioritise walking (PW) (M = 0.334), the participants gave more correct answers than in the ST (M = 0.293; t (69) = -2.85), $p < .001$, $r = -.34$ (Table 8). Unexpectedly, in relation to the other CCR results, when counting was prioritised (PC) (M = 0.270), there was a small DTD compared to the ST (M = 0.293), although this was not significant (Figure 4.6).

This was no different when participants walked and counted back in 3s, without specific prioritisation instructions (NP) (M = 0.503) and when they prioritised counting (PC) (M = 0.535). These performances both produced a DTB, $p < .05$.

In the Serial 3s task, there was no DTB when prioritising walking, but the Serial 3s PC (M = 0.535 performance was significantly better when counting was prioritised than in the PW condition (M = 0.503) when walking was prioritised t (69) = -3.53), *p*< 0.001, *r* = -.39. This result (see Table 4.7) was not surprising, given the less challenging nature of the task. When instructed to prioritise walking (PW) (M = 0.334), the increase in correct responses in the Serial 7s, was significantly higher in relation to both the no prioritisation condition (NP) (M = 0.295), t (69) = -2.86, p<0.05, r = -.326) *and* when prioritisation was on counting (PC) (M = 0.270), t (70) = 4.08, p<0.001, r = .438).

4.4.6 Cognitive load, prioritisation and pace of responding

Looking at the pace of responding in the Serial 3s task, participants took fewer steps per response when concentrating on counting (M = 3.09) than when they prioritised walking (M = 3.56), t (69) = 2.88, *p* < 0.05, *r* = .33. When counting back in 7s they took significantly more steps when prioritising counting (M = 6.76) than when prioritising walking (M = 4.60), t (70) = -3.58, *p* = 0.001, *r* = -.39 (see Figure 4.7). Their performance improved when prioritising walking (in relation to the NP and PC conditions) and this improvement mirrors the DTB for step-time variability and number of correct responses, also in the Serial 7s prioritising walking condition (PW).

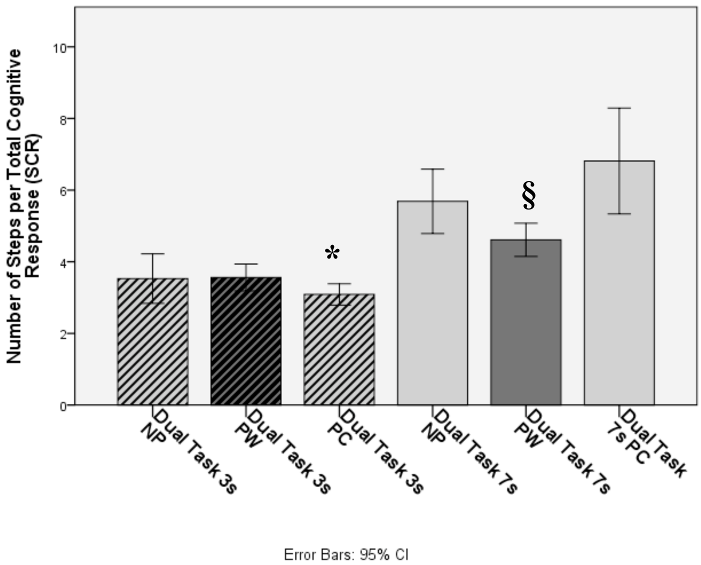

Figure 4.7. Steps per cognitive response outcomes for all ST and DT conditions

* DT (PC) condition was significantly better than the DT (PW) condition. *Post-hoc* tests are significant at the *p*<0.001 level

§ DT (PW) condition was significantly better than the DT (PC) condition. *Post-hoc* tests are significant at the *p*<0.001 level

4.4.7 Relationships between performance outcomes and standardised tests

The standardised cognitive test battery was administered to test the general cognition of the participants (such as memory and intelligence) and to assess their specific higher-level cognitive processes which can be observed, by proxy, in EF tests (see section 4.2.5 and Table 4.2 for details of tests). To assess the relationship and any overlap in executive functioning between the tests, Pearson's coefficient analyses were carried out on the baseline results (see Table 4.10). These revealed some overlap between general cognition and EF (between MMSE/Est IQ and SDMT/TMT) and between SDMT and memory and judgement. These associations perhaps reflected the general processing nature of SDMT. A level of intelligence was also associated with memory in the IR and DS/F tests, both of which rely on good short-term memory for success. The tests which appeared to be most specific in nature were Digit Span F (verbal working memory capacity) and especially DS/B which places greater demands on working memory, tests the ability to retain information in the short term for use in complex tasks which require more cognitive processing. Since these associations did not provide any causal inferences, they were tested for possible relationships with the DT walking and counting outcomes in order to assess their likely predictive value.

Table 4.10
Pearson's significant correlation coefficients between standardised baseline cognitive tests

	MMSE	SDMT	TMT-A	TMT- B	Delta TMT	DS/F	DS/B	IR	DR	CET
MMSE	1	**.417****	**-.399****	**-.435****	-.297*					
Est IQ		**.329****				.278*		.291*		
SDMT	**.417****	1	**-.416****	**-.398****	-.243*				**.359****	**-.256***
TMTA	**-.399****	.416**	1	**.506****						
TMTB	**-.435****	**-.398****		1				-.239*		
Delta TMT	-.297*	-.243*								
DS/F						1	**.504****			
DS/B						**.504****	1			
IR				-.239*				1		.363*
DR		**.359****							1	
CET		256*						-.363*		

* Correlation is significant at the $p < .05$ level (2-tailed)
**Correlation is significant at the $p < .01$ level (2-tailed)

To illuminate the processes underlying differences in performance in the experimental conditions, relationships with the baseline cognitive measures were examined. These revealed that no one baseline cognitive test most strongly related to performance outcome measures but that Delta TMT, SDMT and DSF/B were all strongly related to them. When age, MMSE, estimated premorbid IQ and mood were co-varied, these associations remained (see Table 4.11).

Table 4.11

Pearson's significant correlation coefficients between DT Serial 7s gait and cognitive outcomes and standardised baseline tests

	CV - NP	CV - PW	CV - PC	Velocity NP	Velocity PW	Velocity PC	CCR NP	CCR PW	CCR PC	SCR NP	SCR PW	SCR PC
Delta TMT		.242*			-.300*	-.287*	-.242*					
SDM							.220*	.224*	.298**		-.288*	-.313**
DS-F	-.277*						.302*	.310**	.225*			
DS-B	-.294*						.220*	.253*				
IR										-.273*	-.320**	-.303**
DR												
CET											.304*	
Age											.288*	.252*
MMSE							.207*	.223*			-.263*	-.375**
Est. PMIQ		-.290*	-.257*				.231*	206*	.248*			
BDI				-.246*	-.268*		-.283*	-.303*				

*Significant at the *p*<0.05 level

**Significant at the *p*<0.001 level

Delta TMT = Trail Making Test A score minus B score, SDM = Symbol Digit Modalities Test, DS-F and DS-B = Digit Symbol Forwards and Backwards, IR – Immediate Recall, DR = Delayed Recall, MMSE = Mini-Mental State Examination, PMIQ = Premorbid IQ, BDI = Beck's Depression Inventory

Looking at the baseline mobility measures, gait measures had a strong association with physical flexibility and balance (see Table 4.12). Both speed and steadiness of gait were associated with general mobility, flexibility and balance at baseline. The relationships between mobility and steady gait were positive, in that the better the flexibility and balance measures, the lower the gait CV (indicating steadier gait).

Table 4.12. *Pearson's significant correlation coefficients between ST and DT gait and cognitive outcomes and baseline mobility tests for Serial 7s task*

	Own Pace CV *r =*	Own Pace Velocity *r =*	Brisk Pace Velocity *r =*	Dual Task (PW) CV *r =*
Stand-up Sit-down	-.304**	.308**	.328**	-.243*
Balance on one leg	-.332**	.241*	.415**	-.222*
Tandem Walk		.303*	.248*	

*Significant at the *p*<0.05 level
**Significant at the *p*<0.001 level

The mobility measures were also examined in relation to performance on the cognitive tasks and mood measure. Stand up sit down performance was related to EF as measured by the Cognitive Estimation Test – a measure of judgement. Balance was significantly related to age, mood and EF as measured by the TMT – a measure of attention and processing speed. Controlling for age, the other functions remained associated with mobility (see Table 4.13).

Table 4.13.
Significant correlations between baseline mobility tests and standardised baseline cognitive and demographic tests

	Stand-up, Sit-Down *r =*	Balance on one leg *r =*
Delta TMT		-.333**
CET	.412**	
DR	-.369**	
Age	-.248*	-.462**
BDI		-.311**

*Significant at the *p*<0.05 level
**Significant at the *p*<0.001 level

Delta TMT = Trail Making Test A score minus B score, CET = Cognitive Estimation Test, DR = Delayed Recall, BDI = Beck's Depression Inventory

4.4.8 Principle Component Analyses (PCA)

Principle Component Analysis (PCA) was performed on the variables that were significantly correlated in order to validate the selection of variables to be analysed by simple and multiple regressions. The PCA revealed the items that clustered on the same component (see Table 4.14) and shows the factor loadings after the orthogonal rotation (varimax). The scree plot (see Figure 4.8) clearly indicated that four components should be retained in the final analysis, and these cluster around DT gait outcomes, DT cognitive outcomes, EF and general background characteristics.

Table 4.14

Summary of exploratory factor analysis results for the T1 DT gait and cognitive outcomes

	Rotated Factor Loadings				
Item (Serial 7s)	Gait performance	Cognitive performance	Baseline Cognitive Function and Demographic Characteristics	Specific EF (1)	Others
DT(NP) Velocity	.863				
DT(PW) Velocity	.859				
DT(PC) Velocity	.783				
DT(PW) CV	-.739				
DT(NP) CV	-.731				
Own Pace Velocity	.606				
Own Pace CV	-.558				
DT(PC) CV	-.495				
DT(NP) CCR		.852			
DT(PC) CCR		.770			
DT(PC) SCR		-.670			
DT(PW) SCR		-.651			
DT(NP) SCR		-.553			
Delta TMT			.779		
Age			.752		
Mobility (Balance)			-.696		

MMSE	-.475	-.564		
Brisk Pace		-.471		
DS/B			.820	
DS/F			.694	
SDM		-.468		
IR		-.475		
DT(PW) CCR				-.716
CET				.668

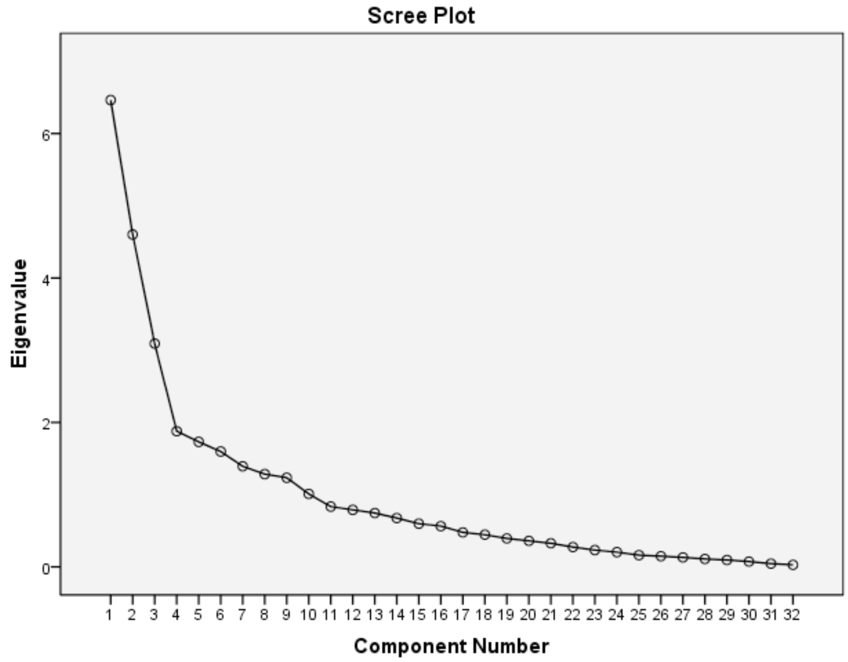

Figure 4.8. Scree plot from Principle Component Analysis of gait, cognition and baseline variables

4.4.9 Linear and multiple regression analyses

The results from the step-time variability, correct cognitive performance and steps per cognitive response outcomes, in the more sensitive (Serial 7s) task, had revealed that the 'optimal' performance occurred when the walking condition was prioritised (PW). That is, all DT performance outcomes in the Serial 7s task were performed best when participants prioritised walking. So that possible performance outcome predictors of these specific conditions could be identified from standardised baseline tests, linear and multiple regression analyses were carried out (see Table 15). These revealed that specific EF tests, Delta Trail Making Test (D/TMT), $p < .001$, and the Digit Span/Backwards test (DS/B), $p < .05$, measured in the standardised battery of cognitive tests, were markers for and predictors of the step-time variability when walking was prioritised (Serial 7s PW) (see Table 4.15) and D/TMT, $p < .05$, was a marker for and predictor of CCR outcomes when walking was prioritised (Serial 7s PW) (Table 4.16).

To investigate this relationship further, the participants were divided into two groups based on both their Serial 7s performance on the DTPW condition for CV and CCR. The high performance group ($n = 28$) comprised participants whose scores were both in the top 50% for step-time variability and the top 50% for CCRs. That is, these participants both walked more steadily and counted better than the participants in the low performance group. T-tests were then carried out on all of the high performance group and the low performance groups' standardised tests at baseline to ascertain if either of the predictors revealed by linear and multiple regression analyses associated most strongly with the 'optimal' DT gait and cognitive performance. The only significant difference between the low performance and high performance groups and their abilities at baseline was in the Cognitive Estimation Test which is a test for EF (judgement) t (36) = 2.167, $p < .05$, $r = .26$. The low performance group for PW CV and CCR gave a higher number of 'bizarre' answers than the high performance group, revealing a lower ability to judge or estimate answers to everyday problems (such as how much a common item might weigh).

Table 4.15.*Linear regression for Serial 7s step-time variability - CV (PW)*

	B	**SE B**	**β**
Constant	0.036	0.009	
Delta TMT	0.000	0.000	.242*

* $R^2 = .058$, $\Delta R^2 = .045$. *$p < .05$

Table 4.16.

Multiple regressions for Serial 7s CCR (PW)

	B	**SE B**	**β**
Step 1			
Constant	0.264	.042	
Delta TMT	0.002	0.001	.332**
Step 2			
Constant	-0.262	0.170	
Delta TMT	0.003	0.001	.396**
SDM Test	0.004	0.002	.233
DS/B	0.055	0.024	.279*
BDI (mood)	0.008	0.006	.178

* $R^2 = .110$ for Step 1, $\Delta R^2 = .194$ for Step 2. *$p < .05$, **$p<.01$

4.4.10 T1 AAI analyses

In order to investigate these healthy older adults' ability to flexibly change their attention-allocation, under explicit instructions, AAI was calculated for all Serial 3s and Serial 7s DT gait and cognition outcomes (see Table 4.17).

Table 4.17.
T1 Attention-allocation Index (AAI) for Serial 7s

	Serial 3s		Serial 7s	
	Mean	**SD**	**Mean**	**SD**
AAI CV	.060	2.09	-.855	2.39
AAI Velocity	.119	.535	-.054	.500
AAI CCR	-.134	.409	.311	.769
AAI SCR	-.159	.472	.272	.662

Values are mean ± Standard Deviation (SD)

The AAI measures the flexibility in attention allocation between the 3 prioritising conditions (NP, PW and PC) with 0 denoting a total inability to flexibly allocate attention and ± 1 indicating the opposite. The only outcome to show a significant difference between the two secondary task cognitive loads (Serial 3s, M = 0.060 and Serial 7s, M = -0.855) was gait step-time variability (CV), t (69) = 2.524, $p < .05$, $r = .29$ (Figure 9). This outcome (CV) was therefore considered to be the most sensitive measure to assess how flexibly participants could allocate their attention during a DT at T1. (See Figure 4.9).

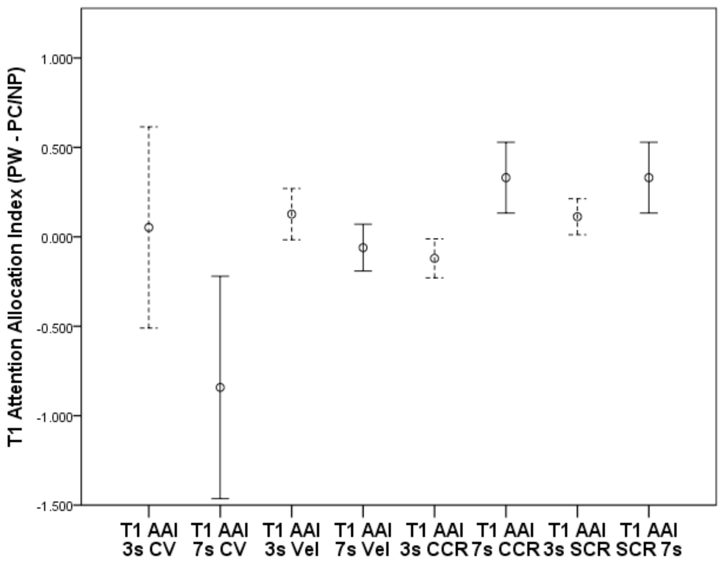

Figure 4.9. Attention Allocation Index (AAI) for Serial 7s CV, Velocity, CCR and SCR at T1

The overall findings from the AAI suggested that it could be a novel method for evaluating *change* in flexible allocation of attention to gait and cognition.

4.5 Discussion

Consistent with previous findings (Beauchet et al., 2005; Yogev-Seligmann et al., 2010), this study revealed that, when healthy adults are asked to divide their attention between two tasks, such as walking and counting out aloud, aspects of their gait are compromised and significant gait dual-task deficits occur. This indicates that either attentional capacity is limited *or* ability to divide attention is inefficient. In this present study, deficits were exacerbated when the cognitive load was increased, but not in all cases, so again it was not clear whether capacity or processing influenced performance outcomes. It was only when attention was specifically instructed to be prioritised on gait or the cognitive task, did very subtle differences in performance appear between task, load and prioritisation conditions. This study, therefore, extended previous findings by assessing both walking *and* counting performances in equal detail, using differing cognitive loads and by varying attention prioritisation, to explore subtle differences in the interplay between cognitive load and prioritisation of attention. Disentangling resource capacity and resource processing in the dual task revealed an understanding of how they interact in a complex every day task.

The participants were physically and cognitively healthy according to the baseline assessments of, cognition, mood and mobility. In some cognitive domains they were above average, for example crystallised intelligence. In respect of their gait these participants' preferred pace (ST) was faster than 1metre per second, which is the cut-off point for risk of adverse events in older age (Studenski et al, 2011). As expected there was a DTD in velocity for all DT conditions for both Serial 3s (see Table 4.5) and Serial 7s (Fitzpatrick et al, 2007) except when asked to walk at a brisk pace, when they walked quicker than in the ST, showing that they were following the instructions and that, even a low level of mental effort directed on walking can affect gait outcomes.

To the naked eye velocity is the most observable gait measure and one of the most widely-used in research. It is also the measure that gives general information about gait, but, as the inconclusive results for both cognitive load and prioritisation revealed, velocity is not as sensitive a measure of cognitive function as gait variability (stride-time and length) (Montero-Odasso et al., 2012). These results, therefore, reflect current understanding of DT performance with healthy adults: that gait speed is adversely affected by a secondary cognitive task, no matter how easy that task is (Beauchet et al., 2005; Springer et al., 2006; Hausdorff, Schweiger, Herman, Yogev-Seligmann & Giladi, 2008). However, it is clear that, under both cognitive loads, in terms of speed at least, these older adults found it more difficult to walk and count backwards, when they were told to concentrate more on counting, than when they were given no instructions about attention-allocation, therefore velocity results are affected by attentional processing ability.

Variability in stride time and length indicates how steadily people walk and can reveal more subtle changes in attention-allocation during a DT than velocity (Montero-Odasso et al., 2012). Step-time variability in this study revealed that subtracting 7s in the DT was not more difficult than subtracting 3s for every prioritising conditions (NP, PW and PC). When attention-prioritisation instructions were given, it was possible to detect changes between performances in the differing cognitive loads (Serial 3s or Serial 7s). For example, when they were specifically asked to prioritise walking, participants' gait became steadier in the more demanding task than when they prioritised counting or when no prioritisation was instructed. In addition, their gait in the prioritising walking condition (PW) was almost as steady in the same condition (PW) in the Serial 3s task. Although this latter result was surprising, it was supported by the attention-allocation index results. It was unclear, why step-time variability should become steadier when carrying out the more difficult secondary cognitive task, although there are several possible explanations (discussed below).

Looking at the pace of cognitive responding during the DT the participants had a significantly more regular pace (fewer steps to response) when they prioritised counting in the easier task (Serial 3s) and when they prioritised walking in the more difficult task (Serial 7s). These results suggest that the action of prioritising attention (either on counting or walking) may have regulated walking (made it more rhythmic or 'automatic'). This has previously been attributed to synchronisation (Escoffier, Sheng & Schirmer, 2010) or a 'magnet' effect (Beauchet et al., 2010).

The idea of synchronicity was supported by the unexpected findings from the DT cognitive response conditions, which produced several dual-task benefits. That is, the participants counted better in the DT than in the ST, without incurring a cost to their gait stability. This phenomenon has been reported before. Beauchet and colleagues (2010) reported improved DT cognitive performance in a previous study (Beauchet et al., 2007), but only in participants with the highest initial stride-time variability (that is, unsteady gait). An increase in the number of verbal responses produced in all prioritisation conditions of the DT over the ST was also observed in a more recent study (Yogev-Seligmann et al., 2010) but the findings revealed that the difference between ST and DT cognitive responses was not significant and the researchers did not suggest an explanation for the increase in numbers.

In this present study, when the cognitive load was easier (Serial 3s), there was a DTB for cognitive responses when counting was prioritised (PC) with no decline in gait stability or speed relative to the other prioritising conditions. There was also a DTB in the Serial 3s task when participants were given no instructions to prioritise, again without detriment to gait (relative to the other two prioritising conditions). This suggests that the participants' 'default' postural strategy, in the case of Serial 3s was to prioritise counting over walking. This suggests that the task was easy for them, and as such presented no threat to their gait security. Thus, they could unconsciously direct their attention to counting, which they may have considered to be the more important task.

More surprisingly, when participants were instructed to prioritise walking in the more difficult task (Serial 7s), they not only walked quicker and more steadily, they produced significantly more correct cognitive responses and took fewer steps per response than when instructed to prioritise counting. In the competition for their attention during a concurrent walking and challenging cognitive task, these healthy older adults achieved better results in all performance outcomes when walking was prioritised. That is, they allocated their attention more efficiently when they prioritised walking than when they prioritised counting and more efficiently than when they were left to decide themselves which task to prioritise (NP condition).

Taking the two gait measures together (step-time variability and velocity), and comparing the prioritising walking with the no prioritising outcomes, the Serial 3s task produced no conclusive findings regarding the notion of a 'default' postural strategy. In the Serial 7s task, participants' gait speed and velocity performance resembled the prioritising walking condition more than the prioritising counting condition which would initially suggest that these older adults did adopt the 'posture-first' strategy when gait security may be under threat from additional attentional demands (Shumway-Cook et al., 1997). However, when considered with the additional improved cognitive performance (in both CCR and SCR) when prioritising walking, it would appear that these healthy older adults were capable of adapting their postural strategy to suit their internal and external goals which were dependent on their notion of the difficulties of the tasks and the environmental constraints on their achieving these goals. In other words, they both maintained their gait and, when there was little risk of falling, they were able to prioritise the cognitive task and improved their cognitive performance. This ‘optimal’ performance profile was achieved in the prioritising walking conditions.

This ability to adapt to changing circumstances by flexibly allocating attention where and when it was most needed could be observed in the AAI for step-time variability and this was associated with underlying executive functioning. Regression results showing that CV (PW) and CCR (PW) were both predicted by baseline EF, specifically attention processing (D/TMT) and working memory capacity (DS/B). Since these tests assess specific executive functions, considered to be sub-functions of working memory, these findings highlight the relationship of executive attention to a concurrent gait and cognitive task and also point to the benefits of attending to walking.

Possible explanations for the ‘optimal’ profile that participants showed in PW (CV) and PW (CCR), that is an increase in cognitive responses in DT conditions at no extra cost to gait, were derived from cognitive psychology and gait analysis theories

1. Arousal Theory

The Yerkes-Dodson law (1908) asserts that performance improves with physiological or mental arousal but only to a certain extent. When levels of arousal become too high, performance declines. Kahneman’s (1973) theory suggests that arousal plays a part in the available attentional capacity in a DT. This would suggest that some of the DT conditions create an optimal level of arousal, enabling performance to actually be better than in the ST, while other conditions present a greater challenge, leading to a decrease in performance (manifested as the DTD).

2. Social Facilitation

Social facilitation theories speak to both the physical and the cognitive domains (Spreen & Strauss, 2002). Two such theories may inform the dual-task benefit found in CCR results.

(i) Distraction-Conflict Theory. When simple tasks are being carried out, there is a great deal of irrelevant stimuli available to a participant, which may impede an optimal performance. However, when the task becomes more complex (such as in a dual task), attention may be stretched or overloaded and the irrelevant stimuli are overlooked or ignored. This would lead to a dual-task increment over the (single) simple task performance (Baron, 1986).

(ii) Performance on simple tasks is sub-optimal because the task may be automatic or well-practised and we do not attend to feed-back on its progress (Abrams & Manstead, 1981). When someone is watching the performance, our attention is more sharply focused on it and the performance is facilitated by the explicit or implicit expectation of feedback. According to this account, social facilitation effects only occur when a task is so well-learned (for example a competent driver or walker) that performance does not rely on continuous monitoring. However, a recent review of this field of social facilitation theory found only weak effects from the mere presence of others on the performance of separate motor and cognitive tasks (Spreen & Strauss, 2002).

3. Automaticity

Following on from Schneider and Shiffrin's (1977) automaticity theory when an activity becomes automatic (through practice or learning), it makes no demands on attentional resources, is unaffected by capacity limitations and is carried out at a subconscious level. This could explain, in this study, why prioritising attention on an already 'automatic' function (i.e. walking) may leave enough spare attention to benefit the secondary (cognitive) task. However, it is unclear whether automaticity results from a speeding up of attentional processes (through practice or learning) or a change in the nature of processing itself, after an individual has acquired more skill at it and so we are left unsure as to whether attention really is being divided, if we adhere to this theory. Moreover, as Hampson (1989) found, activities that were considered to be 'automatic' are affected by being carried out under dual-task conditions. This is certainly supported by concurrent gait and cognitive task literature (Yogev-Seligmann et al., 2010). Even such an apparently 'automatic' activity as walking has attentional demands, to varying degrees, working upon it.

4. 'Posture-first' strategy

As outlined above, the posture-first strategy (Shumway-Cook et al., 1997) proposes that, when no specific prioritisation is imposed on either gait or cognition during a dual task, and the cognitive load becomes heavy, healthy older adults will prioritise walking over the cognitive task to ensure gait stability. That is, here, they will naturally prioritise walking over counting. This strategy would certainly explain how gait performance could be maintained during a demanding DT but it would not fully explain the dual-task benefit (DTB) in the Serial 7s task, which was observed in the simultaneous improvement in the secondary (cognitive) task outcomes. A possible interpretation of these results is that, since there was little immediate danger of falling on a straight, flat corridor, these healthy older adults did not need to prioritise walking (even although they were instructed to) and unconsciously attended to the more pressing (cognitive) task.

5. 'The Magnet Effect'

The 'magnet effect' theory provides a bio-medical explanation for improved dual-task counting over the single-task performance. Beauchet and colleagues (2007) were researching gait and cognition for falls prediction and prevention and found that older adults who were prone to falls produced more correct counting responses while walking, than sitting. These researchers cited Ebersbach, Dimitrijevic and Poewe's (1995) idea that, since counting backwards contains a strong rhythmic element, as does walking, these two rhythmic activities strongly influence each other (Ebersbach et al., 1995). The theory suggests that task similarity reduces interference between 2 concurrent tasks (for example, the rhythmic element in both walking and counting) and leads to an improved DT performance. Beauchet and colleagues (2007) posit that the tendency of biological oscillators to attract each other, and produce a 'magnet effect', is also created in dual-task gait and cognition, such that the action of walking would actually improve the secondary cognitive performance. The 'magnet effect' theory would explain the increase in correct cognitive responses across the dual-task conditions, but it would not fully account for the parallel improvement in CV and CCR in the DTPW condition alone.

None of these theories fully explains why the participants in this study should increase both their dual-task gait and cognitive performance (over their ST performance) when prioritising gait when they did not display the same pattern of behaviour in the other dual-task conditions. The following proposals may help to answer this question:

(i) Previous studies have found a strong association between the way older adults walk and their EF (Allali, van der Meulena & Assal, 2010; Coppin et al., 2006), especially if they show signs of MCI or have clinical executive dysfunction (Persad et al., 2008; Sherdian et al., 2003). However, the results from this T1 study appear to reveal more specific findings than simple associations between walking and underlying EF. The joint improvement in gait (CV) and cognition (CCR) was in the PW condition and this improvement had a positive association with, and was a marker for, good EF as measured by performance on 2 specific tests for attention capacity and processing. In other words, EF at baseline was a predictor for the kind of higher-level cognitive ability which is integral to independent-living in older age. This marker was measured in how efficiently the participants coped with an increase in cognitive load (resource capacity) *and* attention-allocation requirements (processing speed).

(ii) Previous research suggests that physical exercise and physical activity are beneficial for cognitive function well into older age (Kramer, Erickson & Colcombe, 2006). Weekly moderate to vigorous exercise was one factor which explained the maintenance of cognitive function over 8 years in well-functioning older adults (Yaffe et al., 2009). More specifically, walking has been shown to have a beneficial effect on specific executive control processes (Kramer et al., 1999). In addition, the participants in the present study have an above average IQ and many received tertiary education. These are indications of early-life opportunities which are thought to increase cognitive reserve which, in turn, may buffer cognitive decline in later life (Richards & Deary, 2005).

(iii) Treatment of Parkinson's Disease patients had shown that auditory and cognitive cues, produced either externally or self-generated, improved their gait (Kressig, Allali & Beauchet, 2005). It was posited that such cues could compensate for the deficient internal rhythm of the basal ganglia, by providing an external rhythm that would facilitate automatic movement. It is now clear that the cortical and sub-cortical regions do not operate in isolation, in terms of gait and cognition (Coolidge & Wynn, 2005; Yogev-Seligmann et al., 2008) and that the frontal lobes (central too for EF), may be the common link between the two (Allali et al., 2010). The idea that the automaticity of gait could influence cognitive responding and that this could be manipulated externally by influencing prioritising of attention, led to an investigation into the role of rhythmic gait in cognitive performance in a dual-task (Chapter 6).

4.6 Conclusion

Instructing participants to prioritise attention on either gait or cognition during dual tasks with different cognitive loads produced subtle differences in performance outcomes. These appeared to reveal the interaction between attentional resource capacity (observed in performance outcomes when, in the Serial 7s, the more difficult task demanded more mental effort) and cognitive flexibility (when they had to adapt to the changing circumstances of different prioritisation instructions). This revealed that an 'optimal' condition had been discovered in a demanding dual-task, which was achieved when prioritising walking in the Serial 7s task. Both gait and cognitive outcomes in this condition were predicted by underlying attentional processing, as measured by the Trail Making Test. Attentional processing speed (cognitive flexibility) is the cognitive function used by people to adapt to changing priorities in every-day activities (Montero-Odasso et al., 2012).

The participants in this study appeared to cope well with increased cognitive load and changing cognitive priorities (the Serial 7s, PW condition). There could be many explanations for their performance in this optimal condition. The findings in this study suggest that the background characteristics of this group of older adults were contributing factors. The participants had a higher than average IQ and years of education, which may have buffered the effects of normal ageing (Deary, 2009). The findings also suggest that the participants' current healthy lifestyle and history of maintaining good physical health may have built up 'postural reserve', a factor which is thought to contribute to gait stability in older age (Yogev-Seligmann et al., 2012b). These, and other contributing factors to healthy ageing are considered further when the T1 and T2 results are compared in Chapter 5.

Chapter 5: Comparison between Time 1 and Time 2

5.1 Introduction

When investigating inferred ‘causes’ of successful ageing or non-pathological cognitive decline from test scores, single studies do not display the full picture. If possible, it is better if participants can be studied over a period of time so that the mechanisms underlying any changes in test scores and experimental outcomes (maintenance, improvement or decline) can be investigated (Deary, 2009). The findings from T1 (see Chapter 4) revealed that the group of healthy older adults had walked and counted best in an ‘optimal’ condition where they were prioritising their walking and that this was predicted by their underlying ability to flexibly allocate attention. But the study did not explain the mechanisms behind this ‘optimal’ performance, although several possible reasons were discussed, nor was it clear whether this was a pattern of behaviour or a ‘one-off’ event. The T1 study’s findings provided only half a story; that resource capacity is limited in concurrent gait and cognitive tasks (DTDs between STs and DTs), that the outcome measures are progressively affected by the difficulty of the task (performance decrements between Serial 3s and 7s), that prioritising strategies are not rigidly imposed but respond to changing internal and external goals (differences between prioritising conditions) and that capacity limitations and processing ability, in combination, provide the most sensitive means of assessing how well an older adult can perform a complex task (‘optimal’ performance condition (PW) in the Serial 7s task). A more complete hypothesis regarding underlying mechanisms which explain the findings can only be tested by comparing the same individuals after a period of time. A healthy group may not change greatly over a short time; if significant changes and differences are revealed, these can be analysed in relation to results at T1 in order to identify their possible causes. The changes in background characteristics, baseline tests and performance differences hold the key to the cognitive ageing process of this group of older adults. This chapter describes the comparison between T1 and the second phase of the longitudinal study (T2) in order to give a more complete picture of how well these participants were ageing.

5.2 Methods

Participants were randomly assigned a date for the first assessment and then invited to attend the second assessment (one year later) as near the actual date of the first visit as possible. Sixty-eight of the original 72 participants agreed to return for the second phase of the research project. It took 3 months to assess all the participants in each visit period. At the second visit (T2), only 4 out of the 68 participants were assessed outside one month of the day/date of their first visit (T1). These participants attended 14 months after their first visit, instead of between 12 and 13 months. The procedures for the T2 assessment were the same as T1 (as described in Chapter 4), except that, as only one NART is required to produce estimated pre-morbid IQ, the NART was not administered a second time, nor were the years of education recorded again. Any changes from T1 in the latter variable were recorded as cognitive activity in the background characteristics (for example, if the participant had completed further study). In researcher oversight, weight and height data were not recorded at T2. A different version of the story recall was used and, although the same cognitive tests were used for the dual-tasks (Serial 3s and Serial 7s), the starting numbers for each walking condition were different from T1.

To explore the effects of time on dual-task performance outcomes, standardised cognitive tests and other variables, data were compared from the 68 participants who took part in the study at both T1 and T2. Their average age at T1 was 72.75 years (range 65–91 years) and at T2 73.5 (range 66-92 years). The group comprised 43 females and 29 males at T1, and 42 females and 26 males at T2. The average age of the females at T1 was 72.0 years (range 65-91 years) and at T2 was 73.0 (Range 66-92 years). The males were aged 73.1 years (range 66-81 years) at T1 and 74.1 years (range 67-85 years) at T2. Their performance on each of the experimental conditions was compared at both time points in relation to their standardised tests and background characteristics, and regression analyses were used to identify potential predictive factors of change over time.

5.2.1 *Statistical Analysis*

Data were compared using paired sample t-tests and Pearson's correlation coefficients with a significance value $p < .05$. The Bonferroni adjustment for multiple comparisons correction was applied. Linear and multiple regression analyses were carried out to assess predictive value, with a significance level of $p < .05$. All data were analysed using the PASW version 18.0 for Windows (2010) software package. Effect size (*r)* was calculated manually.

5.3 Results

5.3.1 Demographic and Health Characteristics

The overall results suggest that there were no major changes in background measures, such as major illness or onset of disability, and most other items the participants reported maintained or improved changes in behaviour (see Table 5.1). At T2 the percentage of the sample drinking seven or more units of alcohol per week rose from 28.3% to 34.1%. Over the year the number of participants who took three or more medications per week rose by 9.5% and the number of people who spent at least one night in hospital in the last year rose by 4.1%. In particular, there was an 21.1% increase in the number who exercised three or more times a week and a self-reported satisfaction with health status improvement of 3.3%, from an already high 85.3% to 88.6% (see Table 5.1). The overall results suggest that the participants had maintained good physical health during the 12-month period.

Table 5.1
T1 and T2 demographic and health characteristics

Variable	Mean (SD) Range	Mean (SD) Range	%	%	Remarks	Remarks
	T1	**T2**	**T1**	**T2**	**T1**	**T2**
n = Gender (M/F)	**68** **26/42**	**68** **26/42**				
Age	**72.75 ± (5.71) 65-91**	**73.5 ± (5.51) 66-92**				
Total years of Education	**15.52 ± (3.73) 3-22**	**15.53 ± (3.73) 3-22**				
Beck Depression Inventory score	**5.18 (4.23) 0 - 17**	**4.53 ± (3.92) 0 - 19**				
Body Mass Index	**26.2 ± (4.61) 18.4-42.00**		**50.0**	**N/A**	27/68 = Overweight (BMI > 25 < 30) 7/68 = Obese (BMI > 30)	
Regular exercise – 3 or more times per week			**72.1**	**93.2**	Walking, golf, yoga, dancing, gardening, housework, swimming, riding, Pilates, tai-chi, DIY, aerobics, cycling, dancing, tennis, badminton, table-tennis, skiing	As T1 plus bird-watching, looking after toddlers, running, jogging, bowls, hill-walking
% of participants who carried out 5/6 IADLS at least once a week			**92.5**	**90.0**	Shopping for food, preparing meal, taking public transport, managing finances, planning a trip, using IT.	
Walking (3 or more times per week)			**97.2**	**95.9**		
Cognitive activities – 3 or			**97.3**	**97.0**	Cross-words, Sudoku, card-games, reading, Scrabble, bridge, learning musical instrument, writing,	As T1 plus painting, patchwork, listening to

more times per week					planning, committees, computer, tapestry, puzzles, quizzes, genealogy, dressmaking, cooking, U3A, finances	Radio 4, watching ‘Countdown’, strategic thinking, triangular dominoes,

Variable	**Mean (SD) Range**	**Mean (SD) Range**	**%**	**%**	**Remarks**	**Remarks**
	T1	**T2**	**T1**	**T2**	**T1**	**T2**
More than 7 units per week of alcohol			**28.3**	**34.09**		
% of current smokers			**2.94**	**2.27**		
3 or more falls in last year			**4.5**	**4.4**		
Taking 3 or more medications			**38.2**	**47.7**		
At least one night in hospital in last year			**11.8**	**15.9**		
Using spectacles			**100**	**100**		
Using hearing aid			**19.4**	**20**		
Satisfied with own health status			**85.3**	**88.6**		

5.3.2 Standardised Baseline Tests

Over a period of time, such as 12 months, I would have anticipated that these healthy older adults may have either maintained their general cognition and specific executive functions or shown a decline in test results, especially in those tests which rely on fluid intelligence. Older adults can also become less mobile and more at risk of depression as they age. Therefore a change in mood and mobility was also anticipated. However, paired *t*-tests revealed a significant improvement in three areas: firstly, general cognition (as measured by the MMSE) ($p<.05$), secondly, immediate recall (as measured by story recall) ($p< .05$) and thirdly, executive function - judgement (as measured by the Cognitive Estimation Test) ($p< .05$). There was no change in performance on any of the other tests (see Table 5.2) indicating that these older adults' cognitive function had *not* deteriorated but had been maintained or improved during the previous 12 months. However, caution must be observed in reporting these results as practice effects, from T1 to T2, could result in an improvement which actually masks decline.

Table 5.2
T1 and T2 Participant background details and baseline cognitive test results

Time	T1* Range	T1	T2* Range	Significant Difference between T1 and T2		
Variable	(n = 68)	Within Norms?	(n = 68)	t =	$p < .05$* $p < .001$**	r =
MMSE (global cognition)	28.55 ± (1.24) 24 - 30	Yes	28.97± (1.23) 24 - 30	-2.55	*	-.29
Education (total years)	15.52 ± (3.73) 3 - 22	N/A	N/A			
Estimated Premorbid IQ	117.1 ± (9.14) 86 - 131	Yes	N/A			
Symbol Digit Modalities score (right)	45.4 ± (11.66) 16 - 99	Yes	44.82 ± (9.68) 23 - 66	.47	ns	
Delta TMT (seconds)	38.2 ± (27.0) 5.4 – 133.8	Yes	34.08 ± (25.04) 41.5 – 104.09	1.56	ns	
Digit Span Forwards	6.53 ±(1.13) 5 - 8	Yes	6.76 ± (1.12) 5 - 8	-1.33	ns	
Digit Span Backwards	5.23 ± (1.01) 4 - 7	Yes	5.41 ± (1.14) 3 - 7	-.74	ns	
Story Recall – Immediate (score)	11.65 ± (3.87) 2.5 – 18.5	Yes	12.98 ± (3.67) 2 - 23	-2.99	*	-.34
Story Recall – Delayed (as % of Immediate Recall)	83.73 ± (26.03) 14.3 - 180	Yes	87.49 ± (23.1) 0 – 143.5	-.92	ns	
Cognitive Estimation Test (score/9, lower score is better)	2.47 ± (3.0) 0 - 9	Yes	1.41 ± (1.74) 0 - 7	2.51	*	.29
Mobility 1 SUSD (number of completed stand-up/sit-downs)	11.56 ± (3.35) 7 - 30	N/A	11.09 ± (4.31) 0 - 23	.91	ns	
Mobility 2 Balance (seconds)	17.0 ± (11.05) 1.5 – 30.2	N/A	18.29 ± (11.68) 0 - 30	-1.03	ns	

Mobility 3 Heel-to-toe (seconds)	56.86 ± (23.14) 27.26 - 120	N/A	58.85 ± (21.03) 23.77 - 112	-.73	ns
Did not complete Heel-to-toe walk (%)	20.6		17.64		ns

*Values denote mean ± SD

5.3.3 Longitudinal changes –gait outcomes

At T2, there was no significant effect of cognitive load (Serial 3s and Serial 7s) on step-time variability, $F(1,65) = 0.83$, $p > .05$), whereas there had been at T1. Paired-samples *t*-tests were used to investigate changes in performance between T1 and T2 to see if participants' ability to allocate attention efficiently to two concurrent tasks had been maintained, had improved or had declined over the 12 months (see Table 5.3 for means). The results revealed a significant decline in step-time variability (participants walked less steadily) when counting back in 3s, that is carrying out the easier secondary cognitive task (see Figure 5.1) than they did the year before. This was apparent in all three conditions: no prioritisation (T1 M = 0.046 to T2 M = 0.084, $p < .001$), prioritising walking (T1 M = 0.049 to T2 M = 0.066, $p < .05$) and prioritising counting (T1 M = 0.053 to T2 M = 0.068, $p < .05$) (Table 5.4).

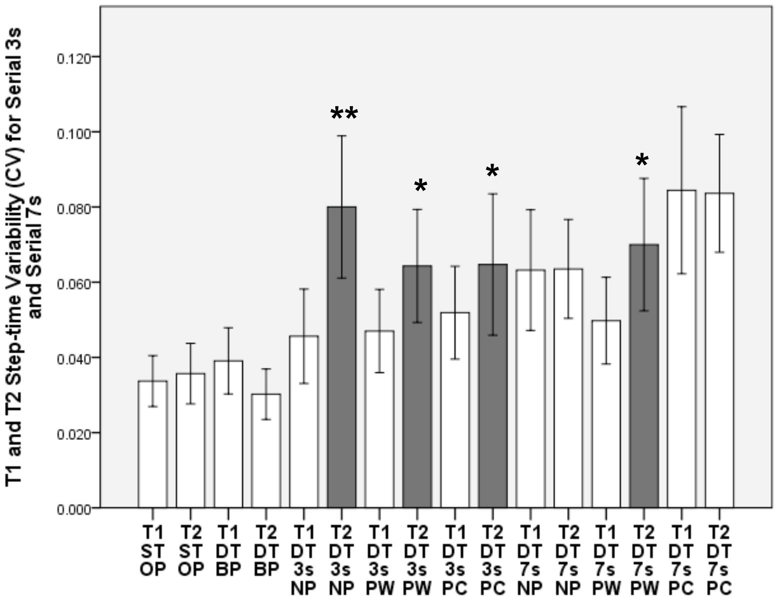

Figure *5.1.* Differences between T1 and T2 step-time variability for Serial 3s and Serial 7s

* $p < .05$

** $p < .001$

Table 5.3

T1 and T2 gait and cognition single and dual-task performance outcomes

Condition	Cognitive Load	**T1** Step-time variability(CV)* in ms	T2 Step-time variability(CV)* in ms	**T1** Velocity in m/s	T2 Velocity in m/s	**T1** CCR	T2 CCR	**T1** SCR	T2 SCR	♦**T1** % Data	♦T2 % Data
Single Task Walking (Own Pace)	N/A	0.036 ± (0.032)	0.037 ± (0.033)	1.186 ± (0.247)	1.430± (.247)	N/A	N/A	N/A	N/A	2.8	0
	N/A					N/A	N/A	N/A	N/A	0	0
Single Task Counting (adjusted to NP time)	Serial 3s	N/A	N/A	N/A	N/A	.445 ± (0.175)	.480 ± (0.190)	N/A	N/A	0	0
	Serial 7s	N/A	N/A	N/A	N/A	.293 ± (0.149)	.321 ± (0.202)	N/A	N/A	0	0
Single Task Brisk Pace	N/A	0.042 ± (0.043)	0.031 ± (0.027)	1.498 ± (0.277)	1.483 ± (.235)	N/A	N/A	N/A	N/A	0	0
	N/A					N/A	N/A	N/A	N/A	0	0
No Prioritisation	Serial 3s	**0.046 ± (0.049)**	**0.084 ± (0.081)**	1.022 ± (0.263)	.916 ± (0.295)	.503 ± (0.182)	.454 ± (0.193)	3.47± (2.85)	3.41± (1.71)	0	0
	Serial 7s	0.064 ± (0.064)	0.068 ± (0.060)	.957 ± (0.313)	.890 ± (0.286)	.295 ± (0.157)	.321 ± (0.202)	3.36± (2.78)	4.99± (3.28)	1.4	0
Prioritising Walking	Serial 3s	**0.049 ± (0.047)**	**0.066 ± (0.061)**	1.053 ± (0.266)	.979 ± (0.289)	.470 ± (0.151)	.437 ± (0.179)	3.56± (1.55)	3.77± (1.69)	1.4	1.4
	Serial 7s	**0.051 ± (0.046)**	**0.071 ± (0.071)**	**.996 ± (0.299)**	**.897 ± (0.283)**	**.334 ± (0.153)**	**.221 ± (0.163)**	**4.58± (1.87)**	**8.09± (8.09)**	0	2.8
Prioritising Counting	Serial 3s	**0.053 ± (0.050)**	**0.068 ± (0.080)**	.978 ± (0.292)	1.254 ± (2.586)	.553 ± (0.179)	.519 ± (0.198)	3.05± (1.26)	3.11± (1.65)	0	0
	Serial 7s	0.087 ± (0.089)	0.085 ± (0.064)	.878 ± (0.284)	.835 ± (0.271)	.270 ± (0.166)	.270 ± (0.183)	6.88 ± (6.24)	6.20± (5.03)	1.4	1.4

Values denote are mean ± (SD), **Bold** = significant differences between T1 and T2, *CV data are transformed, ♦Measures calculated manually

Table 5.4
Significant changes between T1 and T2 Serial 3s and Serial 7s

			Improved/ Declined	**t**	**df**	***p*** **<**	***r***
Serial 3s	CV	DT (NP)	Declined	-3.696	67	.001	-.412
		DT (PW)	Declined	-2.479	65	.05	-.294
		DT (PC)	Declined	-2.121	67	.05	-.251
Serial 7s	CV	DT (PW)	Declined	-2.343	65	.05	-.279
	Velocity	DT (PW)	Declined	3.655	64	.05	.416
	CCR	**ST**	**Improved**	**-2.494**	**66**	**.05**	**-.302**
		DT (NP)	**Improved**	**-2.287**	**66**	**.05**	**-.271**
		DT (PW)	Declined	4.256	64	.001	.469
	SCR	DT (PW)	Declined	-3.782	65	.001	-.424

In the more difficult cognitive task of counting back in 7s participants' steadiness was only affected (declined) when they prioritised walking (T1 M = 0.051 to T2 M = 0.071, $p < .05$) (see Table 5.4 and Figure 5.1). It remained constant when prioritising counting (PC) or not instructed to prioritise attention (NP) (p = ns).

In order to assess whether decline in gait parameters was specific to step-time variability or whether this was a subtle indication of a general decline in walking ability, velocity outcomes from T1 to T2 were also compared. Participants were no slower after a year in any of the experimental conditions except for one: they walked significantly more slowly at T2 when they counted back in 7s *and* prioritised walking (T1 M = 1.053 to T2 M = 0.979, $p < .05$) (see Figure 5.2) than they did one year before (see Table 5.4). Taken together, these results show that gait was compromised at T2, for all prioritising conditions in the Serial 3s task, but in the Serial 7s task, *only* when participants were explicitly instructed to prioritise walking. This suggests that suggests that neither capacity nor processing speed might be the sole factor affecting the DT performance. It is the interaction between them, when conscious mental effort has to be directed to walking that appears to be instrumental in destabilising gait.

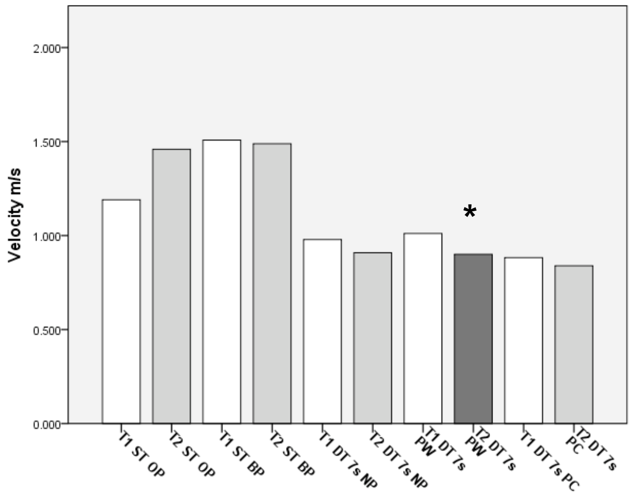

Figure 5.2. Difference between T1 and T2 Serial 7s velocity
*Significance level, p<0.05

5.3.4 Longitudinal changes –cognitive task outcomes

The number of steps per cognitive response is a proxy for the pace of response (a cognitive measure), in relation to the number of steps taken to complete any particular walk. In order to assess whether pace of response had been affected over the 12-month time period between experiments, the paired sample t-tests were used to compare the outcomes between T1 and T2. The only significant difference in pace of response (SCR) was between T1 (M = 4.58) and T2 (M = 8.09) when participants walked and counted backwards in 7s but again *only* when attention was prioritised on walking (PW) ($p < .001$) (see Table 5.3). In this condition, at T2, participants took significantly more steps whilst walking and counting backwards in 7s and prioritising walking than they did the previous year (Figure 5.4). In all other conditions (that is, with the easier cognitive load of the Serial 3s task NP, PW and PC, and the other prioritising directions in the Serial 7s, NP and PC), these older adults took just as many steps per verbal response as a year before (see Table 5.4 and Figure 5.3).

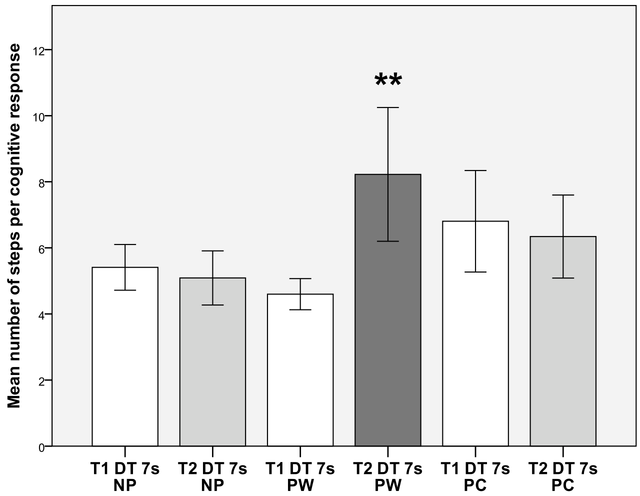

Figure 5.3. Difference between T1 and T2 Serial 7s steps per cognitive response

In order to assess if the changes in gait, over the year, were mirrored in the cognitive performances, CCRs were compared over the twelve months. It was found that participants could count backwards just as well at T2 (see Table 5.4) as at T1 in the Serial 3s cognitive task under all DT conditions (that is NP, PW and PC). In the more cognitively demanding Serial 7s task, participants might have been expected to show a decline after 12 months. However, this group of older adults produced significantly *more* correct responses in the Serial 7s task when just carrying out that task on its own (T1 M = 0.293 to T2 M = 0.321, $p < .05$) and when no specific prioritising (NP) instructions were given (T1 M = 0.295 to T2 M = 0.321, $p < .05$) (see Table 5.4 and Figure 5.4) indicating that cognitive load was not affecting their DT performance. In contrast they produced significantly fewer correct responses when asked to prioritise walking in the Serial 7s task (T1 M = 0.334 to T2 M = 0.221, $p < .001$)

(see Figure 5.4), indicating that they had not compensated for a decline in gait, when they had prioritised walking, by improving their cognitive performance in the same conditions. Cognitive performance (number of correct responses) when prioritising counting remained unaffected between T1 and T2, suggesting that the participants had not shown general attention-prioritising difficulty; the difficulty only became apparent when they were instructed to prioritise walking. In support of the results for gait, the cognitive outcomes revealed that ability to prioritise walking had declined in 12 months, but that this was not due to a general decline in resources or in attentional-processing, rather a specific decline in directing attention on to a normally 'unconscious' or 'automatic' motor-action.

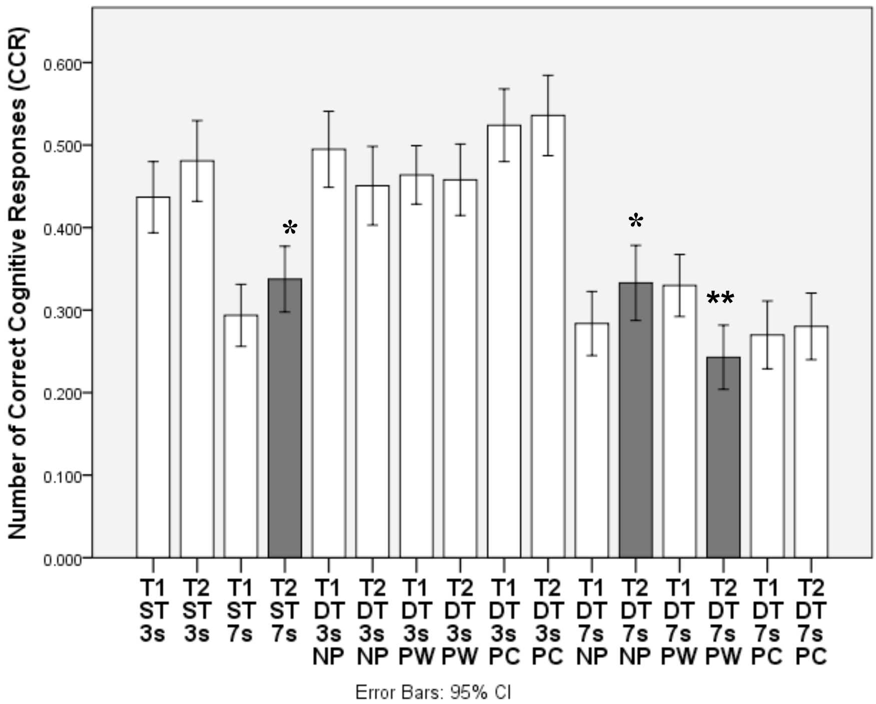

Figure 5.4. Differences between T1 and T2 CCRs for Serial 3s and Serial 7s

* $p < .05$

* $p < .001$

There was very little change overall in this group of healthy older adults, but, when they counted backwards in 7s and were specifically requested to allocate more attention to walking than counting, this condition emerged as particularly sensitive to change over the 12 months and they walked more slowly, were less steady, produced fewer correct responses and had a slower response rate than the previous year. Participants appeared to find it more difficult at T2 to flexibly allocate their attention to walking when the cognitive load of the secondary task was high, that is in the Serial 7s.

5.3.5 Relationships between performance outcomes and underlying cognition

To further investigate attention-allocation in the Serial 7s, prioritising walking condition, potential relationships with EF tests were explored and compared with T1 associations (see Table 5.5). Pearson's correlation coefficient analyses revealed that, when age, global cognition and mood had been co-varied, specific cognitive tests associated most strongly with the T1 – T2 decline in PW gait and cognitive outcomes and these were Delta TMT and SDM (for EF) and delayed memory (see Table 5.5). These were the only standardised tests which showed a strong relationship with all of the Serial 7s PW conditions at T2 and, in some cases, at T1 also. Therefore, these relationships were explored further.

Table 5.5
T1 and T2 Significant correlation coefficients between DT Serial 7s gait and cognition and standardised baseline tests

	Standardised Cognitive Tests							Background Characteristics				
Serial 7s Outcome Measure	Delta TMT	SDM	DS-F	DS-B	IR	DR	CET	Age	MMSE	Est. PMIQ	BDI	Total Years of Education
CV – PW	(.242*)	**-.449****				**-.449****		**.335****	**-.400****	(-290*)		
Velocity PW	**-.212*** (-.300*)	**.488****				**.241***		**-.376****	**.395****		(-268*)	
CCR PW	**-.428****	**.266*** (.224*)	**.217*** (.310*)	**.382**** (.253*)	**.245***	**.240***	**-.289***		**.260*** (.223*)	(.206*)	**-.240*** (-303*)	**.339****
SCR PW	**.312****	**-.221*** (-288*)		**-.273***	-.320**	**-.216***	**.303**** (.304*)	(.288*)	**-.314**** (-263*)			

T1 = (Black), **T2 = Bold,** *Significant at the p < .05 level, **Significant at the p < .001 level

Delta TMT = Trail Making Test B minus Trail Making Test A

SDM = Symbol Digit Modalities Test

DS –F/B = Digit Span Forwards/Backwards

IR = Immediate Story Recall

DR = Delayed Story Recall (as a % of IR)

CET = Cognitive Estimation Test

MMSE = Mini Mental State Examination

Est PMIQ = Estimated Pre-morbid IQ

BDI = Beck's Depression Inventory

5.3.5 Linear and multiple regression analyses

To identify predictors of T2 performance of Serial 7s, linear and multiple regressions were conducted on the all of the performance outcomes which improved or declined over the year. This comprised the ST Serial 7s and the DT no prioritisation cognitive task (NP) and all the prioritising walking (PW) conditions (step-time variability, velocity, CCR and SCR) for Serial 7s. Regression analyses revealed that improved performance in the ST was predicted by the Digit Span/Backwards test which measures more complex cognitive processing in working memory capacity than just memory. Regression analyses also showed that the Symbol Digits Modalities Test (SDMT, an executive function test which measures perceptual/processing speed) at T1 predicted the significant improvement in the Serial 7s no prioritisation condition (DT NP) at T2 ($p<0.05$) (see Table 5.6). When the participants walked, counted back in 7s and prioritised walking (DT PW), the SDMT at T1 was also the only predictor of both of the decline that was observed in the variability in step-time from T1 to T2 ($p<0.01$) and the decline in the number of correct cognitive responses from T1 to T2 (see Table 5.6). No predictors of T2 decline in velocity and steps per cognitive response were found in the performance of standardised tests at T1.

Table 5.6

Linear and multiple regression analyses for T1 predictors of T2 significant changes in DT gait and cognitive performance

Serial 7s PW (CV)	**B**	**SE**	**β**	**R²**	**ΔR²**	**Sig**
Step 1 Constant	0.175	0.036				ns
Symbol Digit Modalities - 1	-0.002	0.001	-.368	.135	.120	**
Step 2 Constant	0.118	0.066				ns
Symbol Digit Modalities - 1	-0.002	0.001	-.335	.213	.139	*
Delta Trail Making Test	0.000	0.000	.175	.213	.139	ns
Digit Span/Forwards	0.007	0.009	-.109	.213	.139	ns
Digit Span/Backwards	0.003	0.010	.042	.213	.139	ns
Serial 7s PW (CCR)						
Step 1 Constant	-0.012	0.071				ns
Symbol Digit Modalities - 1	0.006	0.002	.449	.202	.188	***
Step 2 Constant	-0.076	0.124				ns
Symbol Digit Modalities – 1	0.006	0.002	.449	.236	.179	**
Delta Trail Making Test	0.000	0.001	-.081	.236	.179	ns
Digit Span/Backwards	0.013	0.018	.088	.236	.179	ns
Serial 7s CCR (ST)						
Constant	0.063	0.113		.125	.112	ns
Digit Span/Backwards	0.049	0.02	0.354	0.182	0.143	**
Serial 7s CCR (NP)						
Constant	0.015	0.106				ns
Symbol Digit Modalities	0.005	0.002	.342	0.196	.139	*
Delta Trail Making Test	-0.001	0.001	-.082	0.196	.139	ns
Digit Span/Forwards	0.019	0.022	.118	0.196	.139	ns
Digit Span/Backwards	0.013	0.024	.072	0.196	.139	ns

*p < .05, ** p < .01, ***p < .001

5.3.7 T2 AAI analyses

The Attention Allocation Index (AAI) is a proposed measure of the ability to change prioritisation of attention from one task to another, during a DT (Yogev-Seligmann et al., 2012). No significant changes in AAI over the 12-month period were found in any of the performance outcomes (see Table 5.7). However, there was a trend towards improvement in the participants' flexibility to allocate attention, generally. This is observed in most of the performance outcomes in both Serial 3s and Serial 7s which moved away from 0.00 at T2 compared to T1 (see Figures 5.5 and 5.6). Only in the cases of the AAI velocity for Serial 3s (see Figure 5.5) and AAI step-time variability Serial 7s (see Figure 5.6) did the trend show a move towards 0.00 from T1 to T2, indicating that some ability to flexibly allocate attention had been lost during the year, but this was only noticeable in the gait outcomes. The AAI results for the Serial 7s dual tasks suggest, once again, that, as the requirement for 'mental effort' (attention) increases, step-time variability appears to be more sensitive measure of performance.

Table 5.7

T1 and T2 Attention-allocation Index (AAI) for Serial 3s and Serial 7s

AAI	**Serial 3s**				**Serial 7s**			
	Time 1		**Time 2**		**Time 1**		**Time 2**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
CV	-.060	± 2.09	.564	±1.85	-.855	±2.39	-.441	±2.02
Velocity	.119	± .535	.027	±.203	-.054	±.500	-.069	±.234
CCR	-.134	± .409	-.181	±.323	.311	±.769	-.324	±1.11
SCR	-.159	± .472	.195	±.328	.272	±.662	.353	±1.35

Values denoted are mean ± SD

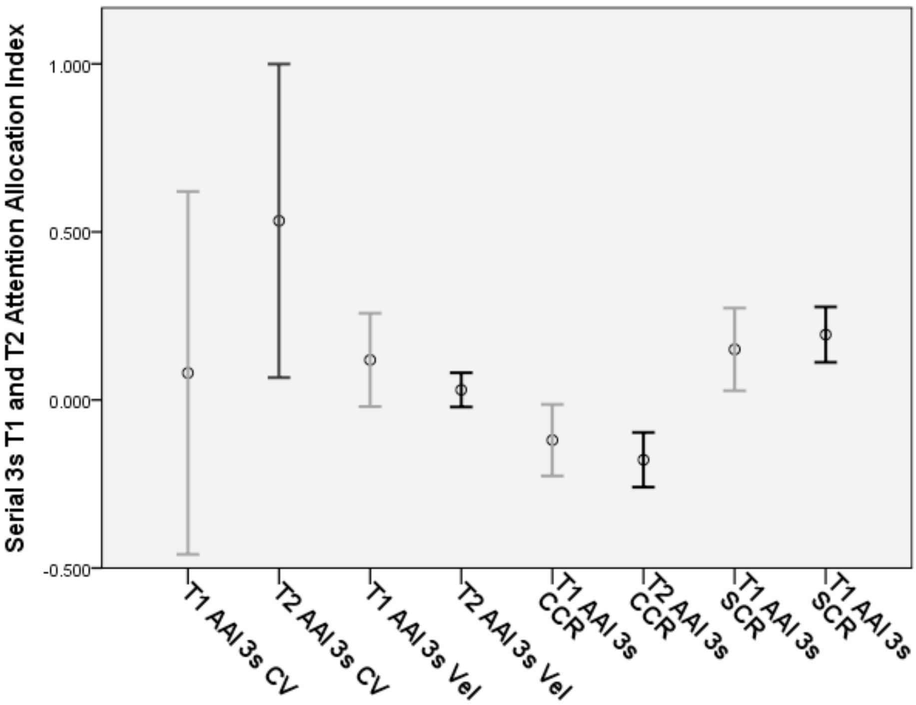

Figure 5.5 T1 and T2 Serial 3s AAI

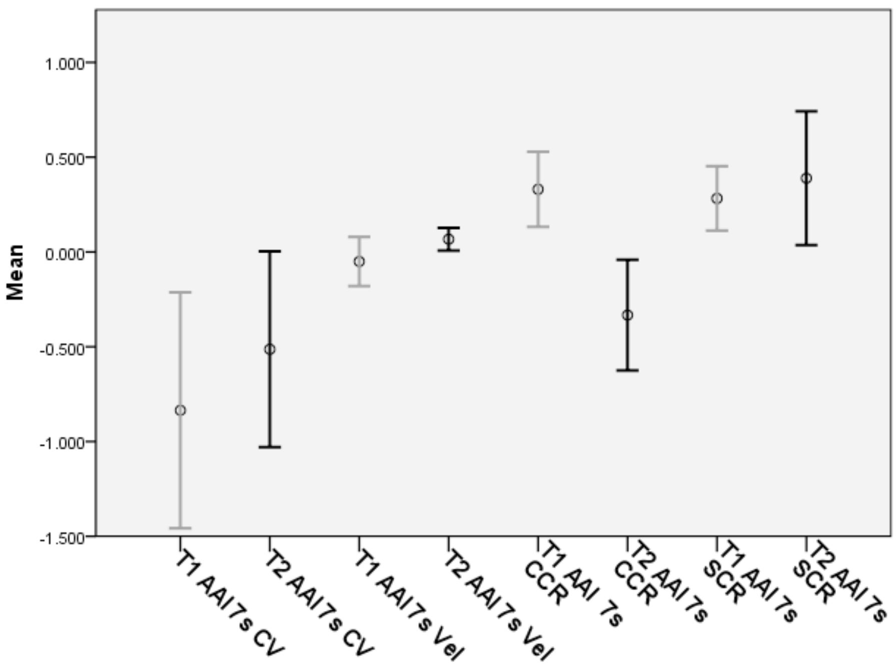

Figure 5.6 T1 and T2 Serial 7s AAI

5.4 Discussion

This group of 68 healthy older adults changed very little over the 12-month period. There were a few small, but non-significant, changes in the group, including small increases in the level of tobacco and alcohol use, the number of medications taken and the number of nights spent in hospital. They also reported walking more regularly and using their physical and cognitive abilities more than the year before. It has been suggested that physical activity, which does not have to be vigorous activity and, for example, could be walking, offers protection against cognitive decline (Weuve et al., 2004; Yaffe et al., 2001). Additionally, Deary (2009) found that increased participation in intellectually stimulating activities was related to the maintenance of cognitive function or reduced cognitive decline in the normal ageing process.

Despite the natural decline in physical and cognitive ability as individuals age, the majority of older people in the general population retain ample ability (both physical and cognitive) to deal with the demands of every-day life, which allows them to lead an independent life, if other health and lifestyle factors do not impact on this capacity (Stuart-Hamilton, 2012). A recent study with healthy older adults found that, a Body Mass Index (BMI) of between 23 and 27 at the beginning of their research was associated with lower risks of functional and cognitive decline in the subsequent 5 years (Deschamps et al., 2002). These findings suggest that a healthy cohort such as the one in this longitudinal study (which had a BMI of 26.2 at T1) might be expected to retain cognitive function over one year. In order to test this, this group's cognitive scores were compared between T1 and T2 and no significant decline in any of the standardised tests was found. Indeed, there were significant improvements in three areas: global cognition, episodic memory and the specific aspect of EF which assesses judgement. This suggests that the participants' general and specific cognitive functions were retained over the year and that, in the absence of any known pathological impairments, they were showing signs of healthy ageing (Yaffe et al., 2010).

5.4.1 Longitudinal changes in DT gait outcomes

Generally, there is an age-related performance decline in the ageing population when attention is divided between two tasks (Vanneste & Pouthas, 1999) but this decline remains constant over time, unless physical or cognitive function has been impaired in the intervening period. When comparisons were made between the T1 and the T2 DT gait and cognitive task performance outcomes, significant differences in both gait measures and cognitive responses began to emerge which suggested that more subtle changes had actually taken place over the year which were not detected by the baseline tests.

At T2, there was no effect of cognitive load on step-time variability, whereas there had been at T1. That is, at T2, the level of difficulty between the two cognitive tasks (Serial 3s and 7s), indicating increasing attentional demands during the dual task, could no longer be distinguished in the step-time variability patterns of the participants' performances (see Figure 5.5). At T2, in comparison to T1, participants were walking just as steadily whether they counted back in 3s or 7s. This lack of effect of cognitive load (in other words, no distinction between the attentional resources required for tasks with varying difficulty) was a subtle indication that this group either found Serial 3s more difficult, or Serial 7s easier, than the year before. This change was not observable in the baseline cognitive tests, detected by change in step-time variability. In fact, in terms of effect on gait steadiness, the participants appeared to find Serial 3s more difficult rather than the Serial 7s being easier, but this would be a premature conclusion to arrive at without first examining the cognitive performance outcomes.

To investigate whether this change in load effect at T2 was due to a reduction in resource capacity (for example in working memory capacity; Baddeley, 2000) or in processing speed ability (for example in specific perceptual or psychomotor functions; Salthouse, 2000). Comparisons between the step-time variability prioritising conditions in both cognitive tasks (from T1 and T2) were made. These revealed that, in the Serial 3s task, gait was less steady at T2, than at T1, when the older adults counted backwards taking away 3s, regardless of prioritisation instructions. It was possible that the inability to allocate attention to either gait or the cognitive task indicated that overall resource capacity had reduced or that processing ability had declined over the year (or a combination of both) but the Serial 3s results did not provide conclusive evidence for either of these hypotheses.

However, in the Serial 7s task, significant decline only occurred in one condition, that is, where participants were instructed to prioritise walking. This means that participants walked less steadily than a year earlier when counting backwards in 7s *only* when prioritising walking (DT PW).

Similarly, the only significant difference in velocity from T1 to T2 in the Serial 7s task was when participants prioritised walking. In this case they walked significantly more slowly than the previous year, in a DT, when asked to prioritise the walking. If the decline were attributed wholly to reduced resource capacity, all prioritising conditions would have been affected similarly (as in the Serial 3s task). In the Serial 7s task, the more attention-demanding task, asking people to prioritise attention on walking, produced the performance which was most sensitive to change. This finding suggests that, when attentional-demands are increased (for example in difficult cognitive task), attention processing ability, and not merely limitations in attentional resources, plays an important role in older adults' gait security.

5.4.2 Longitudinal changes in DT cognitive task outcomes

The number of correct cognitive responses (CCR) between T1 and T2 were compared to examine whether improvements or losses in gait were at a cost or a benefit to the cognitive task. Performance in the easier cognitive task, Serial 3s, did not change over the year. Since there had been a decline in all the step-time variability DT conditions, this suggested that the participants had retained their ability to count when walking, at the cost of their ability to walk when counting, in the easier cognitive task at least.

In the more cognitively-demanding task (Serial 7s), participants produced significantly more correct responses at T2 than they did at T1, both in the ST and the DT, when no prioritisation instructions were issued. This suggests that the decline was not a capacity issue (since the ST performance improved and was predicted by working memory capacity) and that there was a true improvement in the ability to perform a DT, since their gait in the same conditions was also been maintained over the year. That is, as the cognitive task improved, there was no corresponding 'loss' or 'decline' in gait performance. However, when they counted back in 7s and prioritised walking, they produced significantly fewer responses at T2 than they had done in the same condition in the previous year revealing that their improved cognitive performance at baseline and in one DT condition (NP) was not a general improvement in cognitive ability, but was subject to subtle nuances, for example when attention was directed on to walking.

To assess the pace at which these older adults could reason while walking, the number of steps per cognitive response was recorded. Over the 12-month period, there was a significant reduction in the participants' pace of response when they counted back in 7s. Once again, this subtle change was only observed when attention was explicitly directed on to walking (not in the other two prioritising conditions).

5.4.3 Prioritising attention on walking in Serial 7s dual task

The instruction to prioritise walking emerged as the most sensitive/only indicator of subtle decline in this group of healthy older adults who, otherwise, showed no decline over a 12-month period. This is the very condition on which gait security depends when walking is compromised by an intrinsic or extrinsic threat (Woollacott & Shumway-Cook, 2002). The effects of prioritising attention have been found to be relatively preserved in healthy older adults (Yogev-Seligmann et al., 2010) but that, when the postural task becomes more difficult, and requires more attention, the ability to flexibly shift attention allocation and task performance in response to instructions is adversely affected (Kelly et al., 2010). Under the most challenging cognitive conditions, healthy older adults' inability to alter attention-allocation under explicit instructions is directly associated with poorer cognitive flexibility and working memory, specifically set-shifting (Hobert et al, 2011). Here, there is a clear link between ability to prioritise attention and underlying working memory.

The participants in this present study showed a performance pattern in all outcome measures, over the course of 12 months, which showed a decline *only* when they prioritised walking. This pattern suggests that the decline was not a general impairment in attention-processing , but a specific difficulty in allocating attention to a physical function (walking) which, when no risk of falling is present, is otherwise performed 'unconsciously' or 'automatically' (Yogev-Seligmann et al., 2010). When conscious control has to be exerted over walking (for example when someone encounters an obstacle in their way, or when they are specifically instructed to prioritise walking), attention-allocation is under cortical control (top-down) and, therefore, subject to the effect of the integrity of the central executive (Baddeley & Hitch, 1974) or the Supervisory Attentional System (SAS, Norman & Shallice, 1980), depending on the working memory model used. McCabe and colleagues called this over-arching control mechanism 'executive attention' (McCabe et al., 2010).

It could be argued that the participants' decline in all performance outcomes, when explicitly instructed to prioritise walking, is an indication that their executive attention mechanism is less able to efficiently regulate their attentional processing speed (an executive function) which would allow them to prioritise the task that would secure their postural safety in a rapidly-changing environment.

Figure 5.7 illustrates the traditional resource capacity model of cognitive load during an every-day dual task. Flexible attention capacity is limited (boundary outline) with concurrent tasks (dark and light oblong shapes) using more or less attention according to the demands of the changing situation. If a car were to suddenly pull out in front of this driver, s/he would be forced to prioritise attention on driving to ensure her/his security. This individual may have enough resource capacity to cope with the amount of extra cognitive load this would place on her/his resources, but, if her/his ability to efficiently prioritise attention to the more important task were not flexible or were too 'rigid' to adapt to the changing environment, an adverse event (for example, a crash) would occur. It appears that, in this present study, the participants' difficulty in prioritising walking, when instructed, whilst carrying out a difficult cognitive task, provides a small 'window' through which the processes of attention-allocation can be observed. The strong associations between the ability to consciously prioritise walking, while carrying out a difficult cognitive task, and EF (SDMT reflecting fluid cognitive ability in the form of perceptual/processing speed) supports previous findings regarding the association found between EF (TMT reflecting fluid cognitive ability in the form of attentional-prioritisation and set-shifting) in a recent study (Hobert et al., 2011). Both SDM and TMT tests for EF are strongly associated with working memory ability (Lezak, 1995; Spreen & Strauss, 1998) and, therefore, it should not surprise researchers in models of working memory that, every-day life activities also relate strongly to these types of clinical tests.

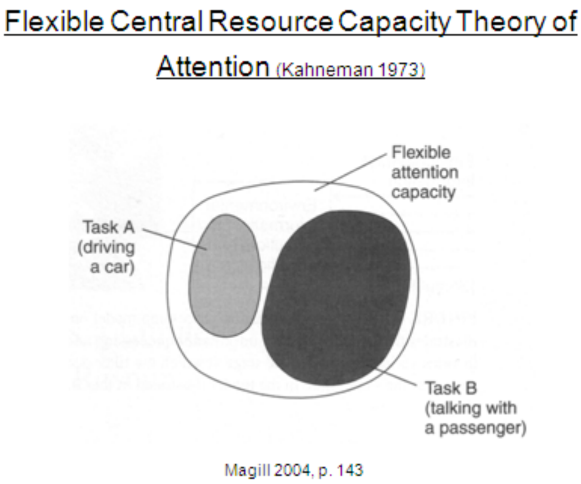

Figure 5.7. Attention-processing within a limited resource-capacity model

Since the participants in this present study were clearly able to allocate attention when no prioritisation instructions were given (DT NP) and prioritise when they were asked to prioritise counting (DT PC), the problem appears to lie with a 'rigidity' or 'inflexibility' of attention-allocation, but only when they were explicitly instructed to prioritise walking. Why this condition should be most sensitive is outside the scope of the study, but possible reasons may lie in pathological decline in dopamine receptors, (Deary, 2009) or impairment in the basal ganglia-thalamic connections (Royall et al., 2002), interference between intrinsic and extrinsic goals (Sanders et al., 2008) or psychosocial factors such as 'judgement' (Brown, Tickner & Simmonds, 1969; Yogev-Seligmann et al., 2012b). The findings of this longitudinal study provide fertile ground for researchers in other neuroscience and related bio-medical and psychological areas to expand on these findings.

Chapter 6: The effect of musical training on gait and cognition

6.1 Introduction

In patients with PD, both EF and attention contribute to functional gait and are used selectively to optimise DT requirements, but attention is more effective in discriminating gait performance (Lord, Rochester, Hetherington, Allcock & Burn, 2010). Interventions to improve attention-allocation when walking and carrying out a cognitive task have been developed for PD patients' and these have shown that training older adults with PD to optimise their division of attention when walking and carrying out a cognitive activity can benefit their gait (Yogev-Seligmann et al., 2012a; Schwenk et al., 2010). For example, rhythmic movement training increases gait regularity and automaticity, which in turn is linked to increased gait safety plus a reduction in fall risk (Bridenbaugh & Kressig, 2010). External rhythmical cues may create spare attentional capacity for DT performance by activating the parieto-prefrontal pathway to reduce attentional cost (Rochester et al., 2007). However, whereas PD patients' gait can benefit from an external cue acting as a constant prompt and reducing attentional cost, a rhythmic cue was found to impair healthy older adults' gait because it increased attentional demand (Baker, Rochester & Nieubower, 2008). Auditory cues, sometimes embedded in music, have been particularly successful at training older adults with PD to walk more steadily (Nieuwboer et al., 2007; Rochester, Burn, Woods, Godwin, & Nieuwboer, 2009; Satoh & Kazuhara, 2008; Thaut et al., 1996; 1997; Trombetti et al., 2011), although, again, one study found that music playing interfered with patients' gait performance, especially when a secondary cognitive task was added (Brown, de Bruin, Doan, Suchowersky & Oksana, 2009).

A musical rhythm, either on or off the beat can affect PD patients' performance of a visual task (Escoffier, Sheng & Schirmer, 2010). These researchers concluded that musical rhythm trains attentional processing to synchronise with the on-beat rhythm. Similarly, matching auditory cues to their preferred walking pace can optimise the gait steadiness of people with PD (Arias & Cudeiro, 2008) but was found to have a deleterious effect on patients with AD (Wittwer, Webster & Hill, 2012). Wittwer and colleagues suggested that the music had overloaded their participants' EF capacity which was already reduced to due to the effects of having AD.

Improving gait steadiness through training could also be of benefit to healthy older adults without cognitive impairment. Recent research has shown that steadiness of gait and rhythmicity are automatic and don't require 'conscious' attention or mental effort in healthy older adults (Yogev et al., 2005). With enough practice and experience, a task can become more of an automatic process and, when another task is added, less interference will be observed between the two. People can use automatic processing for easy or familiar tasks but, when novel tasks, or more demanding ones, are introduced, more controlled processing is required (Shiffrin & Schneider, 1977). This was demonstrated in a dual-task driving situation. Researchers found that, in order to find the right radio station while simulating driving, novice drivers looked away from the 'road' for dangerously long periods compared to experienced drivers (Wikman, Nieminen & Summala, 1998). Training healthy older adults to walk more steadily by making gait more rhythmic and automatic so that it requires less mental effort (Luszcz, 2011; Moors & DeHouwer, 2006) could free attentional resources, which potentially could be transferred to carrying out a secondary cognitive task. This mental effort could then be 'observed' by its effect on the secondary cognitive activity in the DT.

It was anticipated that, after musical training, the music training group's gait would become steadier and more automatic. Performance on the cognitive task was examined for evidence of attention being transferred from the motor task (walking) to the cognitive task (counting) after musical training. We further anticipated that the groups who either just heard music playing or had no music playing would experience no impact on either walking or cognitive performance.

When the cognitive load becomes very demanding, gait stability (which includes a measure of step-to-step variability) suffers (Hausdorff, 2005). This is important because dual-task situations, such as walking and talking, are common in everyday life. Finding ways to improve older adults' attention allocation could be beneficial both for ensuring gait stability and enhancing 'postural reserve', which is an individual's ability to respond effectively to a postural threat (Yogev-Seligmann, Hausdorff & Giladi, 2012b).

6.2 Methods

6.2.1 Participants

Forty-five participants (28 women, 17 men, mean age = 71.7 years, age range, 65 - 88 years) were recruited from the locality of St Andrews in the East of Scotland, by means of leaflets, posters and talks to established groups of older adults. Required participant numbers were calculated using the G-Power program, with a power value of 0.8 and a strong effect size (0.5). Participants were offered reimbursement of their travelling expenses to the research centre. Following recruitment, participants were randomly assigned to Musical Training (MT) Group (n = 15), a Music Playing (MP) Group (n = 15) and a No Music (NM) Group (n

= 15). The first 15 participants recruited were assigned first to the MP group because that group had to provide a mean number of walks for the control groups' intervention procedure. The inclusion criteria were over 65 years of age, able to walk unassisted, living independently and English as first language.

6.2.2 Ethics

The Study was approved by the University of St Andrews Teaching and Research Ethics Committee (UTREC). All participants were given details of the study prior to participation, and had the opportunity to raise any questions about the study before providing signed consent to take part.

6.2.3 Design

The aim of the experiment was to explore the effects of training to walk to an auditory musical cue on gait and cognition measures in both single and dual-task conditions. The experiment used a mixed design. The independent variables were task (ST vs. DT), time (pre- vs. post-intervention training) and group (MT vs. MP vs. NM). The dependent variables for gait were time to walk 15 metres, number of steps, step-time variability and velocity in both single (ST) and dual task (DT) conditions. The dependent variables for cognition were the number of Correct Cognitive Responses (CCR) and steps taken per total number of cognitive response (SCR).

6.2.4 Materials

A demographic questionnaire was constructed to collect self-reported health, mood and lifestyle measures. A battery of norm-referenced cognitive measures was assembled to provide a baseline assessment of participants' functioning, including memory and executive functions. This comprised:

1. Mini-Mental State Examination (MMSE) (Folstein et al, 1975)

The MMSE provides a brief measure of global cognitive function that is scored out of 30 where scores of 27-30 indicate healthy cognitive function, with norm-referenced adjustments for participants over 80 years of age (Spreen & Strauss, 2006).

2. Trail Making Test A and B (TMT A & TMT B: AITB, 1944) (Reitan & Wolfson, 1993).

TMT A and B provide a measure of executive functions (visual attention and task-switching) assessed through speed in seconds to complete both parts (Delta TMT – B minus A).

3. Symbol Digits Modalities Test (SDMT) (Smith, 1982).

SDMT provides a measure of attentional processing speed and perceptual speed where participants match as many numbers to symbols as possible in 90 seconds.

4. Digit Span Forwards and Backwards (DS/F & DS/B) (Thorndike et al., 1987).

These tasks provide a measure of verbal working memory by repeating short strings of numbers both forwards and backwards. The score is based on the number of items correctly repeated

5. Immediate and Delayed Story Recall (Wechsler, 1987)

Story Recall provides a measure of episodic memory by asking participants to recall immediately and after a 30-mintue delay story as much detail as possible from a story read aloud to them. Scoring comprises total number of ideas correctly recalled immediately out of 25 and the percentage of ideas recalled after the delay.

6. National Adult Reading Test (NART) - 2nd Edition (Nelson, 1982)

The NART provides a measure of crystallized intelligence through reading a list of progressively difficult and phonetically irregular English words. The total number of errors is converted to a Full Scale IQ equivalent.

7. Beck Depression Inventory Short Form (BDI) (Beck et al., 1996).

The short-form BDI screens for the presence of clinical depression, where scores above 13 indicate clinically significant problems.

6.2.5 Equipment

The ‘Bigfoot’ footswitches and connected software were developed in the School of Psychology at the University of St Andrews. Bluetooth technology, housed in a PC ‘mouse’ in a box attached to the participant’s waist, was used to measure mean time, velocity, number of steps and step-time via two footswitches which were fastened to their heels with ‘Velcro’ strips and attached by wires to the box containing the ‘mouse’. By using the formula for Co-efficient of Variation (CV), standard deviation divided by the mean, the ‘Bigfoot’ equipment calculated the variability of step-time for each participant. The ‘Bigfoot’ equipment had previously been validated against video recording equipment to capture the gait conditions and a stopwatch to measure the time of each step (See Chapter 2). A video recording (using a Sony Cyber-shot 7.2 camera) was taken and a voice recording (using a Sony Dictaphone) was made of all of the gait experiments. The main gait parameters measured over 15m were mean step-time (ms), velocity (m/s), time of walk (seconds), number of steps and the variability of step-time (ms) expressed as the Coefficient of Variation (CV). Mean values across all the walking conditions for each participant were calculated using the ‘Bigfoot’ software.

The music chosen for training was Jimmy Shand's 'Bluebell Polka', which has a 2/4 rhythm (two strong beats to each bar) which reflected a walking rhythm. The music was composed and performed by a local folk musician and was well-known to local residents. This was verified in a post-experiment questionnaire. The preferred walking pace of each of the participants in the Music Training and the Music Playing Groups was matched to the music using the 'Amazing Slow Downer' downloaded from www.ronimusic.com This software allowed the timing of the selected music to be slowed down or quickened from the 100% pace set on the programme (the difference was calculated by the researcher for each participant after their initial 2 ST walks). The music was placed on a 'loop' and played continuously at the participant's preferred pace. The researcher could then mute and unmute the music at will, depending on the experimental condition.

6.2.6 Procedure

Participants were asked to attend wearing comfortable, flat shoes. Each participant first completed the demographic questionnaire, cognitive test battery and the short-form BDI. Participants then completed as many stand up and sit down manoeuvres as they could in 30 seconds, a timed 15 metre heel-to-toe walk, and stood on one leg for as long as possible up to 30 seconds.

They were then asked to walk along a 15m indoor walkway twice at their self-selected pace. The walkway was a flat corridor marked off at either end with tape indicating the 15m walk plus 1m at either end to allow for acceleration and deceleration. The Single Task (ST) time and number of steps were averaged and used to adjust the pre-selected music to the participant's preferred walking pace. In the pre-intervention Dual Task (DT), participants in all groups walked at their own pace whilst subtracting 7s out loud (DT) from an initial 3-digit figure, which was randomly generated for each DT condition. The numbers in all of the DT conditions were different 3-digit numbers where all the digits were different. The actual numbers used were 183 and 241. The DT walking conditions were carried out twice so that participants could practise the secondary cognitive task, with data from only the second of the two tasks recorded. The initial ST walking conditions were considered to be practice for the other pre- and post–intervention ST walking conditions. A final 15m ST walk, with no music playing, was completed at the end of the experiment by all groups.

The participants completed the 1-minute ST cognitive test whilst seated, counting backwards and subtracting . They were allowed to practise the test once and only the results from the second performance were recorded. The test was counter-balanced between the start and the end of the experiment to reduce possible practice effects during the DT walking conditions. All of the cognitive tasks (both ST and DT, practice and recorded) started with different 3-digit numbers.

6.2.7 Musical training

Each member of the Musical Training Group was then instructed to walk to the music, which had been adjusted to their individual preferred walking pace. This was calculated by taking the average time divided by the average number of steps to walk 15m.

The music was matched to their walking pace by calculating the percentage difference between the participants' preferred walking pace and the speed of the music chosen by the researcher. The speed of the music was then increased, or decreased, manually by the researcher until it matched the participant's preferred walking speed. After adjusting the music, the participants were asked to walk up and down the 15m stretch to the adjusted beat of the music until they felt that they were walking 'in time with the music'. Participants were not told that the music had been adjusted to suit their preferred pace. Participants in the MT group walked for an average of 4 times until they felt they were walking comfortably to the beat of the music 'without having to think about it'. If clarification was required, they were told to walk in time to the music, until they were no longer thinking about the music or the walking. After training, post-intervention conditions consisted of a ST 15m walk to the adjusted music, followed by a DT 15m walk to the adjusted music. A final ST walk without music was completed at the end to test if any change after intervention would persist.

The Music Playing Group carried out all the same conditions as the Musical Training Group without being trained to walk 'in time to the music'. This group was told that there would be music playing in the background, but participants were not instructed to walk in time to it. The same intervention (15 metres x 4 times) was used for this group as for the MT Group and, like the MT group, these participants were not told that the music had been adjusted to suit their preferred pace. They simply heard the adjusted music playing in the background as they walked. The No Music Group completed all the same conditions as the other two groups but heard no music throughout the experiment. Each group completed the walking conditions in the same order to ensure everyone experienced the 4 x 15 metre walks at the same point in the experiment.

The main gait parameters measured over 15m were: step-time (ms), velocity (m/s), time of walk (seconds), number of steps and the variability of step-time (CV). The main cognitive parameters were: total number of responses, errors, total number of correct responses and correct responses as a percentage of the total responses. Participants' correct responses were calculated as a proportion of time taken (in seconds) of the individual's DT walk divided by the proportion of correct cognitive responses to the total number of responses, thereby taking into consideration the number of errors they made. This calculation produced the number of correct responses per second (CCR) for that condition. In this way, each participant's cognitive responses were scored in relation to their individual walking performance in their own DT condition.

The total number of steps in each DT condition was divided by the total number of cognitive responses to give the number of steps per response, as a measure of the pace at which participants simultaneously walked and counted.

6.2.8 Statistical analyses

Responses to the questionnaires and standardised cognitive tests were scored manually and compared between groups using independent t-tests. Descriptive statistics indicated that the gait data were not normally distributed, therefore non-parametric statistical analyses were performed. Kruskal-Wallis test was used to test for group effect and Mann-Whitney (post-hoc) test was used to test for differences between pairs of conditions across the groups. Wilcoxon signed-rank (post-hoc) test was used to compare results between pairs of conditions within groups. Where data were normally distributed, ANOVAs and follow-up t-tests were used. The gait and cognition and descriptive measures were analysed to investigate possible correlations between them. The statistical significance for the experiment was set at .05 and the effect sizes were calculated and reported as *r* values. All data were analysed using PASW Statistics 19.0.

6.3 Results

6.3.1 Participants

The 45 participants were divided into three groups (described in detail in the methods section) and, in order to assess the homogeneity between groups, their background characteristics were compared (see Table 6.1). No single group appeared to differ in their background characteristics from the other two, except that more people in the music playing group drank fewer than seven units of alcohol a week and more of the no music playing group had never smoked. The majority of the participants in the groups that heard music playing were familiar with music (MT and MP groups 87% respectively) and most of the MT group were happier at the end of the experiment than before it began (53%) which was an improvement over the mean for the whole group (37.2%) and larger than the mean of the other two groups (29% respectively).

Table 6.1
Participants' background characteristics at baseline by group

Characteristic	Group Response		
	Musical Training	Music Playing	No Music
No. of Participants	15	15	15
Gender (M/F)	4/11	6/9	7/8
Age (years)	73.2 (±5.36)	69.1(±3.37)	72.9(±6.490)
Beck's Depression Inventory	1.2 (±1.38)	1.33 (±1.98)	0.47 (±0.74)
Self-reported chronic medical conditions	1.67	1.53	2
Self-reported nights in hospital in previous year	1.13	1.07	1.07
Self-reported falls in previous year	1.33	1.2	1.53
Less than 7 units of alcohol a week (%)	60	73	60
Never smoked (%)	46.6	40	73
Alzheimer's Disease in immediate family (%)	26.6	33	20
BMI indicates overweight or obese (%)	60	50	57
Self-reported satisfaction with health status (%)	93	80	73
Walking every day (%)	93	87	93
Carry out at least 5/6 Instrumental Activities of Daily Living a week (%)	80	80	87
Perform more exercise than peer group (%)	53	60	60
Exercise at least 3 times a week (%)	80	87	100
More cognitive activities than peer group (%)	60	80	87
Cognitive activities - at least 3 times/week (%)	100	100	100
Recognised the music played	87	87	N/A
Mood improved over experiment (%)	53	29	29

6.3.2 Standardised baseline tests

In order to verify the homogeneity of the 3 groups, in term of cognitive ability, their standardised baseline tests were analysed and compared between groups. The 45 participants were all in the normal range of global cognitive function as measured by the MMSE and all performed within the age-appropriate norms on each of the baseline cognitive tests (see Table 6.2). Their premorbid IQs suggested they were an above average sample (see Table 6.2) and none was suffering from depression as measured by the BDI. Twelve out of the 45 healthy older adults, four in the MT group, three in the MP group and 5 in the NM group, chose not to attempt the heel-to-toe walk. Declining to perform this walk has previously been taken as an indicator of fear of falling (Nakamura, Holm & Wilson, 1999) but closer inspection of the falls history of these 12 participants in the previous year, compared to the participants who completed the walk, did not support this concern.

Table 6.2

Participant physical and cognitive functions and mood at baseline

Characteristics	Music Training (MT) Group #	Music Playing (MP) Group #	No Music (NM) Group #
Mini Mental State Examination	28.4 (±1.18)	29.1 (±1.28)	28.7 (± 1.83)
Estimated Pre-morbid IQ	119.6 (±4.32)	117.33 (±5.52)	117.5 (±7.72)
Digit Score/Forwards	10.6 (±2.09)	10.4 (±2.7)	10.6 (±2.6)
Digit Score/Backwards	6.87 (±1.8)	8.2 (±2.4)	8.6 (±2.9)
Delta/Trail Making Test	50.5 (±28.3)	48.1 (±25.4)	34.1 (±19.3)
Symbol Digit Modalities Test	39.9 (±7.2)	43.6 (±10.8)	47.0 (±9.3)
Immediate Recall (Story)	11.1 (±3.8)	11.4 (±2.92)	9.9 (±5.3)
Delayed Recall (% of Immediate Recall)	94.3 (±14.6)	102.8 (±13.9)	83.9 (±26.6)*
Number of complete stand-up/sit - downs	9.35 (±2.12)§	12.17 (±2.89)	11.83 (±4.02)
Time taken in Heel-To-Toe Walk (15m)	19.3 (±28.4)	39.15 (±26.5)	37.77 (±31.7)
Number who completed Heel-To-Toe Walk	10/14	12/15	10/15
Balance on one leg time (seconds)	15.54 (±10.5)	20.99 (±9.9)	19.29(±11.06)

#Values denoted are mean (± Standard Deviation)

*Significant difference between NM and MP groups, $p < .05$

§Significant difference between MT and MP groups, $p < .05$

In order to investigate the effect of the intervention training period on the groups, their single task and dual task performances were compared within groups and between the groups, before and after training. These comparisons were carried out using Mann-Whitney and Wilcoxon signed rank tests, as appropriate. The significant changes and differences are given in relation to medians and ranges in Table 6.3. There were no missing data due to 'Bigfoot' malfunction, therefore none of the analyses had to be carried out manually.

Table 6.3

Changes in gait and cognition performance - ST and DT, pre- and post-intervention training – median values and (ranges)

	Music Training Group (*n* = 15)					**Music Playing Group (*n* = 15)**					**No Music Group (*n* = 15)**				
	Single Task			**Dual Task**		**Single Task**			**Dual Task**		**Single Task**			**Dual Task**	
Parameter	**Pre-Trg**	**Post-Trg**	**Post-Trg (end)**	**Pre-Trg**	**Post-Trg**	**Pre-Trg**	**Post-Trg**	**Post-Trg (end)**	**Pre-Trg**	**Post-Trg**	**Pre-Trg**	**Post-Trg**	**Post-Trg (end)**	**Pre-Trg**	**Post-Trg**
Velocity	1.22 (.77)	1.09 (.87)	1.23 (.61)	**1.06‡** (1.15)	1.08 (.81)	1.38 (.59)	1.36 (.53)	1.34 (.67)	**1.15‡‡** (.83)	**1.16‡‡** (.85)	1.25 (.88)	1.31 (.75)	1.27 (.72)	**.986‡‡** (.97)	**1.12‡‡** (.98)
Step-time variability (CV)	.130† (.62)	**.060*** (.61)	.062 (.81)	.282§ (.99)	**.070** (.45)**	.050 (.31)	.060 (.26)	.045 (.33)	070 (.27)	.080 (.43)	06 (.43)	.060 (.42)	.059 (.47)	060 (.90)	.170 (.69)
Correct Cognitive Responses per second	.324 (1.15)			.352 (1.15)	.323 (1.28)	.415 (.74)			.399 (.77)	.343 (.65)	.361 (.56)			.348 (.65)	.296 (.60)
Steps/Total Cognitive Responses				4.0 (9.4)	4.0 (18.8)				3.38 (7.67)	3.71 (16.33)				4.12 (9.10)	4.75 (16.03)

Values are Median (range), Trg - Training

‡ Significant changes from ST to DT, $p < .05$

‡ ‡Significant changes from ST to DT, $p < .001$

† Significant difference between MT's ST pre-training CV and MP group's ST pre-training CV**,** $p < .05$

§ Significant difference between MT's DT pre-training and MP and NP groups' DT pre-training CV**,** $p < .01$

* The MT group's ST step-time variability (CV) improved after training, $p < .05$

* * The MT group's DT step-time variability (CV) improved after training, $p < .05$

6.3.3 Correct cognitive responses

Before training the three groups performed similarly at counting backwards in 7s both singly and when walking F (2, 42 = .210, p >.05) (see Table 6.2). It was anticipated that any impact of the musical training would reflected in the cognitive performance of the MT group, in the form of improvement (training freed up attentional processes from gait for the cognitive task), reduction (training drew attentional resources away from gait for the cognitive task) or no change (training did not affect attentional resources available for the cognitive task). After training, there was also no significant difference either between or within the groups' performances F (2, 42 = .136, p > .05). This means that the MT group's cognitive performance was unaffected by the intervention training, whilst, at the same time, their step-time variability improved (see Table 6.3 and later results) whereas the MP and NM groups also maintained their cognitive performance but their gait did not improve. Further investigation revealed that there were no differences between the groups' ST cognitive responses, $\chi^2(2) = 2.99$, p >.05, DT pre-training responses, $\chi^2(2) = 1.29$, p >.05 and DT post-training responses, $\chi^2(2) = 1.12$, p >.05.

6.3.4 Steps per cognitive response

The intervention training had no effect on the pace of correct responses (SCR) across the groups F(2,42) = .063, p >.05) or between conditions within groups (see Table 3). Further investigation revealed that there were no differences between the groups' DT pre-training responses, $\chi^2(2) = 0.636$, p > .05 and DT post-training responses, $\chi^2(2) = 1.068$, p >.05.

6.3.5 Velocity

Velocity results in the baseline conditions, across all groups, were similar in previous literature for healthy older adults (for example Hollman et al., 2010). Velocity in all three groups was slower in the DT (pre- and post-training) than in the ST conditions (MT group $\chi^2(2) = 33.70$, p <.05, MP group $\chi^2(4) = 30.6$, p <.05 and NM group $\chi^2(4) = 39.1$, p <.05). Wilcoxon tests were used to follow up these findings. The MT group's velocity was significantly slower in the pre-training DT (Mdn = 1.06), T = 10, p <.05, r = -.52 (Table 5 and Figure 2) but the MT group's post-training DT speed (M = 1.08) was not significantly different from the ST post-training performance (M = 1.09) p >.05. That is, after intervention training, the MP and the NM groups' dual-task 'cost' was that both groups walked more slowly when performing the gait and cognitive tasks together, relative to when they walked without counting, but the MT group who, after training, showed no DT deficit speed, relative to the same ST condition (see Table 6.3 and Figure1).

Participants in the MP group also walked significantly more slowly in the pre-training DT (Mdn = 1.15) T = 0, p <.05, r = -.62 and in the DT post-training (Mdn = 1.6) T = 0, p <.05, r = -.61 than in the ST (Mdn = 1.38). Likewise, the NM group walked significantly more slowly in the pre-training DT condition (Mdn = 0.99), T = 0, p <.05, r = -.62 and in the post-training condition (Mdn = 1.17), T = 3, p <.05, r = -.59 than in the ST (Mdn = 1.25). That is all of the groups walked more slowly when performing the gait and cognitive tasks together, relative to when they walked without counting. This is the 'cost' of performing two tasks together.

The three groups' ST velocity at the very end of the experiment (with no music playing) was investigated for possible lasting effects of musical training but there was no significant group effect H(2) = 3.62, p >.05, suggesting that speed had not been changed by the musical intervention training.

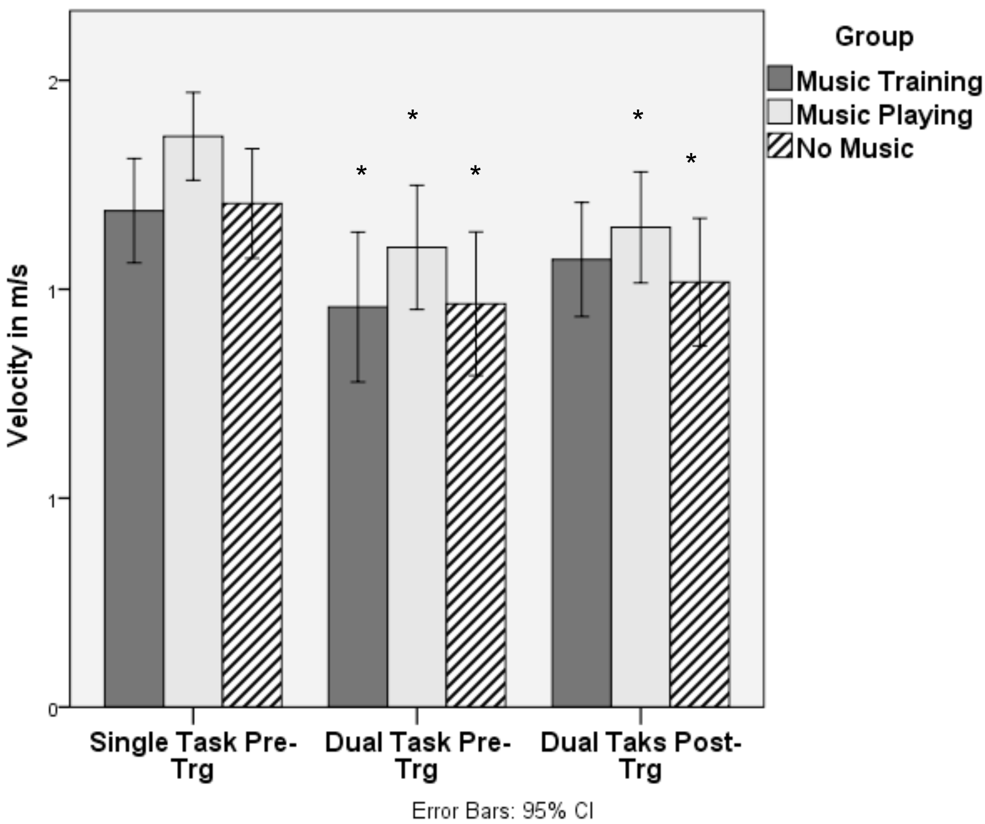

Figure 6.1. Changes in ST to DT Velocity pre- and post-training

*Significant change between ST and DT pre-training conditions (p <.05)

** Significant change between ST and DT post-training conditions (*p* <.05)

6.3.6 Gait step-time variability

Step-time variability is often expressed as a Coefficient of Variation or CV (as calculated by the SD divided by the Mean) and provides a well-used measure of gait stability. Baseline step-time variability results in this study were similar to previous literature for healthy older adults (for example Hollman et al, 2007; 2010). Statistical analysis of data revealed that there was an effect of group in the ST (H (3) = 7.02, p <.05). It appeared that, at baseline, in the ST, there was no difference in step-time variability between the MT group (Mdn = 0.13), and the NM group (Mdn = 0.06), (U = 98.5, z = -0.585, p >.05, r = -.11) and no difference between the MP group ((Mdn = 0.05) and the NM group (Mdn = 0.06), (U = 102.5, z = -0.42, ns, r = -.08) but that the MT group (Mdn = 0.13) had significantly less steady gait than the MP group (Mdn = 0.05), U = 53.4, z = -2.47. p <.05, r = -.45 (see Table 6.3). Immediately after the intervention, there were no significant differences in step-time variability (CV) between the groups, H(2) = .232, p >.05 (see Table 6.3 and Figure 2).

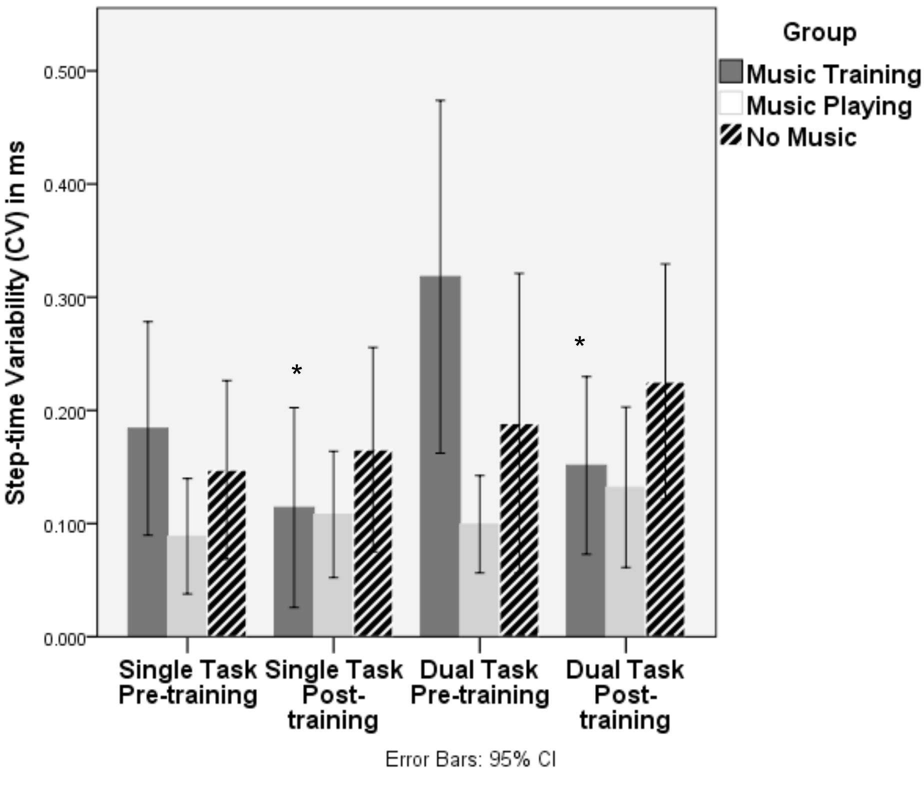

Figure 6.2. Significant group differences between ST and DT pre- and post-training CV.
*Change between ST Pre- and Post-training conditions significant at p < .05

**Change between DT Pre- and Post-training conditions significant at *p* < .05

When the CV was analysed further within groups, Freidman's test confirmed that there were significant differences within the MT group's gait performances, χ^2 (4) = 14.59, *p* < .05). In the ST, the step-time variability of the Musical Training group (Mdn = 0.130) improved after training (Mdn = 0.06), (T = 0, *p* <.05, *r* = -.62). There were no significant changes in either the MP group's pre- (Mdn = 0.05) to post-training (Mdn = 0.60) or in the NM group pre- (Mdn= .060) to post-training performances (Mdn = .060) in the ST pre- and post-training conditions (see Figure 6.3).

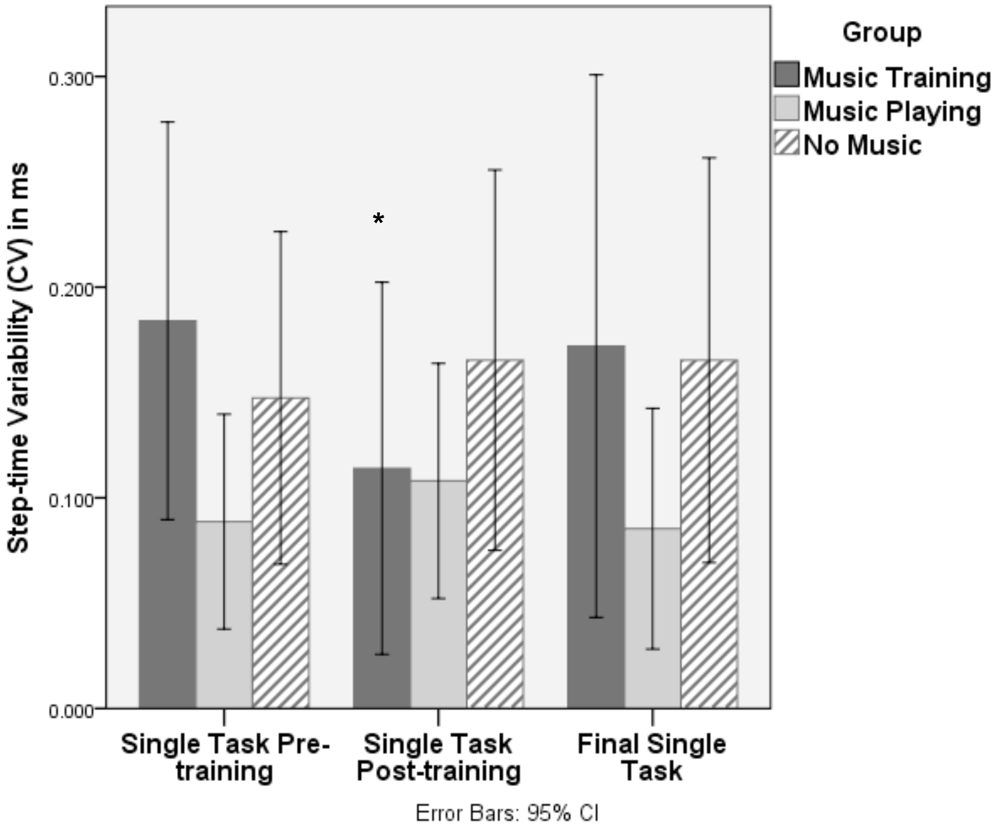

Figure 6.3. Changes in ST pre- and post-training conditions
*Change between ST Pre- and Post-training conditions significant at *p* < 0.05

There was also a significant group effect of the DT in the pre-intervention condition (*H* (2) = 6.69, *p*<0.05), whereas in the DT post-training condition, there were no significant differences between the groups (*H* (2) = 2.07, *p* >.05).

When this was followed up, tests revealed that the MT group (Mdn = 0.282) walked significantly less steadily in the DT pre-training condition than the MP group (Mdn = 0.070), (U = 49.5, z = -2.62, *p* <.05, r = -.48). The significant improvement in DT CV was produced at no 'cost' to DT cognition, i.e. there was no decline in performance on the secondary cognitive task in the DT condition. There were no significant differences between the MT group (Mdn = 0.282) and the NM group (Mdn = 0.060), U = 70, z = -1.77, p >.05, r = -.14) or between the MP group (Mdn = 0.070) and the NM group (Mdn 0.06), U = 107, z = -0.230, p >.05, r = -.04) (Figure 6.2).

The step-time variability (CV) showed significant changes between experimental conditions within the MT group $\chi^2(4) = 12.75$, p <.05. The MT group improved significantly from pre- (Mdn = .282) to post-training (Mdn = .070) in the DT, T = 16.5, p <.05, r = - .41. The improvement was such that after training, the MT group's gait became steadier in the DT (Mdn = 0.070) than it had been in the ST at baseline (Mdn = 0.130). Although this was not statistically significant (T = 13, p >.05, r = - .18), it did show a noticeable return to ST steady gait whilst maintaining DT cognitive performance (see Figure 6.4). There was no significant change in step-time variability (CV) in either the MP group's DT pre- (Mdn = .070) to post-training performance (Mdn = .080) (T = 42, p >.05, r = -.1) or in the NM group's pre- (Mdn = .060) and post-training performance (Mdn = .170) T = 47, p >.05, r = -.16 (see Table 6.4 and Figure 6.2).

6.3.7 Magnitude of change

So that the effect of intervention could be measured, the amount of change was measured and compared between the groups. This was carried out using the means of performance outcomes, rather than the medians which had been used for statistical analyses (see Table 6.4). The magnitude of pre- to post-intervention change in step-time variability (CV) in the ST and DT conditions was compared between groups. This revealed a significant group difference in the change in the DT performance H(2) = 8.14, p <.05. Further tests showed that the MT group's performance change (in this case improvement) was significantly greater (than either the MP group (U = 58, r = -.34, p <.05,) or the NM (U = 55, r = -.36, p <.05) (see Table 6.4 and Figure 6.4).

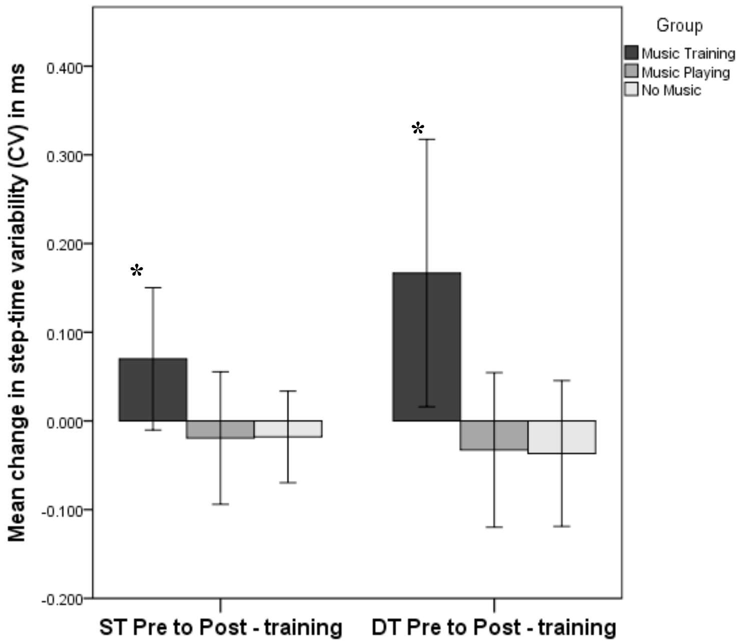

Figure 6.4. Changes across groups between DT pre- and post-training step-time variability
*Change significant at p <.05

Table 6.4

Changes in gait and cognition performance - ST and DT, pre- and post-intervention training. mean values (± SD)

	Music Training Group					**Music Playing Group**					**No Music (Control) Group**				
	Single Task			**Dual Task**		**Single Task**			**Dual Task**		**Single Task**			**Dual Task**	
Parameter	**Pre-Trg**	**Post-Trg**	**Post-Trg (end)**	**Pre-Trg**	**Post-Trg**	**Pre-Trg**	**Post-Trg**	**Post-Trg (end)**	**Pre-Trg**	**Post-Trg**	**Pre-Trg**	**Post-Trg**	**Post-Trg (end)**	**Pre-Trg**	**Post-Trg**
Velocity m/s	1.18 (±.22)	1.11 (±.25)	1.2 (±2.9)	.96± (.32)	1.07 (±.25)	1.37 (±.19)	1.35 (±.157)	1.33 (±.19)	1.1 (±.27)	1.15 (±.24)	1.2 (±2.4)	1.25 (±.22)	1.19 (±.22)	.96 (±.31)	1.10 (±.28)
Step-time variability (CV) ms	.18 (±.17)	.11 (±.16)	.17 (±.23)	.32 (±.28)	.15 (±.14)	.09 (±.09)	.11 (±.10)	.09 (±.10)	.09 (±.07)	.13 (±.19)	.15 (±.14)	.16 (±.16)	.16 (±.17)	.19 (±.23)	.22 (±.18)
Number of Correct Cognitive Responses	.36 (±.30)			.32 (±.320	.29 (±.33)	.41 (±.24)			.37 (±.260	.31 (±.22)	.34 (±.17)			.35 (±.16)	.23 (±.17)
Steps/Total Cognitive Responses				4.8 (±2.9)	6.1 (4.9)				3.7 (±1.9)	5.9 (±4.7)				4.5 (±2.3)	5.5 (±3.8)

Table 6.5
Changes between pre- and post-training conditions across the groups

	Music Training Group (*n* = 15)		Music Playing Group (*n* = 15)		No Music Group (*n* = 15)	
	Single Task	Dual Task	Single Task	Dual Task	Single Task	Dual Task
Parameter	Pre-Trg to Post-Trg#	Pre-Trg to Post-Trg#	Pre-Trg to Post-Trg	Pre-Trg to Post-Trg#	Pre-Trg to Post-Trg	Pre-Trg to Post-Trg
Velocity	**.07** (.123)**	-.06 (.198)	.02 (.3)	-.048 (.360)	-.04 (.250)	-.08 (.310)
Step-time variability (CV)	-.099 (.397)	**-.039* (.325)**	-.042 (.160)	.00 (.224)	-.05 (.288)	.004 (.195)
Correct Cognitive Responses		-.03 (.540)		.02 (.540)		.11 (.450)
Steps/Total Cognitive Responses		.6 (15.3)		.62 (21.33)		.39 (9.6)

Medians (range), Trg - Training
* Significant change (improvement) in the difference between the MT and MP/NM groups DT pre- and post-training, $p < .05$
‡ Significant change (decrement) in the difference between the MT and NM ST pre- and post- training, $p < .05$

In order to assess the effect that training had on the amount of mental effort they required for either the gait or cognitive task, the MT group's ST and DT pre- and post-intervention training performances were analysed for percentage improvement or diminution. Step-time variability in the ST improved (gait steadied) by 38.9% after musical training whereas it improved (became steadier) by 53.1% in the DT after training, with no concurrent detrimental effect to the performance in the cognitive task. This result suggests the mental effort used in completing the cognitive task was 14.2%. Further, the MT group's ST to DT pre-training performance diminished by 43.7% whilst their ST to DT post-training performance was only 26.7% worse. This indicates that the mental effort released by musical training and re-directed to gait in the DT was 17% (Table 6.5 and Figure 6.5).

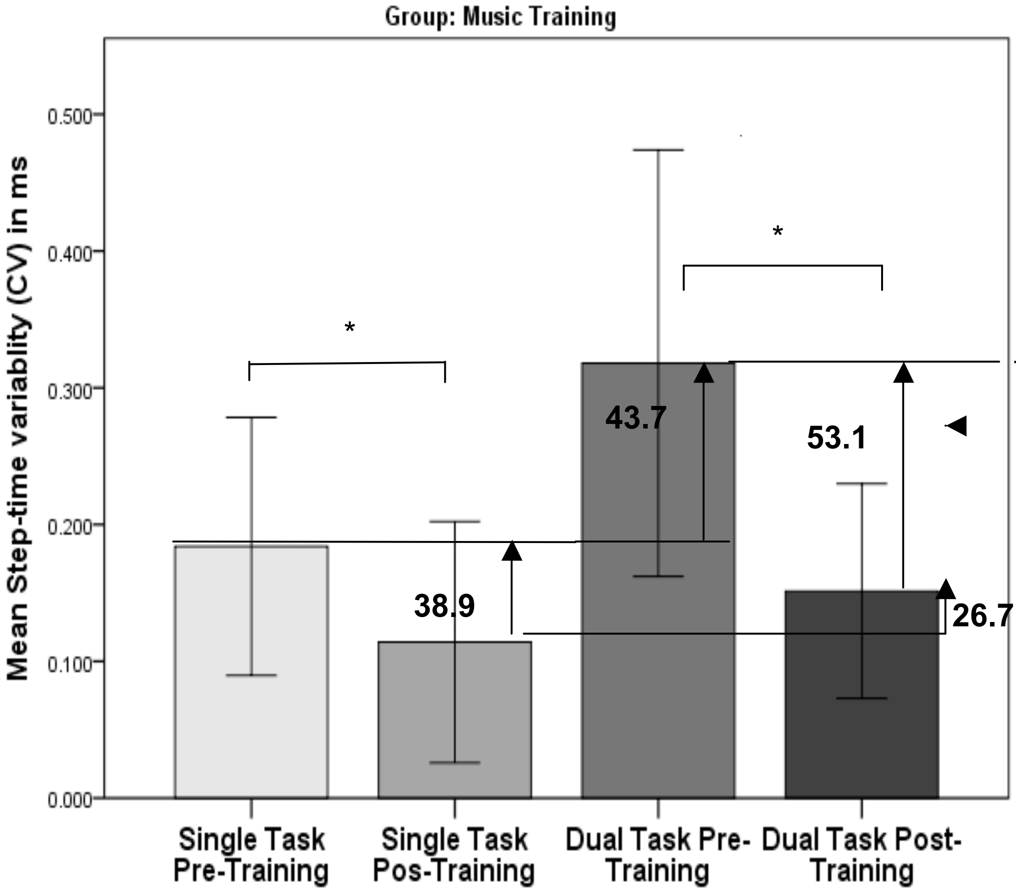

Figure 6.5. Magnitude of changes in MT group's pre- and post-training step-time variability
*Significant Difference between Music Group's mean ST step-time variability, $p < .05$
** Significant Difference between Music Group's DT mean step-time variability, $p < .001$

The three groups' ST step-time variability (with no music playing) at the very end of the experiment was investigated for possible longer-term effects of musical training but there was no significant group effect $H(2) = 2.51$, $p > .05$, suggesting that gait improvement was dependent on the music playing during walking.

6.3.8 Relationship between performance improvement and underlying factors

In order to investigate the relationship between the MT group's significant gait improvement, relative to the other two groups, and the measures taken at baseline, the MT group's experimental condition outcomes and their scores from the background and cognitive tests at baseline were compared, using correlation coefficients. The results showed strong associations between baseline cognitive function and the experimental cognitive outcomes, and between walking ability and age, mood and general mobility (see Table 6.7). However, when the possible associations between significant gait improvement, in the ST and DT post-training gait step-time variability and baseline tests were compared, only age showed a strong positive relationship with the ST post-training gait (r = . 553, p <.05). In other words, the less steady the gait, after training, the older the age.

In the DT post-training condition, DS/F (r = .495, p <.05), immediate recall (IR) (r = .504, p <.05) and general mobility (Stand Up/Sit Down test) (r = .497, p <.05) showed a strong positive relationship with CV. In other words, the more steady the participants' step-time variability, the better their EF, memory and general mobility (Table 6.6). There was also a strong association between DT velocity and age in that, the older the participant the slower they walked in the DT (r = .444, p <.05), which was to be expected. In the secondary cognitive task, participants' performances were strongly related to their EF and memory. As expected, the better the CCR measures in the DT post-training condition at baseline, the better the DS/F (r = .527, p <.05), DS/B (r = .462, p < .05), SDM (r = -.497, p <.05) and IR (r = .745, p<0.001) measures during the post-training DT. The only association between the pace of walking and counting (steps per cognitive response) and baseline variables was in the pre-training condition (DT SCR) and intelligence (r = -.581, p <.05) (see Table 6.6).

Table 6.6

MT group's correlations between dependent variables

MT Group	AGE	MMSE	BDI	Est PM IQ	DSF	DSB	SDMT	IR	DR	Mob SU/SD
ST Pre-Training CV		.507*						**.618****		
ST Post-Training CV	.553*									
DT Post-Training CV					.495*			.504*		.497*
Pre-training DT Velocity	-.500*						-.589*	.589*	.479*	
Post-training DT Velocity	-.444*									
Pre-training DT SCR				-.581*						
Post-training DT SCR									.498*	
Single Task CCR					**.620****	.489*	-.568*	**.640****		
Pre-training DT CCR					.619**	.552*		**.650****		
Post-training DT CCR					.527*	.462*	-.497*	**.745****		
SDM	**.646****									
DS/F			**-.689****							
DS/B			**-.622****		**.757****					
IR	-.459*									
DIR			-.484*							

MT Group	AGE	MMSE	BDI	Est PM IQ	DSF	DSB	SDMT	IR	DR	Mob SU/SD
BDI		.475*								
Mob SU/SD			.469*							
Mob TW		**.631****								
Mob BAL	**.633****									

* $p<0.05$, ** $\boldsymbol{p<0.001}$

MMSE – Mini Mental State Examination

BDI – Beck's Depression Inventory

Est PMIQ – Estimated Premorbid IQ

DSF – Digit Span/Forwards

DSB – Digit Span/Backwards

SMDT – Symbol Digit Modalities Test

IR – Immediate Recall

DR – Delayed Recall

Mob SU/SD – Mobility Stand-Up/Sit-down

6.4 Discussion

This study investigated the effects of musical training on the gait and cognitive performance of healthy older adults living in the community. Comparisons across groups revealed that the MT group's step-time variability (CV) was less steady in both the ST and the DT pre-training conditions than the MP group but was comparable with the NM group's CV and was, after investigation, considered to be representative of a random sample of healthy community-living older adults. Moreover, as gait variability is, by its very nature, 'variable', researchers are interested in significant changes which occur between experimental conditions (Hausdorff, 2005). As predicted, the gait of the MT group became more steady after musical training, and this was demonstrated by a significant decline in CV in both ST and DT post-training conditions and also by there being no DTD in velocity after intervention training. In other words, gait velocity after training did not decline in the DT relative to the ST. This cannot be attributed simply to hearing music as there was no change in the gait of the group who had music playing in the background as they walked and counted. The results also cannot be explained as a practice effect as there was no improvement in the gait of the group who completed the walking and counting conditions with no music playing.

The improvement in gait stability after musical training can, therefore, be attributed to the rhythmic quality of the music which regulates gait and causes it to become more 'automatic', therefore in need of less controlled attention (Shiffren & Schneider, 1977).

The MT group's improvement in both ST and DT step-time variability after intervention training contrasts with the other two group's step-time variability which did not improve in either ST or DT after intervention training. In fact, in both the ST and DT post-training conditions, the MP and NM groups' step-time variability worsened, but not significantly so. We expected that the MT group would maintain their ST pre-training gait stability in the DT post-training condition and that we would observe a dual task deficit for the other two groups. However, the MT group's step-time variability significantly improved in comparison to the DT pre-training condition, so much so that it was better even than their ST gait (although not significantly so) whilst also maintaining their DT cognitive performance. Moreover, the only significant change in performance between pre and post-training across the three groups was the improvement in the MT group's DT step-time variability (CV). Taken together, these results suggest that musical intervention training improves gait stability, whilst having music playing and simply walking as interventions have no effect on steadiness of gait.

Although, to the author's knowledge, this is the first study to investigate the effect of musical training on high-functioning older adults, at least one small study has used PD patients with a healthy older control group. Neither group was instructed to walk to the music while subtracting 3s, and the music was self-selected and unadjusted (Brown et al., 2009). Brown and colleagues found that the music interfered with the PD patients' gait velocity which became worse when the cognitive task was added. This was in comparison to the control group whose gait velocity was unaffected by the music and which improved slightly when the cognitive task was added. Unfortunately, the analyses of the cognitive outcomes were not reported but the findings of this current study replicate, in part, Brown and colleagues' (2009) results. These healthy older adults' gait velocity did not change significantly whether music was present or not. But all of the groups' gait velocity did deteriorate when asked to perform a demanding concurrent cognitive task. This suggests that, in contrast to Brown and colleagues' (2009) control group, the Serial 7s demands more attentional resources and/or processing than the Serial 3s which may have been too easy a task to effect a significant change in velocity.

When considering the effect of musical training on the cognitive task, what we observed was that, firstly, in the ST, the MT group's gait became steadier after musical training (by 38.9%). This could have been because gait became more 'automatic', requiring less mental effort, or being instructed to walk to the rhythm of the music could have attracted more attention (from a limited, but under-utilised capacity in the ST) to gait and decreased step-time variability (improved performance). However, the MT group's gait steadied by 53.1% in the DT after training which suggested that this 14.2% extra mental effort was used in the cognitive task. In line with the 'posture first hypothesis', we predicted that if musical training improves gait, this would free up attention, which may then be transferred from gait to the cognitive task. However, when we analysed the results of the DT conditions, the improvement between the ST to DT pre- (43.7%) and ST to DT post- intervention step-time variability (26.6%) clearly demonstrates that the MT group had spare mental effort due to the intervention (musical) training since there was a 17% improvement in gait stability without loss to cognitive function. This suggests that musical training accounted for 17% of the DT post-training performance. But, since there was no significant improvement in the cognitive performance of the MT group post-training, this suggests that the freed-up attention was not automatically allocated to the cognitive task but was re-directed back to the primary walking task.

There are two possible explanations for the Musical Training group's correct cognitive responses (CCR) remaining unaffected by the musical training. Firstly, the participants, who were cognitive healthy older adults, had reached their cognitive performance ceiling (Tehan & Mills, 2007) and no amount of freed-up attention could have increased their cognitive

responses. Therefore the extra attention freed by the intervention training was unconsciously allocated back to gait. Alternatively, the MT group, being cognitively healthy, would naturally adopt a 'posture first' strategy in any situation where gait was threatened.
We also anticipated that the cognitive performance of the two groups who did not receive music training would remain unchanged and this was the case. Since their gait did not become any steadier either, this suggests that they were unaffected by the experimental intervention.

6.5 Conclusion

To the author's knowledge, this is the first study to attempt to quantify the allocation of attentional resources to either gait or cognition in the DT involving healthy older adults and the findings have both theoretical and applied implications.
Current understanding of gait suggests that it depends on the integrity of various aspects of cognition, particularly the higher executive functions of which attention is one (van Iersel et al., 2008). Working memory regulates the attentional flow, which allows gait to be either consciously under control ('effortful') or unconsciously automatic ('effortless') (Stuart-Hamilton, 2012). The MT group's improved gait performance suggests that rhythmic training may tap into the ability of the working memory to process demands for attention and allocate it according to a changing situation (Baddeley, 1996; Logie et al., 2004; Yogev-Seligmann, Hausdorff & Giladi, 2008) for example a demanding dual task. Our findings support the suggestion that walking while listening to music may demand less attention in healthy older adults than in the cognitively impaired (Yogev et al, 2005; Brown et al., 2010; Wittwer, Webster & Hill, 2012).
Under the control of the Central Executive, within Baddeley & Hitch's (1974) working memory model, attention can be controlled and directed to the task which is considered more important for the attainment of either external or internal goals. Good attentional flow between two concurrent tasks, is a marker for good working memory (Smith & Kosslyn, 2009), itself an important component in higher-level executive functions which impact the ability to live independently in older age (Atkinson et al., 2007; Montero-Odasso et al., 2009). In our study, it is possible that, because the cognitive task was very demanding, and threatened gait stability, the freed attention was unconsciously allocated to improve gait stability even further, as seen by the large improvement in their DT post-intervention CV.
These findings from this group of physically and cognitively healthy older adults have relevance for both other healthy older adults and those with impairment in gait and/or

cognition. In the first case, postural reserve, one of the factors in an individual's ability to respond effectively to a postural threat, and an important factor affecting task prioritisation when walking, decreases with age and disease (Yogev-Seligmann, Hausdorff & Giladi, 2012c). Improving healthy older adults' gait by making it more rhythmic through musical training, whilst maintaining cognitive capability, could result in enhanced postural reserve. Secondly, if musical training frees up attention, this could be beneficial to older adults with cognitive impairment who naturally adopt a 'posture second' strategy whereby they allocate attention equally to gait and cognition, thus increasing their risk of falling. Training them to allocate more attention to gait could be a preventative intervention for falls (Yogev-Seligmann et al., 2012a) in older adults where talking adversely affects walking ability (Beauchet et al, 2008; Lundin-Olsson, Nyberg & Gustafson, 1997).

This experiment was conducted in a controlled environment over a flat surface, with healthy older adults, but it has the potential to be applicable in a more ecologically valid and complex environment, such as outdoors or in the home. Further research is required to establish the practical application and therapeutic value to practitioners of these findings.

Chapter 7: Experiment 4: Comparing methodologies

7.1 Introduction

Frailty is associated with ethnicity, socio-economic status, poor health and genetic disposition and is an independent predictor of falls, disability, hospitalisation and death (Fried et al., 2001). Fried and colleagues (2001) proposed a clinical definition for frailty, which includes the presence of three or more of the following five criteria: unintentional weight loss in the previous year of at least 10lbs, self-reported exhaustion, weak grip-strength, low physical activity and slow walking-speed.

Meta-analyses have revealed that walking speed in particular is associated with survival in older adults (Studenski et al., 2011). For example older adults whose comfortable walking speed is lower than 1m/s are at 'high risk' of health-related outcomes (Cesari et al., 2005). Additionally, where medium gait velocity was determined to be greater than 0.07m/s but less than 1.1m/s, a slow gait velocity (< 0.7m/s) was strongly associated with adverse effects for healthy adults aged over 75 years (Montero-Odasso et al., 2005). Data collected from over 34,000 independently-living adults aged over sixty-five years, followed up for between 6 and 21 years, revealed that the median speed for age and gender at which faster speed predicted life expectancy beyond the median was 0.8 m/s. Using 0.8 to 1m/s as a cut-off point for older adults aged 65–74 years, Studenski and colleagues (2011), suggested that men would have an 85% chance of living another five years and a 67% chance of living another ten years. Women in the same age bracket would have a 93% chance of living another five years and an 80% chance of living another ten years (Studenski et al., 2011).

Clearly gait speed is an important measure of healthy ageing but subtle changes are difficult to detect. Clinical measurement tools have been developed but these are carried out in very controlled settings. Detecting change in the natural environment (for example, people's homes or the outside world) is much more challenging. Furthermore, in the field of gait analysis researchers have debated which is the more sensitive measure of gait disturbance – gait speed or gait (step/stride-time/length) variability - even in frail older adults (Montero-Odasso, 2011). Finally, it has been suggested that gait speed should only be considered valid at distances of 6 - 10m (18 – 30 feet) (Montero-Odasso, 2006) and gait variability at distances over 50 feet (Sheridan et al., 2003), over 20 strides (Hollman et al., 2010) and/or two minutes' continuous walking (Galna et al., 2013) which, realistically, can only be assessed outside the average home.

7.2 'DataGait' pilot study

This study attempted to address the issues of gait measures, discussed in previous chapters, by assessing both gait speed and step-time variability in the homes of older adults and comparing these data with that collected in a clinical setting. The data were collected using two methods – video recording as used in the previous 2 studies (Chapters 4 & 5) and 'DataGait', a new technology using accelerometer engineering. 'DataGait' is an automated gait analysis system devised by Dr Patrick Oxford Brookes University (Esser, Dawes, Collett, Feltham & Howells, 2011) that had only been previously used in a clinical setting. It comprises a laptop computer and small box, measuring 36 x 56 x 19mm and weighing 38g (Figure 7.1) that is attached to the participant's lower back, using unobtrusive body tape.

Figure 7.1. Size of 'DataGait' system (right) compared with USB stick (left)

'DataGait' had not previously been tested with older adults and, therefore, this pilot study was novel in two respects: it compared speed in an ecologically valid environment (the home) with that in a clinical setting (Tayside Clinical Research Centre) and it used new technology with older adults. The 'DataGait' results were compared with the results obtained from the manual analyses of the video recordings, in both a home and clinical setting to determine whether 'DataGait', as a smaller, neater piece of equipment, could replace the 'Bigfoot' gait analysis system in any future dual-task gait and cognition research.

The aims of the pilot study were:

(i) To compare video recording with 'DataGait' measures in the home and clinical setting

(ii) To compare gait measures (gait step-time variability and gait speed) in the home and clinical setting, using two different measuring systems

(iii) To determine which system and which measure would be more sensitive in a 'real world' (home) context, over short distances.

Hypotheses

(i) There would be no differences between the measuring systems either in the home or in the clinical setting.

(ii) There would be differences between the home (2/3m) and the clinical setting (10m) but no differences between the measures over those distances.

(iii) Measuring gait in the home setting would be less accurate and, therefore less sensitive than in the clinical setting.

7.2.1 Methods

Participants

Thirty-six participants (21 female, 15 male) with an average age of 71.8 years took part in this gait analysis methodology pilot study. Participants aged 65 years and over were recruited as part of a larger study – Novel Assessment of Nutrition and Ageing (NANA) – from in and around St. Andrews and Sheffield through leaflets, flyers, talks and advertisements. Inclusion criteria were that participants must be 65 years old or over, were not on a weight loss diet and had not recently undergone treatment for heart disease. Participants were excluded if they were suffering with a serious illness or were not able to understand/communicate effectively.

Materials

A Nokia stopwatch and Sony Cybershot 7.2 video camera were used to measure participants' gait manually. The 'DataGait' system, supplied by Dr Esser, comprised a Toshiba laptop, the 'DataGait' analysis software, a small blue box, and double-sided body-tape. A tape-measure was also necessary to measure the participants' right legs, from the outside hip to the inside ankle, and these measurements were used with the 'DataGait' clinician's tool.

Design

A 4x2 within participants design was used. The 4 independent variables were the 4 methods of recording data namely: 1. home video-recording 2. home 'DataGait' 3. clinic video-recording and 4. clinic 'DataGait'. The dependent variables were gait speed and step-time variability assessed using step-time, expressed as co-efficient of variation (CV) (standard deviation divided by mean).

Procedure

Home

The researcher marked a 4 or 5m walkway using tape. This allowed for a 2-3m recording space plus one metre either side for acceleration and deceleration. The DataGait box was fitted to the participants' 4th lumbar vertebrae, in line with the top of the iliac crest (as determined by the trained researcher), with double-sided body tape. The 'DataGait' system (which used accelerometer technology to track motion) began recording gait parameters when the researcher depressed the space bar on the laptop. The 'DataGait' instructions for operating and analysis are at Appendices E and F. They were instructed to walk, at a comfortable pace, from the first to the last tape, turn and walk back to the beginning. Only the second walk was analysed, thus providing the participant with a chance to practise. The data for each participant was saved in a separate file. At the same time, the participants' walks were video-recorded by the researcher.

Clinic

As in the home, participants were recorded simultaneously using the video and the 'Datagait' methodologies as described above, except that the distance of the walk was 10m, in accordance with the 'DataGait' operating instructions (Appendix E). An additional 1m was added to each end of the 10m walkway to allow for acceleration and deceleration, in line with current thinking in gait analysis. The participants walked 10m twice but only the second of the two 10m walks was analysed.

Analyses

Video-recordings

Each video-recording was analysed using the lap-time setting on the stopwatch to give the individual step-times for each walk. The mean step-time and standard deviation were then used to produce the step-time CV for each participant. In addition, the time for each walk was recorded and the speed for each walk was manually calculated from the equation distance divided by time.

Datagait

The data in the 'DataGait' files were analysed using the 'DataGait' Clinician Tool provided by Dr Esser. This tool was used to pinpoint the exact number of steps walked by each participant (as observed in the video-recording) during each walk, either in the home or in the clinic. The 'DataGait' software then calculated the mean step-time, standard deviation, step-time CV and speed.

Statistical Analyses

Descriptive statistics indicated that the gait step-time variability data were non-parametric therefore the Wilcoxon signed-rank test was used to compare results between pairs of measures (manual analyses from video-recordings and 'DataGait' analyses). The statistical significance for the experiment was set at 0.05 and a Bonferroni adjustment for multiple comparisons was made. Effect sizes were calculated and reported as *r* values. All statistical analyses were performed using SPSS 18.0 for Windows.

7.2.2 Results

Different Settings

Gait speed and step-time variability in the home and clinic were compared (Table 7.1). Over the 10m walk in the clinic there were no differences between the video recording method and the 'DataGait' method for either gait step-time variability (CV; p >.05) and gait speed (p>.05). Over the shorter 2-3m walk in the home there was no difference in step-time variability (CV) between the video-recording method and 'DataGait' (CV: p >.05). However, there was a significant difference in gait speed between video-recording (M = 1.07) and 'DataGait' (M = 1.003) in the home (p <.05). Descriptive statistics and any differences in the measures recorded in the two different settings and between the two measures, using the two different methodologies, are given at Table 7.1.

Table 7.1

Comparison between home and clinic measures of gait step-time variability (CV) and gait speed

Setting	**Measure**	**Method**	**Mean (±SD)**	**Median (±SD)**	**T**	***p* =**	***r***
Home	CV	Video	0.067 (±.030)	0.061 (±.030)	367.5	0.968	-.005
		'DataGait'	0.082 (±.105)	0.048 (±.105)			
	Speed	Video	1.07 (±.261)	1.14 (±.261)	184.5	**.021**	-.30
		'DataGait'	1.00 (±.294)	1.04 (±.254)			
Clinic	CV	Video	0.064 (±.019)	0.060 (±.019)	329.0	0.547	-.07
		'DataGait'	0.095 (±.114)	0.059 (±.114)			
	Speed	Video	1.22 (±.191)	1.26 (±.191)	380.5	0.156	.17
		'DataGait'	1.26 (±.189)	1.27 (±.189)			

Different measures

Gait step-time variability and gait speed were compared using manual analysis of video-recordings and 'DataGait' technology. There were no differences in step-time variability (CV) between the home and clinical setting when using video recording ($p > .05$) or when using 'DataGait' ($p >.05$) but there were significant differences in speed between using video recording in the home (M = 1.07) and the Clinic (M = 1.22), ($p <.05$) and using 'DataGait' in the home (M = 1.00) and in the Clinic (M = 1.26), ($p <.05$). Descriptive statistics and differences between the two performance measures, by the two different methods, in the two settings are shown at Table 7.2.

Table 7.2

Comparison between step-time variability (CV) and gait speed measures

Measure	**Method**	**Setting**	**Mean (±SD)**	**Median (±SD)**	**T**	***p* =**	***r***
CV	Video	Home	0.067 (±.030)	0.061 (±.030)	292.5	0.724	-.04
		Clinic	0.064 (±.019)	0.060 (±.019)			
	'DataGait'	Home	0.082 (±.105)	0.048 (±.105)	272.0	0.336	-.11
		Clinic	0.095 (±.114)	0.059 (±.114)			
Speed	Video	Home	1.07 (±.261)	1.14 (±.261)	95.5	**0.000**	-.45
		Clinic	1.22 (±.191)	1.26 (±.191)			
	'DataGait'	Home	1.003 (±.294)	1.04 (±.254)	47.0	**0.000**	-.54
		Clinic	1.26 (±.189)	1.27 (±.189)			

7.2.3 Discussion

The aim of this study was to compare the utility and efficiency of two methods of collecting gait data - video-recording and DataGait - outside a clinical or laboratory setting. Data were collected in people's homes over necessarily short distances, which also permitted investigation of how large a sample of gait (for example, what distance, is needed to calculate a reliable gait measure). In addition, the study looked at the ease of collecting two different gait measures – speed and step-time variability – in the home versus the clinic.

In terms of the two different methodologies, the results indicate that there was no significant difference between video-recording and 'DataGait' for step-time variability (CV) in the home or clinical setting or for speed in the clinical setting. However, there was a significant difference in the recording of gait speed between the video recording and 'DataGait' in the home. This may be because there may not have been enough data points in the 2m and 3m walks to allow for accurate calculation of speed (Montero-Odasso, 2006). The parity of CV measures in both settings, using both methodologies indicates that step-time variability can be reliably measured over short distances by either video-recording participants, as they walk, or by using 'DataGait'. However, the significant differences which were observed, when speed was compared between methods and between settings, suggests that it is not possible to accurately measure participants' speed over the kind of short distances found in a typical home setting.

These results add to the debate about using speed as a gait measure at distances under 10m (Montero-Odasso, 2006) or 30 steps (Galna et al, 2013).

7.2.4 Summary

Gait analysis is a well-established means of observing and measuring individuals' gait. It uses a variety of methods, including body-worn sensors, wearable computers, instrument mats, foot switches, accelerometer engineering, gyroscopes, gait mats, Bluetooth technology accelerometers and force-plate mounted treadmills to analyse a variety of gait measures, including speed and stride/step-time/length variability (Hausdorff, 2005). However, it is acknowledged that analysis of gait is still far from an exact science and gait analysts still debate which parameter and methodology is best (Kirtley, 2006). In this study, gait was measured over as short a distance as 2 or 3m, and the minimum number of steps was 4, whereas, as previously mentioned, some gait analysts would not accept gait measures from under 2 minutes of continuous walking or under 30 or 50 steps (Galna et al, 2013; Herman, Mirelman, Giladi, Schweiger & Hausdorff, 2010) for analysis. Therefore, we must treat these results with caution. The distances are short, but one could not expect to have much longer in the home setting. It would appear that, to obtain a more accurate measure of both gait step-time variability and speed, would require longer distances (only possible, perhaps, in a laboratory or a specialised outdoor area). However, for a variety of reasons, researchers may wish to measure gait in the home with more sophistication than a stopwatch. Therefore, in this instance, it would appear that step-time variability is a more reliable measure to employ than gait speed when ecological validation is paramount.

In terms of methodologies, 'DataGait' was quick and easy to fit to the participants and, once the researcher was trained in using the clinicians' tool to analyse the recordings, the results were immediately available and easily transferred to compatible PC software. The manual analysis of video-recordings is very time-consuming and is subject to human error. It has the advantage of allowing the researcher access to a replay of the actual walk. However, over short distances, neither method appeared to capture enough data points to give an accurate speed and so they are both only suitable for longer distances. For this reason, it will be necessary to conduct further research comparing 'DataGait' with another validated mechanical means of gait analysis, before using it as a primary gait measurement system in concurrent gait and cognitive task research, and based on the findings in this present pilot study, it would be advisable not to assess speed in the home over the distances, particularly over the short distances used in this experiment. However, in comparison, step-time variability appeared to be consistent across settings, suggesting that measuring step-time variability is a reliable measure that can permit investigation of gait in a naturalistic setting. Further research is still required regarding the most appropriate methodology for that purpose.

Chapter 8: Summary

8.1 The research question

As we age, living independently for as long as possible is crucial for survival and well-being (Black & Rush, 2002) and the ability to do so relies on maintaining good physical and cognitive function. The focus of this research was to better understand why some older adults have greater functional well-being than others by looking at the mechanisms underlying healthy older adults' ability to maintain higher-level cognitive functions which involve flexible allocation of attention to multiple tasks. These particular participants were of above average intelligence, had above average years of education and took part in regular cognitive and physical activity. In addition, they all lived in or near a relatively affluent university town with a variety of amenities suitable for older adults. Therefore, one could hypothesise that any decline in their performance might be indicative of pathology rather than a general factor (Deary & Gow, 2008). However, when tested over 12 months these participants not only maintained their general physical and cognitive function but, improved aspects of EF and memory. Yet specific aspects of their DT performance did decline and investigation of the underlying mechanisms of attention-allocation in a DT provided a possible explanation for these results.

8.1.1 Working Memory

Although non-pathological age-related cognitive decline has been attributed more to limitations in processing speed than resource capacity (Deary, 2009; Luszcz, 2011) the suggestion that 'attention' can be defined either in terms of a unitary capacity resource or a unitary processing system is by no means universally held. (Cocchini, Logie, Della Sala, MacPherson & Baddeley, 2002). This opens up research to consider the mechanism that investigates how the 2 constructs inter-relate. This present research probed the notion of interconnectedness between attentional capacity and processing in order to disentangle these constructs and found that the interplay between them led to subtle differences in performance which were not detected by other tests. Ability to allocate attention appropriately is a function of working memory and is subject to an over-arching control mechanism, which has been termed 'central executive' (Baddeley & Hitch, 1974) but, for the purposes of this research, is termed 'executive attention' (McCabe et al., 2010). It is executive attention which appears to control the interplay between resource capacity and processing that contributes to successful negotiation of complex tasks.

8.1.2 Dual task paradigm

The dual-task paradigm is a convenient method of exploring executive attention (Logie, 2011) by measuring attention-allocation to concurrent tasks against performance on each task singly. In this study increasing cognitive load and instructing the participants to focus on one task or the other were used to explore attention allocation. This particular methodology permitted exploration of the way in which participants allocated their attention between walking, an apparently 'unconscious' activity to counting backwards, a 'conscious' action. Both tasks in concurrent walking and counting tap into executive attention processing, are thought to share neural substrates and in combination provide a task that simulates everyday life. This has an advantage over other dual task methodologies, which may rely on participants' ability to learn complicated task rules, familiarisation with computer technology or practice effects and by doing so introduce possible confounds (Lindendberger et al., 2000).

8.1.3 Longitudinal study

Explicitly manipulating attention in a DT revealed that a combination of attentional storage capacity and processing limitations influenced concurrent gait and cognitive performances but that an 'optimal' condition resulted in the most effective dual-task performance. This occurred when participants performed the more demanding cognitive task and prioritised walking. Moreover, this optimal condition was predicted by how efficiently participants could flexibly divide their attention in a classic working memory baseline test (TMT). The results of the comparison between T1 and T2 confirmed the main conclusion from the 'snapshot' performance, taken of these participants at T1, that ability to prioritise walking was the key to efficient or inefficient allocation of attention to a dual-task. Since inefficient attention-allocation to walking has been linked to cognitive decline (Atkinson et al., 2007; Tabbarah, Crimmons & Seeman, 2002), it is crucial for healthy and impaired adults to maintain or improve this ability for future well-being. Cognitive flexibility, rather than capacity or processing speed, should be considered when assessing older adults' functional ability to live independently. The findings suggest that efficient executive attention involves not primarily an individual's resource capacity, nor how quickly they process information but which attentional prioritisation strategy they adopt. That is, whether they prioritise (in this case) walking or counting and that this ability to prioritise efficiently is predicted by their underlying ability to flexibly switch attention from 'bottom-up' to 'top-down' (as indexed by a test of their executive attention). In other words, these research findings suggest that their performance in concurrent walking and counting could be used as a barometer of their underlying cognitive flexibility; more specifically it is a means of measuring whether or not healthy older adults are using their remaining higher-level cognitive flexibility to the full. Where the gait and cognitive dual task has been used in the past to examine gait irregularities, this naturalistic, yet subtle methodology could be employed, relative easily and at little cost, to assess the a combination of higher-level cognitive processes which domain-specific EF tests cannot do.

8.1.4 Early detection of change

This research addressed the question of well-being in healthy older adults from the perspective of the interaction between their physical and cognitive ability in a concurrent task. The results from one experiment in ageing research cannot suggest any idea of causation which is why longitudinal research is preferred (Deary, 2009). The overall finding, then, is that underlying processing speed (a specific executive function under the control of executive attention) as measured by SDMT (Salthouse, 2000), predicted both the improvement and the decline in DT gait and cognitive performances, depending on prioritisation direction and cognitive load. These findings indicate that the symbol digit modalities test (SDMT), which is a measure of the specific executive functions of processing and perceptual speed (Salthouse, 2000), is a possible marker (proxy) for the maintenance or decline of executive attention within a resource capacity working memory model (Norman & Shallice, 1980; Baddeley, 1996).

8.1.5 Rhythmicity

The improvement in performance when instructed to prioritise walking indicates that it is possible to alter older adults' gait stability, by giving it more attention. In order to maximise their resources, it would be even better to be able to improve gait stability without using up more of their attention. The musical training study confirmed that it is possible to improve older adult's gait stability through walking to a musical rhythm without detracting from their cognitive performance. It had been hypothesised that if the rhythmic training made walking automatic, then this might free-up attention, which could be transferred to the cognitive task, and which would manifest as an improvement in cognitive task performance. The finding that there was neither improvement nor decrement in cognitive performance suggests three possible explanations: 1. the musical training did not free up resources, just transferred them to the rhythmic walking; 2. freed up attention was actually transferred to the cognitive task which resulted in maintenance of cognitive performance; 3. the participants had reached ceiling performance on the cognitive task and extra attention could not benefit their performance. Training participants to walk rhythmically and then introducing a new cognitive task in the DT could be used to test these hypotheses. If gait is maintained when trying to carry out a new cognitive task this would suggest that the automaticity does free up attention for cognition. If gait is perturbed then this would indicate that attention that is required to maintain gait is being taken for the cognitive task. If participants have a ceiling for cognitive performance then gait should initially be perturbed but then quickly recover. As they stand the results have potential practical application as the finding that gait can be improved with no cost to cognition for could be used to train older adults with and without physical and cognitive impairment.

8.1.6 Prioritisation strategy

It has previously been suggested that people who are at greater risk of falls or with early cognitive decline deviate from the 'healthy' strategy of prioritising walking above everything else, the so-called 'posture first' strategy (Bloem et al., 2006). That is, rather than prioritising walking when performing another task, people at greater risk of falls, focus instead on the other task, thereby increasing their risk of falls (Yogev-Seligmann et al, 2012b). The findings from the current studies suggest firstly, that healthy older adults do not necessarily prioritise walking in all conditions. Rather they make judgements about how much attention is required to carry out walking and another task depending on the task demands. This suggests that the difficulties noted in people with physical or cognitive impairment result from reduced ability to flexibly allocate attention between tasks, resulting in insufficient attention being applied to either task. The results of the musical training study suggest that there may be potential for improving this through improving gait stability.

8.1.7 Cognitive flexibility

Cognitive flexibility appeared to be the defining characteristic of whether healthy older adults improved their walking and counting dual-task performance, or showed early signs of rigidity in allocating attention to walking, while counting. This 'window' through which cognitive flexibility could be observed suggested that neither resource capacity nor task difficulty on their own was the sole influence on how well the participants could divide their attention between 2 tasks, but the it was flexibility with which the participants could react to the subtle change in the combination of the two factors, as the cognitive load and prioritisation instructions changed. This fits well with Logie et al.'s (2004) definition of a distinct DT coordinating function. The very subtle changes in the efficiency of prioritising walking were evident in healthy older adults when no other sign of decline had been revealed and in the face of evidence of some improvement in cognition. Therefore, it is possible that ability to prioritise walking is a marker or proxy for very subtle and early cognitive decline. This hypothesis might be tested in older adults with known mild cognitive impairment (MCI), in those with already obvious gait irregularities or with an even older cohort of healthy adults who may be experiencing (as yet undetected) natural cognitive decline.

8.1.8 Relationship between gait and cognitive function

Montero-Odasso and colleagues (2012) proposed a model of the relationship between gait and cognitive function that acknowledges the importance of executive function. Their model proposes that impaired 'executive function' affects gait and/or cognition. Given the intimate relationship between gait and cognitive function (Yogev-Seligmann et al., 2008), the next stage is to be able to identify those older adults at some, little or no risk of future falls, or indeed dementia (Montero-Odasso et al., 2012). The findings from the three studies presented here expand Montero-Odasso et al.'s (2012) model (see Figure 8.1; with additions in bold) to highlight the pivotal role of executive attention in maintain gait and cognitive performance. Executive attention controls executive functions and regulates the prioritisation of attention on either gait or on the cognitive task, according to the priorities of the environment and/or task. It is this ability that is important when individuals have to rapidly adapt to changes in an environment or to obstacles which might threaten gait security.

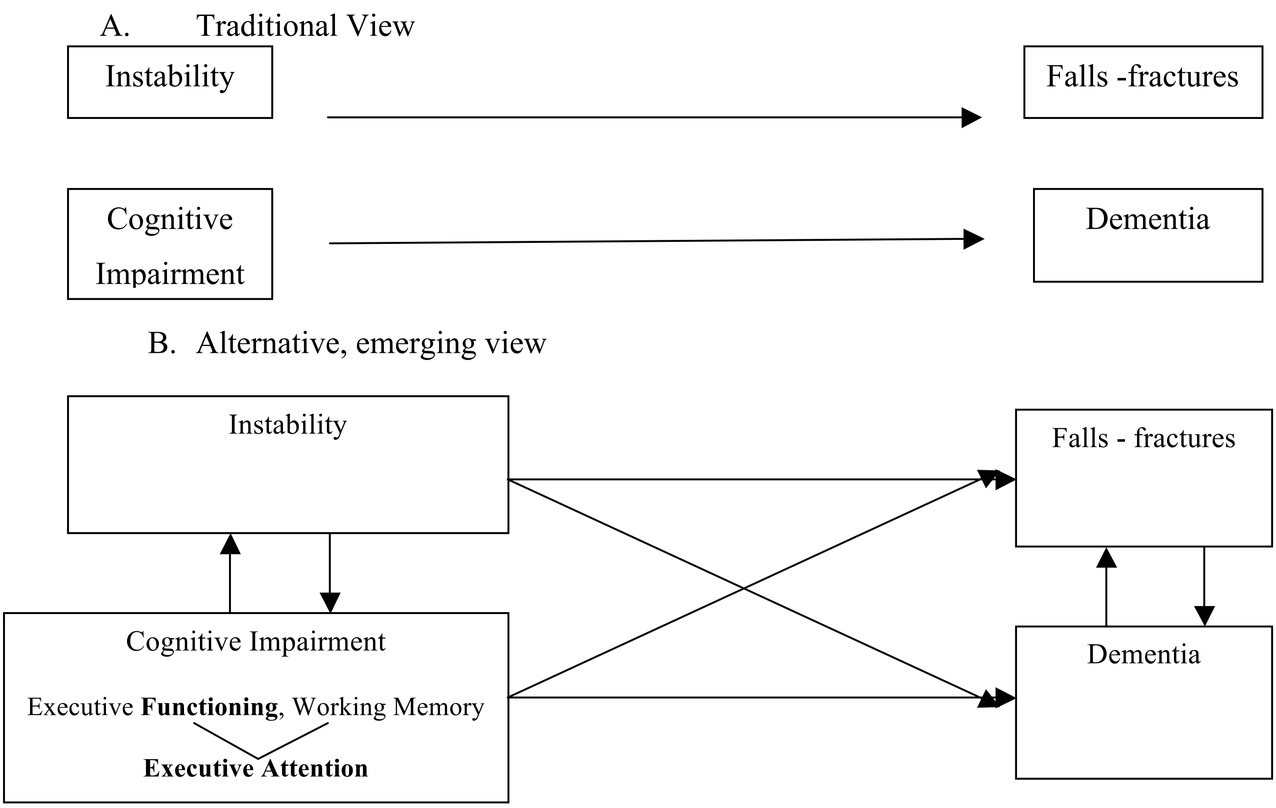

Figure 8.1. Maclean, 2012. An integrated model of executive function/working memory and gait/cognitive tasks (Montero-Odasso et al., 2012) adapted by author.

The following model differs from Montero-Odasso and colleagues (2012) in that it provides and explains a controlling mechanism which is not only a component in the interaction between working memory and gait/cognitive tasks but drives it. The oval in Figure 8.2 represents the dual task, the parameters of which are constantly changing, according to the priorities of internal goals or external (environmental) demands. The arrows represent the flexibility (adaptability) shown by an individual in response to the changing priorities. Attention is not necessarily limited (the model allows for resources being domain-specific or attention being fractionated), but when required for complex tasks, it is flexibly allocated by the executive attention component within working memory, as efficiently as is required by the constantly-changing nature of the tasks.

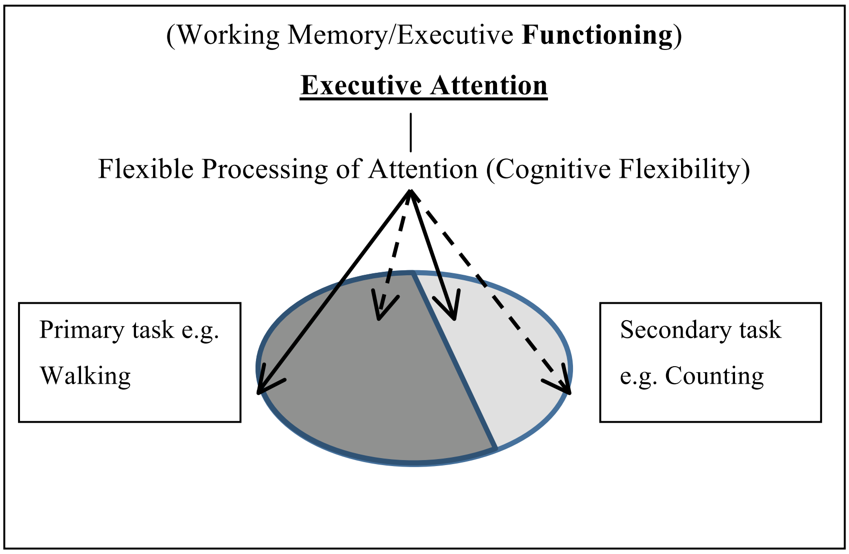

Figure 8.2. Model of executive attention in a gait and cognitive dual task revised from Montero-Odasso et al, 2012 by Maclean, 2013.

Solid lines indicate an example of attention allocation to either walking or counting under low cognitive-demand. Broken lines indicate a higher cognitive demand which requires a change in attention-allocation and prioritisation of attention. The difference between the two examples illustrates the notion of cognitive flexibility.

8.1.9 Healthy Ageing

The overall results indicate that the retention of cognitive flexibility between conscious and unconscious demands for attention is critically important, especially when walking has to be prioritised in a rapidly-changing environment. Testing the ability to flexibly allocate attention to walking, when required, revealed very subtle changes in behaviour which were not detected by other tests. It may hold the key to how well older adults maintain their ability to carry out every-day tasks such as preparing a meal, managing finances and taking public transport, where many cognitive functions have to be completed simultaneously in fast-moving environment and where there is a risk that a slow reaction might result in an adverse event. In this study, cognitive flexibility was predicted by standardised tests of fluid cognitive ability at baseline (SDMT and Delta TMT), tests which might now be considered a proxy for Logie at al.'s (2004) notion of an executive dual-task coordination function in the healthy brain which allocates specialised resources to concurrent tasks.

The practical application, from both the longitudinal study and the intervention study are applicable to healthy older adults as strategies for retaining functional well-being for as long as possible. All of the findings from the experimental studies conducted during the course of this research point in one direction, namely that attending to gait during concurrent walking and cognitive activity improved healthy older adults' step-time variability and that steadier gait is strongly associated with better cognitive flexibility. Together, these are markers independent-living and healthy ageing and are encouraging signs that intervention training to improve gait and cognitive performance would enhance older adults' ability to remain independent for as long as possible as they continue to live longer.

8.2 Limitations of the study

The following suggestions generally concern measures which would have enhanced the studies and not limitations of the methods used in the studies. If the longitudinal study were to be repeated, the participants' background characteristics would include a measure of socio-economic status (or previous occupation) and accurately measured (not self-reported) height and weight would be recorded at both time points. In terms of performance measures, the Timed-up-and-go (TUG) (Podsiadlo & Richardson, 1991) would be used for general mobility, as this test has normative data (Schoppen et al., 1999) and other EF tests which are recognised as specific to cognitive flexibility, such as the Wisconsin Card Sorting Test or the Stroop Test (Lezak, 1995) would be included. In order to specify which function was the more sensitive measure of the SDMT (processing speed or perceptual speed) the Digit Copying Test would have been used before the SDMT so that SDMT scores would have been normalised (for variations in participants' fine motor skills). Similarly, the musical intervention study would have used the TUG to test for general mobility, height and weight would have been measured by the researcher and the intervention period of walking would have been set at an equal number of walks for all participants, in order to ensure complete standardisation for all 3 groups.

8.3 Suggestions for future research

Theoretically, longitudinal studies reveal more when the same participants are investigated at several time points. Therefore, future research would aim to follow these healthy older adults over the course of their lifetime. This would test whether changes observed between T1 and T2 were due to the normal (non-pathological) ageing process or to the presence of pathological disease. Cohort effects often influence research findings (Stuart-Hamilton, 2012) and, in order to obviate these, this research would be replicated in different in groups with different socio-economic status and with different known physical and cognitive function. So that the notions of 'automaticity' and 'rhythmicity' might be further investigated, the effect of musical training would be extended to a group of older adults with cognitive impairment. Similarly, the effect of musical training on the gait and cognitive performances of an experimental group comprising ex or serving Armed Forces personnel (whose step/stride-time/length variability may have already been regulated by 'drill') could be undertaken.

References

Aalfaro-Acha, A. S., Raji, M., Markedes, M., Ottenbacker, K. J. . (2007). Does 8-foot walk time predict cognitive decline in older Mexican Americans? *Journal of the American Geriatrics Society, 55*, 245-251.

Abrams, D. M., Manstead, A.S.R. (1981). A test of theories of social facilitation using a musical task. *British Journal of Social Psychology, 20*(271-278).

Allali, G., Assal, G., Kressig, R. W., Dubost, V., Herrmann, F.R., Beauchet. (2008). Impact of impaired executive function on gait stability *Dementia and Geriatric Cognitive Disorders, 26*, 364–369.

Allali, G., van der Meulena, M., Assal, F. (2010). Gait and cognition: the impact of executive function. *Schweizer Archiv fur Neurologicie und Psychiatrie 161*(6), 195-199.

Allport, D. A. (1980). *Attention and performance*. London: Routledge and Kegan Paul.

Arias, P., Cudeiro, J. (2008). Effects of rhythmic sensory stimulation (auditory, visual) on gait in Parkinson's disease patients. *Experimental Brain Research, 186*(4), 589-601.

Atkinson, H. H., Rosano, C., Simonsick, E.M., Williamson, J.D., Davis, C., Ambrosius, W.T., Rapp, S.R., Cesari, M., Newman, A. B., Harris,T.B., S.M., Rubin, Yaffe, K., Satterfield, S., Kritchevsky,S.B. (2007). Cognitive function, gait speed decline, and comorbidities: the health, aging and body composition study Hal. *Journal of Gerontology 62A,*(8), 844–850.

Ayyappa, E. (1997a). Normal Human Locomotion, Part 1: Basic Concepts and Terminology. *JPO: Journal of Prosthetics and Orthotics, 9*(1), 10-17.

Baddeley, A. D., Hitch, G.J. (Ed.). (1974). *Working Memory* (Vol. 8). New York: Academic Press.

Baddeley, A. D. (1986). *Working Memory*. Oxford: Oxford Scientific Publications.

Baddeley, A. D. (1996). Exploring the central executive. *The Quarterly Journal of Experimental Psychology, 49A*(1), 5-28.

Baddeley, A., Sala, S. D., Robbins, T. W., & Baddeley, A. (1996). Working Memory and Executive Control [and Discussion]. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences, 351*(1346), 1397-1404.

Baddeley, A. D. (2000). The episodic buffer: a new component of working memory? *Trends in Cognitive Sciences, 4*(11), 417-423.

Baddeley, A. D., Baddeley, H. A., Bucks, R. S., & Wilcock, G. K. (2001). Attentional control in Alzheimer's disease. *Brain, 124*(8), 1492-1508.Baker, K., Rochester, L., & Nieuwboer, A. (2008). The effect of cues on gait variability—Reducing the attentional cost of walking in people with Parkinson's disease. *Parkinsonism & Related Disorders, 14*(4), 314-320.

Baker, K., Rochester, L., & Nieuwboer, A. (2008). The effect of cues on gait variability—Reducing the attentional cost of walking in people with Parkinson's disease. *Parkinsonism & Related Disorders, 14*(4), 314-320.

Barker, S., Craik, r., Freedman, W., Herrmann, N., Hillstrom, H. . (2006). Accuracy, reliability and validity of a spatiotemporal gait analysis system. *Medical Engineering and Physics, 28*(5), 460-467.

Baron, R. S. (Ed.). (1986). *Distraction-conflict theory.* Orlando, FL: Academic Press.

Beauchet, O., Dubost, V. Herrmann, F.R., Kressig, R. W. (2005). Stride-to-stride variability while backward counting among healthy young adults. *Journal of NeuroEngineering Rehabilitation, 2*(26).

Beauchet, O., Dubost V., Allali, G., Gonthier,R., Hermann, F.R., & Kressig, R. (2007). 'Faster counting while walking' as a predictor of falls in older adults. *Age and Ageing, 36*(4), 418-423.

Beauchet, O., Annweiler, C., Allali, G., Berrut, G., Herrmann, F. R., & Dubost, V. (2008). Recurrent Falls and Dual Task–Related Decrease in Walking Speed: Is There a Relationship? *Journal of the American Geriatrics Society, 56*(7), 1265-1269.

Beauchet, O., Allali, G., Poujol, L., Barthelemy, J., Roche, F., & Annweiler, C. (2010). Decrease in gait variability while counting backward: a marker of "magnet effect"? *Journal of Neural Transmission, 117*(10), 1171-1176.

Beauchet, O., Allali, G., Thiery, S., Gautier, J., Fantino, B., & Annweiler, C. (2011). Association Between High Variability of Gait Speed and Mild Cognitive Impairment: A Cross-Sectional Pilot Study. *Journal of the American Geriatrics Society, 59*(10), 1973-1974.

Beck, A.T., Steer. R.A, Brown, G.K. (1996). *Manual for the Beck Depression Inventory-II* San Antonio, TX: Psychological Corporation.

Berg K, Wood-Dauphinee, S., Williams, J.I., Maki, B.W., (1992). Measuring balance in the Elderly: Validation of an Instrument. . *Can. J. Pub. Health Jul/Aug Supplement, 2:S7-11*.

Bilney, B., Morris, M., Webster, K. (2003). Concurrent related validity of the GAITRite† walkway system for quantification of the spatial and temporal parameters of gait. *Gait and Posture 17*, 68 -74.

Black, S. A., & Rush, R. D. (2002). Cognitive and Functional Decline in Adults Aged 75 and Older. *Journal of the American Geriatrics Society, 50*(12), 1978-1986.

Bloem, B. R., Grimbergen, Y. A. M., van Dijk, J. G., & Munneke, M. (2006). The "posture second" strategy: A review of wrong priorities in Parkinson's disease. *Journal of the Neurological Sciences, 248*(1–2), 196-204.

Bock, O. (2008). Dual-task costs while walking increase in old age for some, but not for other tasks: an experimental study of healthy young and elderly persons. *Journal of NeuroEngineering and Rehabilitation, 5*(27).

Bowling, A., Dieppe, P. (2005). What is successful ageing and who should define it? *British Medical Journal, 331*, 1548–1551.

Bridenbaugh, S. A., Kressig, R.W. (2010). Laboratory Review: The Role of Gait Analysis in Seniors' Mobility and Fall Prevention. *Gerontology*, 1-9.

Broadbent, D. E. (1958). The selective nature of learning *Perception and communication* (pp. 244-267). Elmsford, NY, US: Pergamon Press.

Brown, I. D., Tickner, A. H., & Simmonds, D. C. (1969). Interference between concurrent tasks of driving and telephoning. *Journal of Applied Psychology, 53*(5), 419-424.

Brown, L. A., de Bruin, N., Doan, J. B., Suchowersky, O., & Hu, B. (2009). Novel Challenges to Gait in Parkinson's Disease: The Effect of Concurrent Music in Single- and Dual-Task Contexts. *Archives of Physical Medicine and Rehabilitation, 90*(9), 1578-1583.

Camicioli, R., Howieson, D., Lehman, S., & Kaye, J. (1997). Talking while walking: the effect of a dual task in aging and Alzheimer's disease. *Neurology, 48*, 955 - 958.

Camicioli, R., Howieson, D., Oken, B., Sexton, G., & Kaye, J. (1998). Motor slowing precedes cognitive impairment in the oldest old. *Neurology, 50*, 1496 - 1498.

Camicioli, R., Wang, Y., Powell, C., Mitnitski, A., Rockwood, K. (2007). Gait and posture impairment, parkinsonism and cognitive decline in older people. *Journal of Neural Transmission 114*, 1355–1361.

Canning, C. G. (2005). The effect of directing attention during walking under dual-task conditions in Parkinson's disease. *Parkinsonism and Related 11*, 95–99.

Carter, R. (1999). *Mapping the mind*. Berkley and Los Angeles: University of California Press.

Cesari, M., Kritchevsky, S., Penninx, B., Nicklas, B., Simonsick, E., Newman, A., et al. (2005). Prognostic value of usual gait speed in well-functioning older people--results from the Health, Aging and Body Composition Study. *J Am Geriatr Soc, 53*, 1675 - 1680.

Cho, C., Gilchrist, L., White, S., & A.D. Baddeley, M. D. K. a. B. A. W. (2008). A Comparison between Young and Old Adults in Their Ability to Rapidly Sidestep during Gait when Attention Is Divided. *Gerontology 54*, 120–127.

Cocchini, G., Logie, R., Sala, S., MacPherson, S., & Baddeley, A. (2002). Concurrent performance of two memory tasks: Evidence for domain-specific working memory systems. *Memory & Cognition, 30*(7), 1086-1095.Collette, F., Hogge, M., Salmon, E., & Van der Linden, M. (2006). Exploration of the neural substrates of executive functioning by functional neuroimaging. *Neuroscience, 139*(1), 209-221.

Collette, F., Hogge, M., Salmon, E., & Van der Linden, M. (2006). Exploration of the neural substrates of executive functioning by functional neuroimaging. *Neuroscience, 139*(1), 209-221.

Coolidge, F. L., Wynn T. . (2005). Working memory, its executive functions and the emergence of modern thinking. *Cambridge Archaeological Journal 15(1)*, 5-26.

Coppin, A. K., Shumway-Cook, A., Saczynski, J. S., Patel, K. V., Ble, A., Ferrucci, L., et al. (2006). Association of executive function and performance of dual-task physical tests among older adults: analyses from the InChianti study. *Age and Ageing, 35*(6), 619-624.

Cowan, N. (2005). *Working Memory Capacity*. New York: Taylor and Francis Group.

Craik, F. I. M., & Byrd, M. . (1982). Aging and cognitive deficits: The role of attentional resources. In F. I. M. C. S. E. Trehub (Ed.), *Aging and cognitive processes*. New York: Plenum Press.

Craik, F. I. a. Salthouse., T.A. (2000). *The Handbook of Aging and Cognition*.

Deary, I., Gow, A.J. (2008). *Determinants of normal cognitive ageing: implications for mental capital* (No. State of science review: E14): Government office for science.

Deary, I. J., Corley, J., Gow, A. J., Harris, S. E., Houlihan, L. M., Marioni, R. E., et al. (2009). Age-associated cognitive decline. *British Medical Bulletin, 92*(1), 135-152.

de Bruin, E., & Schmidt, A. (2010). Walking behaviour of healthy elderly: attention should be paid. *Behavioral and Brain Functions, 6*(1), 59.

Della Sala, S., Baddeley, A., Papagno, C., Spinnler, H. (1995). Dual-task paragidgm: A means to examine the central executive. *Annals New York Academy of Sciences, 769*, 161-172.

Deschamps, V., Astier, X., Ferry, M., Rainfray, M., Emeriau, J. P., & Barberger-Gateau, P. (2002). Nutritional status of healthy elderly persons living in Dordogne, France, and relation with mortality and cognitive or functional decline. *European journal of clinical nutrition, 56*(4), 305-312.

Dickens, W. E., & Smith, M. F. (2006). Validation of a visual gait assessment scale for children with hemiplegic cerebral palsy. *Gait & Posture, 23*(1), 78-82.

Duff, K., Mold, J. W., & Gidron, Y. (2008). Cognitive functioning predicts survival in the elderly. *Journal of Clinical and Experimental Neuropsychology, 31*(1), 90-95.

Ebersbach, G., Dimitrijevic, M. R., & Poewe, W. (1995). Influence of concurrent tasks on gait: A dual-task approach. *Perceptual and Motor Skills, 81*(1), 107-113.

Escoffier, N., Sheng, D. Y. J., & Schirmer, A. (2010). Unattended musical beats enhance visual processing. *Acta Psychologica, 135*(1), 12-16.

Esser, P., Dawes, H., Collett, J., Feltham, M.G., Howells, K. (2011). *'DataGait' can accurately measure gait parameters in neurological conditions.* . Paper presented at the Annual Meeting of Clinical Movement Analysis Society UK & Ireland.

Fitzpatrick, A. L., Buchanan, C.K., Nahin, R.L.. DeKosky, S.T.,Atkinson, H.H., Carlson, M.C., Williamson, J.D.,. (2007). Associations of Gait Speed and Other Measures of Physical Function With Cognition in a Healthy Cohort of Elderly Persons. *Journal of Gerontology: Medical Sciences 62A*(11), 1244–1251.

Fodor, J. A. (1983). *The Modularity of Mind*. Cambridge MA: MIT Press.

Folstein, M., Folstein, S., & McHugh, P. (1975). "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. *J Psychiatr Res, 12*, 189 - 198.

Fried, L. P., Tangen, C. M., Walston, J., Newman, A. B., Hirsch, C., Gottdiener, J., et al. (2001). Frailty in Older Adults. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 56*(3), M146-M157.

Galna, B., Lord, S., & Rochester, L. (2013). Is gait variability reliable in older adults and Parkinson's disease? Towards an optimal testing protocol. *Gait & Posture, 37*(4), 580-585.

Giladi, N. (2007). Gait and mental function: the interplay between walking, behavior and cognition. *J Neural Transm 114*, 1241–1242

Grant, I., Adams, K.M (Ed.). (1996). *Neuropsychological assessment of neuropsychiatric disorders*. Oxford: Oxford University Press.

Hampson, P. J. (1989). Aspects of attention and cognitive science:. *Irish Journal of Psychology 10*, 261-275.

Hartley, A. A., & Little, D. M. (1999). Age-related differences and similarities in dual-task interference. *Journal of Experimental Psychology: General, 128*(4), 416-449.

Hasher, L., Zacks, R.T. (1988). Working memory, comprehension and aging: A review and new view. *The Psychology of Learning and Motivation, 22*, 193-371.

Hausdorff, J. M., Rios, D. A., & Edelberg, H. K. (2001). Gait variability and fall risk in community-living older adults: A 1-year prospective study. *Archives of Physical Medicine and Rehabilitation, 82*(8), 1050-1056.

Hausdorff, J. M., Yogev, G., Springer, S., Simon, E. S., & Giladi, N. (2005). Walking is more like catching than tapping: gait in the elderly as a complex cognitive task. *Experimental Brain Research, 164*(4), 541-548.

Hausdorff, J. M., Schweiger, A., Herman, T., Yogev-Seligmann, G., & Giladi, N. (2008). Dual-Task Decrements in Gait: Contributing Factors Among Healthy Older Adults. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 63*(12), 1335-1343.

Herman, T., Mirelman, A., Giladi, N., Schweiger, A., Hausdorff, J.M. (2010). Executive control deficits as a podrome to falls in healthy older adutls: A prospective study linking, thinking, walking and falling. *Journal of Gerontology, 65A*(10), 1086-1092.

Hobert, M. A., Niebler, R., Meyer, S. I., Brockmann, K., Becker, C., Huber, H., et al. (2011). Poor Trail Making Test Performance Is Directly Associated with Altered Dual Task Prioritization in the Elderly - Baseline Results from the TREND Study. *Plos One, 6*(11).

Hollman, J. H., Kovash, F.M., Kubik, J.J., Linbo, R.A. (2007). Age-related differences in spatiotemporal markers of gait stability during dual task walking. *Gait & Posture 26*, 113–119.

Hollman, J. H., Childs, K. B., McNeil, M. L., Mueller, A. C., Quilter, C. M., & Youdas, J. W. (2010). Number of strides required for reliable measurements of pace, rhythm and variability parameters of gait during normal and dual task walking in older individuals. *Gait & Posture, 32*(1), 23-28.

Holtzer, R., Verghese, J., Xue, X., Lipton, R.B. (2006). Cognitive Processes Related to Gait Velocity: Results From the Einstein Aging Study. *Neuropsychology, 20*(2), 214-223.

Holtzer, R., Friedman, R., Lipton, R., Katz, M., Xue, X., Verghese, J. (2007). The relationship betweem specific cognitive functions and falls in aging. *Neuropsychology 21*, 540-548.

Holtzer, R., Mahoney, J. R., Izzetoglu, M., Izzetoglu, K., Onaral, B., & Verghese, J. (2011). fNIRS Study of Walking and Walking While Talking in Young and Old Individuals.

The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 66A(8), 879-887.

Inzitari, M., Di Carlo, A., Baldereschi, M., Pracucci, G., Maggi, S., Gandolfo, C., et al. (2006). Risk and Predictors of Motor-Performance Decline in a Normally Functioning Population-Based Sample of Elderly Subjects: The Italian Longitudinal Study on Aging. *Journal of the American Geriatrics Society, 54*(2), 318-324.

Inzitari, M., Newman, A.B., Yaffe, K., Boudreau, R., de Rekeneire, N., Shorr, R., Harris, T.B., Rosano, C. (2007). Gait Speed Predicts Decline in Attention and Psychomotor Speed in Older Adults: The Health Aging and Body Composition Study. *Neuroepidemiology, 29*, 156-162.

Kahneman, D. (1973). *Attention and effort*. Englewood Cliffs, NJ: Prentice-Hall.

Kamijo, K., Hayashi, Y., Sakai, T., Yahiro, T., Tanaka, K., & Nishihira, Y. (2009). Acute Effects of Aerobic Exercise on Cognitive Function in Older Adults. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 64B*(3), 356-363.

Kandel., E. R., Schwartz, J. H., Jessell, T.M. (2000). *The Principals of neural science*: McGraw-Hill.

Katz, M., Branch, L.G., Branson, M.H., Papsideri, J. A., Beck, M. D. and Greer, M. D. . (1983). Active Life Expectancy. *New England Journal of Medicine, 309*, 1218-1224.

Kelly, V. E., Janke, A. A., & Shumway-Cook, A. (2010). Effects of instructed focus and task difficulty on concurrent walking and cognitive task performance in healthy young adults. *Experimental Brain Research, 207*(1-2), 65-73.

Kelly, V. E., Schrager, M.A., Price, r., Ferrucci, L., Shumway-Cook A. (2008). Age-associated effects of a concurrent cogntiive task on gait speed and stabilityduring narrow-base walking. *Jounal of Gerontology, 63*(12), 1329-1334.

Kirtley, C. (2006). *Clinical Gait Analysis: Theory and Practice*. London, UK: Elsevier Ltd.

Kramer, A. F., Hahn, S., Cohen, N. J., Banich, M. T., McAuley, E., Harrison, C. R., et al. (1999). Ageing, fitness and neurocognitive function. [10.1038/22682]. *Nature, 400*(6743), 418-419.

Kramer, A. F., Erickson, K. I., & Colcombe, S. J. (2006). Exercise, cognition, and the aging brain. *Journal of Applied Physiology, 101*(4), 1237-1242.

Kressig, R. W., Allali G, Beauchet O. (2005). Long-term practice of Jaques-Dalcroze eurhythmics prevents age-related increase of gait variability under a dual task. . *Journal of the American Geriatrics Society., 53(4)*, 728–729.

Laessoe, U., Hoeck, H.C., Simonsen, O., Voigt, M. (2008). Residual attentional capacity amongst young and elderly during dual and triple task walking. *Human Movement Science 27*, 496-512.

Lajoie, Y., Teasdale, N., Bard, C., & Fleury, M. (1996). Upright Standing and Gait: Are There Changes in Attentional Requirements Related to Normal Aging? *Experimental Aging Research, 22*(2), 185-198.

Lezak, M. D. (1995). *Neuropsychological Assessment* (3rd ed.). Oxford: Oxford University Press.

Li, K. Z. H., Abbud, G. A., Fraser, S. A., & DeMont, R. G. (2013). Successful adaptation of gait in healthy older adults during dual-task treadmill walking. *Aging, Neuropsychology, and Cognition, 19*(1-2), 150-167.

Lindenberger, U., Marsiske, M., & Baltes, P. (2000). Memorizing while walking: increase in dual-task costs from young adulthood to old age. *Psychol Aging, 15*, 417 - 436.

Logie, R. H., Cocchini, G., Della Sala, S., Baddeley, A.D. (2004). Is There a Specific Executive Capacity for Dual Task Coordination? Evidence From Alzheimer’s Disease. *Neuropsychology 18*(3), 504-513.

Logie, R.H. (2011, June). *Recent Research.* Paper presented at the Working Memory Group Meeting, Queen Margaret's University , Edinburgh.

Lord, S., Rochester, L., Hetherington, V., Allcock, L. M., & Burn, D. (2010). Executive dysfunction and attention contribute to gait interference in 'off' state Parkinson's Disease. *Gait & Posture, 31*(2), 169-174.

Lovden, M., Schaefer, S., Pohlmeyer, A.E. & Lindenberger, U. (2008). Walking variability and working -memory load in aging: A dual-process account relating cognitive control to motor control performance. *Journal of Gerontology, 63*(3), 121-128.

Lundin-Olsson, L., Nyberg, L., & Gustafson, Y. (1997). "Stops walking when talking" as a predictor of falls in elderly people. *Lancet, 349*(9052), 617.

Luszcz, M. (2011). Executive Function and Cognitive Aging. In K. W. W. Schaie, S.L. (Ed.), *Handbook of the Psychology of Aging* (7th ed.). London: Adademic Press.

Magill, R. A. (2004). *Motor learning and control: concepts and applications*: McGraw-Hill.

Marquis, S., Moore, M.M., Howieson, D.B., Sexton, G., Payami, H., Kaye, J.A., Camicioli, R. (2002). Independent Predictors of Cognitive Decline in Healthy Elderly Persons. *Arch Neurol, 59*, 601-606.

McCabe, D. P. R. I., Henry L.; McDaniel, Mark A.; Balota, David A.; Hambrick, David Z. . (2010). The relationship between working memory capacity and executive functioning: Evidence for a common executive attention construct. *Neuropsychology, 24(2)*, 222-243.

McDowd, J. M. &. Shaw, R.J. (2000). *Attention and Aging: a Functional Perspective*

Meguro, K., Constans, J.-M., Shimada, M., Yamaguchi, S., Ishizaki, J., Ishii, H., et al. (2003). Corpus Callosum Atrophy, White Matter Lesions, and Frontal Executive Dysfunction in Normal Aging and Alzheimer's Disease. A Community-Based Study: The Tajiri Project. *International Psychogeriatrics, 15*(01), 9-25.

Montero-Odasso, M., Schapira, M., Soriano, E. R., Varela, M., Kaplan, R., Camera, L. A., et al. (2005). Gait Velocity as a Single Predictor of Adverse Events in Healthy Seniors Aged 75 Years and Older. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 60*(10), 1304-1309.

Montero-Odasso, M. (2006). The value of gait velocity test for high-function populations. *Journal of the American Geriatrics Society, 54*(12), 1949-1950.

Montero-Odasso, M., Bergman, H., Phillips, N., Wong, C., Sourial, N., & Chertkow, H. (2009). Dual-tasking and gait in people with Mild Cognitive Impairment. The effect of working memory. *BMC Geriatrics, 9*(1), 41.

Montero-Odasso, M., Muir, S. W., Hall, M., Doherty, T. J., Kloseck, M., Beauchet, O., et al. (2011). Gait Variability Is Associated With Frailty in Community-dwelling Older Adults. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 66A*(5), 568-576.

Montero-Odasso, M., Muir, S. W., & Speechley, M. (2012). Dual-Task Complexity Affects Gait in People With Mild Cognitive Impairment: The Interplay Between Gait Variability, Dual Tasking, and Risk of Falls. *Archives of Physical Medicine and Rehabilitation, 93*(2), 293-299.

Moors, A., & De Houwer, J. (2006). Automaticity: theoretical and conceptual analysis. . *Psychological Bulletin, 132*, 297-326.

Moritz, D. J., Kasl, S.V., Berkman L.F. (1995). Cognitive Functioning and the Incidence of Limitations in Activities of Daily Living in an Elderly Community Sample. *American Journal of Epidemiology, Vol. 141*(1), 41-49

Muir, S. W., Speechley, M., Wells, J., Borrie, M., Gopaul, K., & Montero-Odasso, M. (2012). Gait assessment in mild cognitive impairment and Alzheimer's disease: The effect of dual-task challenges across the cognitive spectrum. *Gait & Posture, 35*(1), 96-100.

Nakamura, D. M., Holm, M. B., & Wilson, A. (1999). Measures of Balance and Fear of Falling in the Elderly. *Physical & Occupational Therapy in Geriatrics, 15*(4), 17-32.

Nelson, H. E. (1982). *National Adult Reading Test,* Windsor.

Nieuwboer, A., Kwakkel, G., Rochester, L., Jones, D., van Wegen, E., Willems, A. M., et al. (2007). Cueing training in the home improves gait-related mobility in Parkinson's disease: the RESCUE trial. *Journal of Neurology, Neurosurgery & Psychiatry, 78*(2), 134-140.

Njegovan, V., Man-Son-Hing, M., Mitchell, S. L., & Molnar, F. J. (2001). The Hierarchy of Functional Loss Associated With Cognitive Decline in Older Persons. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 56*(10), M638-M643.

Norman, D. A., Shallice, T. (1980). Attention to Action: Willed and Automatic Control of Behavior.

Pashler, H. (1994). Dual-Task Interference in Simple Tasks: Data and Theory. *Psychological Bulletin, 116*(2), 220-244.

Pérès, K., Helmer, C., Amieva, H., Orgogozo, J.-M., Rouch, I., Dartigues, J.-F., et al. (2008). Natural History of Decline in Instrumental Activities of Daily Living Performance over the 10 Years Preceding the Clinical Diagnosis of Dementia: A Prospective Population-Based Study. *Journal of the American Geriatrics Society, 56*(1), 37-44.

Persad, C. C., Jones, J. L., Ashton-Miller, J. A., Alexander, N. B., & Giordani, B. (2008). Executive Function and Gait in Older Adults With Cognitive Impairment. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 63*(12), 1350-1355.

Phillips, L. H., Hamilton, C. (2001). The working memory model in adult aging research. In J. Andrade (Ed.), *Working memory in perspective* (pp. 101-125). Hove: Psychology Press Ltd.

Podsiadlo, D., Richardson, S. (1991). The Timed 'Up & Go': A test of basic functional mobility for frail elderly persons. *Jounal of the American Geriatrics*.

Posner, M. I., & Petersen, S. E. (1990). The Attention System of the Human Brain. *Annual Review of Neuroscience, 13*(1), 25-42.

Posner, M. I. a. d., G.J. . (2000). Attention in cognitive neuroscience: an overview. In G. MS (Ed.), *The New Cognitive Neurosciences (2nd ed.)* (pp. p. 623–631.). Cambridge, MA: MIT Univ. Press.

Priest, A. W., Salamon, K.B., Hollman, J. H. (2008). Age-related differences in dual task walking: a cross sectional study. *Journal of NeuroEngineering and Rehabilitation, 5*(29).

Reitan, R. M., & Wolfson, D. . (1993). *The Halstead–Reitan Neuropsychological Test Battery: Theory and clinical interpretation* (2nd ed ed.). Tucson, AZ: Neuropsychology Press.

Richards, M., & Deary, I. J. (2005). A life course approach to cognitive reserve: A model for cognitive aging and development? *Annals of Neurology, 58*(4), 617-622.

Rochester, L., Nieuwboer, A., Baker, K., Hetherington, V., Willems, A. M., Chavret, F., et al. (2007). The attentional cost of external rhythmical cues and their impact on gait in Parkinson's disease: effect of cue modality and task complexity. *Journal of Neural Transmission, 114*(10), 1243-1248.

Rochester, L., Burn, D. J., Woods, G., Godwin, J., & Nieuwboer, A. (2009). Does auditory rhythmical cueing improve gait in people with Parkinson's disease and cognitive impairment? A Feasibility study. *Movement Disorders, 24*(6), 839-845.

Rosano C, B. J., Studenski S, Longstreth Jr. WT, Newman AB. (2007). Gait Variability Is Associated with Subclinical Brain Vascular Abnormalities in High-Functioning Older Adults. *Neuroepidemiology, 29*, 193-200.

Rovio, S., Kåreholt, I., Helkala, E.-L., Viitanen, M., Winblad, B., Tuomilehto, J., et al. (2005). Leisure-time physical activity at midlife and the risk of dementia and Alzheimer's disease. *The Lancet Neurology, 4*(11), 705-711.

Rowe, J., & Kahn, R. (1987). Human aging: usual and successful. *Science, 237*(4811), 143-149.

Royall, D. R., Lauterbach, E.C., Cummings, J. L., Reeve, A., Rummans, T.A., Kaufer, D. I., LaFrance, W.C. Coffey, C.E. (2002). Executive control function: A reivew of its promise and challenges for clinical control. *Jounal of Neuropsychiatry and Clinical Neurosciences 377-397, 14*(4).

Ryberg, C., Rostrup, E., Stegmann, M. B., Barkhof, F., Scheltens, P., van Straaten, E. C. W., et al. (2007). Clinical significance of corpus callosum atrophy in a mixed elderly population. *Neurobiology of Aging, 28*(6), 955-963.

Salthouse, T. (1985). *A theory of cognitive aging*. Amsterdam: Elsevier Science Publishers B.V.

Salthouse, T. A. (1992). Influence of processing speed on adult age differences in working memory. *Acta Psychologica, 79*(2), 155-170.

Salthouse, T. A., & (1996). The processing-speed theory of adult age differences in cognition. *Psychological Review, Vol 103(3)*, 403-428.

Salthouse, T. A. (2000). Ageing and measures of processing speed. *Biological Psychology, 54*(1-3), 35-54.

Salthouse, T. A. A., Thomas M.; Berish, Diane E. . (2003). Executive Functioning as a Potential Mediator of Age-Related Cognitive Decline in Normal Adults. *Journal of Experimental Psychology: General,, Vol 132(4)*, 566-594.

Salthouse, T. A. (2010). *Major Issues in Cognitive Aging*. New York: Oxford University Press.

Salthouse, T. (2011). What cognitive abilities are involved in trail-making performance? *Intelligence 39*, 222–232.

Samper-Ternent, R., Al Snih, S., Raji, M. A., Markides, K. S., & Ottenbacher, K. J. (2008). Relationship Between Frailty and Cognitive Decline in Older Mexican Americans. *Journal of the American Geriatrics Society, 56*(10), 1845-1852.

Sanders, A. E., Holtzer, R., Lipton, R. B., Hall, C., & Verghese, J. (2008). Egocentric and Exocentric Navigation Skills in Older Adults. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 63*(12), 1356-1363.

Satoh, M., & Kuzuhara, S. (2008). Training in Mental Singing while Walking Improves Gait Disturbance in Parkinson's Disease Patients. *European Neurology, 60*(5), 237-243.

Schneider, W., Shiffren, R.M. (1977). Controlled and automatic human information processing: 1. Detection, search and detection. *Psychological Review, 84*, 1-66.

Schoppen T, B. G., Groothoff JW, de Vries J, Goeken LNH, Elisma WH., & Go", T. T. U. a. (1999). The Timed "Up and Go" Test: Reliability and Validity in persons with unilateral lower limb amputation. *Archives of Physical Medicine and Rehabilitation Engineering, 80(7*, 825-828.

Schwenk, M., Zieschang, T., Oster, P., & Hauer, K. (2010). Dual-task performances can be improved in patients with dementia. *Neurology, 74*(24), 1961-1968.

Shallice, T., Evans, M.E. (1978). The involvement of the frontal lobes in cognitive estimation. *Cortex, 14*, 294-303.

Sheridan, P. L., Solomont, J., Kowall, N., & Hausdorff, J. M. (2003). Influence of Executive Function on Locomotor Function: Divided Attention Increases Gait Variability in Alzheimer's Disease. *Journal of the American Geriatrics Society, 51*(11), 1633-1637.

Shiffrin, R. M. & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending, and a general theory. *Psychological Review, 84*, 127-190.

Shumway-Cook, A., Woollacott, M., Kerns, K. A., & Baldwin, M. (1997). The Effects of Two Types of Cognitive Tasks on Postural Stability in Older Adults With and

Without a History of Falls. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 52A*(4), M232-M240.

Siu, K., Chou, L., Mayr, U.,van Donkelaar, P., Woollacott, M.H. (2008). Does Inability to Allocate Attention Contribute to Balance Constraints During Gait in Older Adults? *Journal of Gerontology: MEDICAL SCIENCES 63A*(12), 1364–1369.

Siu, K., Choua, L., Mayrb, U., van Donkelaara, P., Woollacott, M.H. (2009). Attentional mechanisms contributing to balance constraints during gait: The effects of balance impairments. *Brain Research, 1248*, 59-67.

Smith, A. (1982). *Symbol Digits Modalities Test,* Los Angeles Western Psychological Services.

Smith, E. E. & Kosslyn, S. M. (2007). *Cognitive Psychology Mind and Brain*. New Jersey Pearson Education.

Smulders, K., Esselink, R., Weiss, A., Kessels, R., Geurts, A., & Bloem, B. (2012). Assessment of dual tasking has no clinical value for fall prediction in Parkinson's disease. *Journal of Neurology*, 1-8.

Snijders, A. H., Verstappen, C. C., Munneke, M., & Bloem, B. R. (2007). Assessing the interplay between cognition and gait in the clinical setting. *Journal of Neural Transmission, 114*(10), 1315-1321.

Spreen, O., Strauss, E. (1998). *A Compendium of Neuropsychological Tests* (2nd ed.). Oxford: Oxford University Press.

Springer, S., Giladi, N., Peretz, C., Yogev, G., Simon, E., & Hausdorff, J. (2006). Dual-tasking effects on gait variability: the role of aging, falls, and executive function. *Mov Disord, 21*, 950 - 957.

Srygley, J. M., Mirelman, A., Herman, T., Giladi, N., & Hausdorff, J. M. (2009). When does walking alter thinking? Age and task associated findings. *Brain Research, 1253*(0), 92-99.

Stern, Y. (2002). What is cognitive reserve? Theory and research application of the reserve concept. *Journal of the International Neuropsychological Society, 8*, 448–460.

Strauss, B. (2002). Social facilitation in motor tasks: a review of reearch and theory. *Psychology of Sport and Exercise*(3), 237-256.

Stuart-Hamilton, I. (2012). *The Psychology of Ageing* (5th ed.). London: Jessica Kingsley.

Studenski S, P. S. P. K., & et al. (2011). Gait speed and survival in older adults. *JAMA: The Journal of the American Medical Association, 305*(1), 50-58.

Styles, E. A. (2006). *The psychology of attention* (2nd ed.). Hove: Psychology Press.

Tabbarah, M., Crimmins, E. M., & Seeman, T. E. (2002). The Relationship Between Cognitive and Physical Performance. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 57*(4), M228-M235.

Tehan, G., & Mills, K. (2007). Working memory and short-term memory storage. What does backward recall tell us? In N. Osaka., Logie, R., & D'Espositio, M. (Ed.), *The cogntiive neuroscience of working memory* (pp. 153-163). Oxford: Oxford University Press.

Thaut, M. H., McIntosh, G. C., Rice, R. R., Miller, R. A., Rathbun, J., & Brault, J. M. (1996). Rhythmic auditory stimulation in gait training for Parkinson's disease patients. [Article]. *Movement Disorders, 11*(2), 193-200.

Thaut, M. H., Rathbun, J. A., & Miller, R. A. (1997). Music versus metronome timekeeper in a rhythmic motor task. *International Journal of Arts Medicine, 5*(1), 4-12.

Theill, N., Martin, M., Schumacher, V., Bridenbaugh, S. A., & Kressig, R. W. (2011). Simultaneously Measuring Gait and Cognitive Performance in Cognitively Healthy and Cognitively Impaired Older Adults: The Basel Motor–Cognition Dual-Task Paradigm. *Journal of the American Geriatrics Society, 59*(6), 1012-1018.

Thorndike, R. L., Hagen, E. P., & Sattler, J. M. . (1987). *The Stanford-Binet Intelligence Scale* (4th ed.). Chicago, Riverside.

Trombetti, A., Hars, M., Herrmann, F. R., Kressig, R. W., Ferrari, S., & Rizzoli, R. (2011). Effect of Music-Based Multitask Training on Gait, Balance, and Fall Risk in Elderly People: A Randomized Controlled Trial. *Arch Intern Med, 171*(6), 525-533.

van Iersel, M., Hoefsloot, W., Munneke, M., Bloem, B., & Olde Rikkert, M. (2004). Systematic review of quantitative clinical gait analysis in patients with dementia. *Z Gerontol Geriatr, 37*, 27 - 32.

van Iersel, M. B. van Kessels, R. P. C., Bloem, B. R., Verbeek, A. L. M., & Olde Rikkert, M. G. M. (2008). Executive Functions Are Associated With Gait and Balance in Community-Living Elderly People. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 63*(12), 1344-1349.

Vanneste, S. (1999). Timing in Aging: The Role of Attention. *Experimental Aging Research, 25*(1), 49-67.

Vellas, B. J., Wayne, S. J., Romero, L. J., Baumgartner, R. N., & Garry, P. J. (1997). Fear of falling and restriction of mobility in elderly fallers. *Age and Ageing, 26*(3), 189-193.

Verghese, J., Lipton, R. B., Hall, C. B., Kuslansky, G., Katz, M. J., & Buschke, H. (2002). Abnormality of Gait as a Predictor of Non-Alzheimer's Dementia. *New England Journal of Medicine, 347*(22), 1761-1768.

Verghese, J., Kuslansky, G., Holtzer, R., Katz, M., Xue, X., Buschke, H., et al. (2007). Walking While Talking: Effect of Task Prioritization in the Elderly. *Archives of Physical Medicine and Rehabilitation, 88*(1), 50-53.

Verhaeghen, P., Steitz, D. W., Sliwinski, M. J., Cerella, J. . (2003). Aging and dual-task performance: A meta-analysis. *Psychology and Aging, 18*(3), 443-460.

Verhaeghen, P., Steitz, D. W., Sliwinski, M. J., Cerella, J. (2011). Cognitive Processes and ageing. In I. Stuart-Hamilton (Ed.), *Introduction to Gerontology* (pp. 159-193). Cambridge: Cambridge University Press.

Voss, M. W., Prakash, R. S., Erickson, K. I., Basak, C., Chaddock, L., Kim, J.S., Alves, H., Heo, H., Szabo, A.N., White, S. M., Wojcicki, T. R., Mailey, E.L., Gothe, N., Olson, E.A., McAuley, E., Kramer, A.F. (2010). Plasticity of brain networks in a randomized intervention trial of exercise training in older adults. *Frontiers in Aging Neuroscience, 2*.

Wechsler, D. (1987). *Wechsler Memory Scale - Revised (WMS-R)*. San Antonio, TX: Psychological Corporation.

Weuve, J., Kang, J.H., Manson, J.E., Breteler, M.M.B., Ware, J.H., Grodstein, F. (2004). Physical Activity, Including Walking, and Cognitive Function in Older Women. *JAMA, 292*(12), 1454-1461.

Wikman, A. S., Nieminen, T. & Summala, H. (1998). Driving experience and time-sharing during in-car tasks on roads of different widths. *Ergonomics, 41*, 358-372.

Wittwer, W. H. (2012). *The Effect of Rhythmic Auditory Cueing on Temporo-spatial Gait Measures and Gait Variability in People with Alzheimer's Disease.* Paper presented at the 1st Joint World Congress ISPGR and Gait and Mental Healthy.

Woollacott, M., & Shumway-Cook, A. (2002). Attention and the control of posture and gait: a review of an emerging area of research. *Gait & Posture, 16*(1), 1-14.

Yaffe, K., Barnes, D., Nevitt, M., Lui, L.-Y., & Covinsky, K. (2001). A Prospective Study of Physical Activity and Cognitive Decline in Elderly Women: Women Who Walk. *Arch Intern Med, 161*(14), 1703-1708.

Yaffe, K., Fiocco, A.J., Lindquist, K., Vittinghoff, E., Simonsick, E.M., Newman, A.B., Satterfield, S., Rosano, C., Rubin, R., Ayonayon, H.N., Harris, T.B. (2009). Predictors of maintaining cognitive function in older adults. *Neurology, 72*(23).

Yaffe, K., Lindquist, K., Vittinghoff, E., Barnes, D., Simonsick, E. M., Newman, A., et al. (2010). The Effect of Maintaining Cognition on Risk of Disability and Death. *Journal of the American Geriatrics Society, 58*(5), 889-894.

Yogev, G., Giladi, N., Peretz, C., Springer, S., Simon, E. S., & Hausdorff, J. M. (2005). Dual tasking, gait rhythmicity, and Parkinson's disease: Which aspects of gait are attention demanding? *European Journal of Neuroscience, 22*(5), 1248-1256.

Yogev-Seligmann, G., Hausdorff, J., & Giladi, N. (2008). The role of executive function and attention in gait. *Mov Disord, 23*, 329 - 342.

Yogev-Seligmann, G., Rotem-Galili, Y., Mirelman, A., Doclsteom. R., Giladi, N., Hausdorff, M. (2010). How does explicity prioritization alter walking during dual-task performance? Effects of age and sex on gait speed and variability. *Pysical Therapy, 90*(2), 177-186.

Yogev-Seligmann, G., Rotem-Galili, Y., Dickstein, R., Giladi, N., & Hausdorff, J. M. (2012a). Effects of explicit prioritization on dual task walking in patients with Parkinson's disease. *Gait & Posture, 35*(4), 641-646.

Yogev-Seligmann, G., Giladi, N., Brozgol, M., Hausdorff, J. M. (2012b). A Training Program to Improve Gait While Dual Tasking in Patients With Parkinson's Disease: A Pilot Study. *Archives of Physical Medicine and Rehabilitation*.

Yogev- Seligmann, G., Hausdorff, J. M., & Giladi, N. (2012c). Do we always prioritize balance when walking? Towards an integrated model of task prioritization. *Movement Disorders*, 1-6.

Appendix A
'Bigfoot' User Guide

BigFoot Project: User Guide

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BigFoot Project: User Guide

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Contents

Chapter 1

Introduction

The system is designed to record and analyse a participant's steps whilst walking and carrying out a cognitive task. It uses the BigFoot software in tandem with bespoke hardware.

The software is detailed in Chapter 3, Experiment and the hardware in Appendix A, Hardware.

1.1 Conventions Used in This Guide

The following typographical conventions are used in this guide:

- `Constant width`
  Used for any keyboard inputs or any text that appears on screen.
- `Menu->Item`
  Shorthand to indicate selection of a menu item, e.g., to close the program you click the `File` menu followed by the `Exit` item, which is, `File->Exit`.

Chapter 2

Installation

2.1 System Requirements

2.1.1 Software

The program has been designed to work with Microsoft Windows XP, but should also work with Vista and Windows 7, but has not been tested with them.

Installation Procedure

Run the installation file, `bigfoot.msi` – the program will install automatically. On completion you'll have a desktop shortcut to the program, `BigFoot`.

The program is now ready to be configured — for details, see Chapter 4, Options.

2.1.2 Hardware

The system requires bespoke hardware. See Appendix A, for details

Chapter 3

Experiment

This chapter explains the running and maintaining of experiments.

3.1 Overview

The experiment consists of a practice trial at the start, followed by 8 experimental trials presented in random order. Each trial is started and terminated by pressing the space bar. The trial conditions are not under the control of the system – the user is responsible for their management; the program simply processes and records the participant's responses (steps).

3.2 Running an experiment

First, set up the hardware per Appendix A.

An experiment is run via `Run->Experiment`[1]. A dialogue box will open asking for your participant's ID, gender, and the trial distance. N.B. If you attempt to reuse a participant ID, the program will check that you want to overwrite the file or re-enter the ID, before proceeding.

After entering these details the experiment is ready to run. The results are automatically saved to a file when the experiment is complete.

3.2.1 Practice Trial

The first trial is designed to allow participants to familiarise themselves with the apparatus and to allow the user to check that it is working properly.

1. The trial description will state it is for practice.
2. Press the space bar to start (per experimental trial).
3. Ask the participant to walk around, and check that the steps are being correctly noted by the program (times will be echoed to the screen).
4. Conclude the practice by pressing the space bar.

[1] It can also be run via Ctrl-R or the run button on the toolbar.

3.2.2 Participant Input

All participant input is via a sensor (attached to foot) which emits a tone on an ultra-sound speaker on each step of one leg – see Appendix A, for details

3.2.3 Aborting an Experiment

An experiment can be aborted via the key press `Ctrl-Alt-X`. This will abort the current Trial. The program will save all the trials up to the point at which it was aborted; you are free to discard this file.

3.3 Trial

3.3.1 Trial Order

Trials are presented in a randomised order for each experiment.

3.3.2 Trial Sequence

1. Instructions
   The instructions are presented to the user.

2. Start Trial
   User presses space bar to initiate trial.

3. Data collection
   Collect participant inputs and echo corresponding times to screen.

4. End Trial
   User presses space bar to terminate trial.

5. Process Data
   Calculate statistics on the collected data.

3.4 Maintaining an Experiment

3.4.1 Backup of files

You should backup all the files contained in your Results directory (File Handling: Appendix B) at the end of every session. Furthermore, if you change the instructions, back these up after you've made changes. Finally, the `bigfoot.cfg` file contains the trial settings for your program, and should also be backed up.

3.4.2 Accessing the Results

You can view the results' files via `File->Results Directory`. This brings up an *Explorer* window for the results directory listing all the results to date.

3.4.3 Deleting Results

You are free to delete or move results files, the program only uses them to check for duplicate participant IDs. By the same token, don't use this directory as a dumping ground for other files (which would be a dubious practice in any event).

Chapter 4

Options

The program allows you to configure the trial description used in the experiment. Options are loaded and saved automatically at the start and end of the program.

4.1 Trials

The trial options are available via `Options->Trials`. Each trial is identified by a number with an associated text. The description is presented at the start of the trial as either an aide-mémoir for the user, or to be read out to (or by) the participant.

Appendix A

Hardware

This appendix describes the system's hardware, its set-up, and use.

A.1 Overview

The wearable step detector generates a radio signal (Bluetooth) when the participant takes a step. These signals are detected by a radio-receiver box, which translates them to a simulated mouse (middle button) click, which the program then processes.

A.2 Components

There are 2 distinct pieces of hardware.

1. Radio-receiver box
2. Wearable step detector

A.3 Setting up the hardware

This section describes how to set up the hardware.

A.3.1 Interface Box

- Plug the radio-receiver box into a spare USB socket on your computer.
- Check that the power LED comes on.

A.3.2 Wearable step detector

TBA.

Appendix B

File Handling

This appendix looks at how the program organises its files and directories.

B.1 Files and Directories

There are 3 distinct directories used by the program:

1. Results
   Can be viewed via `File->Results Directory`. All the experiment's results files are stored here. They all have the extension `.txt` with the participant's ID providing the filename, e.g., a participant with ID part666 would yield the file `part666.txt`. The files are simple text files and can be loaded into almost any application you care to name. N.B. The actual results data will need to be imported as a tab-delimited file which is an option on most well-known applications. The results format is explained in Appendix C, Results File. Files can be deleted; the program's only subsequent use for them is to check for duplicate participant IDs.

2. Data
   This directory can be viewed via `File->Data Directory`. It contains the program's configuration file (`bigfoot.cfg`).

3. Program
   The program's home directory where the program (`bigfoot.exe`) is stored along with this associated help file (`bigfoot.pdf`) — this is located at `c:\Program Files\University of St Andrews\bigfoot`.

Appendix C

Results File

This appendix provides a formal syntax (with informal semantics) for the results file along with an elided example file.

C.1 Formal Syntax

C.1.1 Explanation of Formal Syntax:

- Text enclosed in `< >` is considered non-atomic, i.e., it will be further expanded at the next level down.
- Text enclosed in `[ ]` indicates an optional feature.
- Text enclosed in `{ }` denotes that the enclosed may be repeated 0 or more times. A number following the closing } indicates a fixed number of items.
- x..y denotes an inclusive number range where $x < y$
- The `::=` operator is shorthand for *is defined as*.
- Pipe `|` operator indicates alternatives, e.g., `a | b`
- Comments, for informal semantics, start with a //

C.1.2 Results File: Formal Syntax

```
<Results File> ::=
  <Header>
  <Results>

<Header> ::=
  <Timestamp> <nl>
  <Separator>
  Participant  <ws> <ID> <nl>
  Gender  <ws> <Gender> <nl>
  Distance  <Distance> <nl>
  <Separator>
<Timestamp> ::= // date and time of experiment
```

```
<ID> ::= // alphanumeric string identifying participant
<nl> ::= // new line
<Gender> ::= F | M
<Distance> ::= // trial distance measured in metres
<Separator> --<space> <nl>
<space> ::= // space character
<tab> ::= // tab character
<ws> ::= // one or more whitespace characters

<Results> ::= {<Trial>} 8 // in presentation order

<Trial> ::=
  <Trial Condition> <nl>
  M <ws> <Mean> <nl>
  SD <ws> <SD> <nl>
  CV <ws> <CV> <nl>
  T <ws> <T> <nl>
  V <ws> <V> <nl>
  {<Time Stamp> <Time Delta>} // no of samples in trials: min of 3 for stats
  <Time Stamp> // time at which trial terminated by user
<Trial Condition> ::= Trial + [1..8]
<Time Stamp> ::= // milliseconds since start of trial
<Time Delta> ::= // time difference between current and previous time stamp
<Mean> ::= // mean of the time deltas
<SD> ::= // standard deviation of the time deltas
<CV> ::= // coefficient of variation of the time deltas
<T> ::= // duration of trial in S
<V> ::= // velocity = <Distance> / last <Time Stamp>
```

C.2 Results File: Elided Example

```
2009-11-10 16:14
--
Participant     part42
Gender          F
Distance        15
--
Trial3
M       1089.286
SD      83.617
CV      0.0768
T       16.000
V       0.937
500
1600    1100
2650    1050
3500    850
4600    1100
5750    1150
6900    1150
8000    1100
9150    1150
10200   1050
11250   1050
12300   1050
13500   1200
14650   1150
15750   1100
--
Trial1
... and so on until we have all the trials
```

C.3 Calculation of Statistics

Each trial has an associated statistics block:

- Mean (M)
  M is the mean of the time deltas.
- Standard Deviation (SD)
  SD is the standard deviation of the time deltas.
- Coefficient of Variation (CV)
  $CV = SD/M$
- Time (T)
  Time from start-trial key press to end-trial key press.
- Velocity (V)
  $V = D/T$
  Where T is Time, and D is the input trial distance.

Appendix B
Participant Information Sheet: Experiment 1

Participant Information Sheet

NANA: Novel Assessment of Nutrition and Ageing

Gait and Cognition Study

University of St Andrews

The background to the study

The NANA project aims to collect better information about dietary habits and to integrate this with information about physical activity, cognitive function and mental health. This particular study on gait and cognition is part of the wider NANA project and hopes to provide information about the mental well-being of older people in relation to their physical ability.

This research is being sponsored by the Economic and Social Research Council and we are inviting people, with English as their mother-tongue, over 65 years of age, who live in their own homes and who can walk without assistance, to participate.

What will I be asked to do?

You are being invited to participate in Phase 2 of the wider NANA project. Phase 2 is a physical and mental health study undertaken by a PhD student, **Lin Maclean** whose contact details are: 01334 461990 or e-mail:lmm18@st-andrews.ac.uk . As a participant you will be asked to complete a number of assessments of your walking and thinking ability. The PhD research project will investigate how these factors relate to each other and what is the best way to measure them.

Do I have to take part?

It is up to you to decide whether to take part. If you do decide to participate, you may keep this information sheet and you will be asked to sign a consent form. Even although you sign the consent form, you are still free to withdraw from the study at any time, before or during the research, and without giving a reason. A decision to withdraw at any time, or a decision not to take part, will not affect the care you receive or affect your relationship with medical staff looking after you, now or in the future.

What will happen at the visits to the University?

You will be asked to visit the University of St Andrews 4 times in the next 2 years (approximately once every 6 months). Each time you visit, your travelling expenses will be reimbursed and you will be offered refreshments. At the initial visit, you will be asked to complete a short questionnaire and a series of problem-solving and puzzle-like tasks with the researcher, Lin Maclean. These cognitive tasks should take no longer than one hour altogether. You will then be given a refreshment break before completing a series of physical activities designed to measure your balance and walking ability. These should also last no longer than one hour. You will not be asked to walk more than 15 metres (35 feet) at a time and, during this time, you will be asked to combine a walking and a thinking task. You should wear comfortable walking shoes when taking part in the study.

At subsequent visits to the University, the sessions will be shorter and include fewer tasks. At the end of the study, you will be asked to complete a short questionnaire about your experience as a participant.

What will happen to the information collected in the study?

We will ask if we may video-record you, as well as record your vocal responses, whilst you are performing the tasks. We will ensure that there will be nothing on these tapes that could identify you in person. The information we collect will be stored in a locked filing cabinet in the office of the Principal Investigator, Dr Arlene Astell, and will only be accessible to members of the research team. All data will be anonymised for presentation purposes and stored for 10 years and then destroyed.

What are the possible disadvantages and risks of taking part?

We do not anticipate any health risks from taking part in this study. You may find some aspects of the research tiring but you will be given plenty of opportunity to take breaks. *We do not anticipate any adverse effects from taking part in the study. However, if you wish to complain, or have any concerns about any aspect of the way you have been approached or treated during the course of the study, the complaints procedure is outlined below.*

What are the benefits of taking part?

There will be no direct benefit to you by taking part and your individual results will not be revealed to you. However, we will make any future publications of the finding available to you and we will arrange for you to have a personal debrief, regarding the general findings, if you should so wish. It is hoped that this research will improve our knowledge about the link between walking ability and the ability to reason which may influence our understanding of problems related to nutrition and ageing.

Who is organising and funding the research?

The research is being completed in fulfilment of PhD requirements for the School of Psychology at the University of St Andrews. The research is supervised by Dr Arlene Astell, a Chartered Clinical Psychologist and Senior Lecturer at the University of St Andrews and Dr Gerry Quinn, a Cognitive Psychologist and Senior Lecturer at the University of St Andrews. It is funded by the Economic and Social Research Council.

What happens now?

If you agree to take part you will be asked to complete a consent form. If you decide not to take part, this will have no bearing on your future care or treatment from the NHS. If you do decide to talk part, we would like permission to inform your GP. However, if you do not agree to us informing your GP, you can still take part. The Fife and Forth Valley Committee on Medical Research Ethics, which has responsibility for scrutinising proposals for medical research on humans, has examined the proposal and has raised no objections from the point of view of medical ethics. It is a requirement that your records in this research, together with any relevant medical records, be made available for scrutiny by monitors from NHS Fife and Forth Valley and the University of St. Andrews, whose role is to check that research is properly conducted and the interests of those taking part are adequately protected.

If you have any questions or would like to discuss this research further, or if you have any complaints about the procedures, please contact the Project Director directly - **Dr Arlene Astell,** 01334 462056. Thank you for taking time to read this Information Sheet and for considering taking part.

If you have read and understood the contents of this sheet and wish to take part, please sign the enclosed consent form and return it in the pre-paid envelope provided.

Appendix C

Participants' Background Questionnaire

Centre Number:

Study Number:

Patient Identification Number for this trial:

University of St Andrews

GAIT AND COGNITION STUDY – BACKGROUND QUESTIONNAIRE

1. What is your date of birth? ______________________________

2. What is your gender?

    Female
    Male

3. How many years of formal education have you had since primary school (0.5 years for distance learning)?

    Primary_________________________________

    Secondary_______________________________

    Further/higher education___________________

4. Which of the following activities do you do on a weekly basis?

Shopping for food and clothes
Managing your own or other's finances
Preparing meals for yourself and/or others
Travelling on public transport
Planning an trip or visit (e.g. to cinema or meeting friends)
Communicating with others via phone, e-mail or other technology (not writing letter/card)

5. Compared to other people of your own age, how much exercise do you do?

Less
Same
More

6. What type of exercise (including brisk walking) do you do?

____

7. How often do you exercise (including brisk walking) per week?

Never
Once or twice
Three or more times

8. How much exercise do you do now compared to the past?

Less
Same
More

9. Which of the following activities can you do on a regular basis?

Walk unassisted for at least a quarter of a mile
Walk up and down at least 10 steps
Neither of these

10. Compared to other people of your own age, how much time do you spend on cognitive or thinking activities (e.g. work-related, reading, crosswords, Sudoku)?

Less
Same
More

11. What type of thinking activities do you do?

____

12. How often do you do thinking activities per week?

Never
Once or twice
Three or more times

13. How much alcohol per week do you drink? (One unit is approximately equal to one small glass of wine, one standard measure of sherry/port, one small measure of spirits or a half pint of beer, lager or cider)

Nothing
Less than 7 units
7 or more units

14. What is your tobacco use?

Current smoker
Regular smoker in the past but not now
Never smoked

15. How many medications are you currently taking?

None
Less than 3
3 or more

16. Please list your current medical conditions that require medication.

____

17. How many times have you been in hospital in the last year?

None
Once or twice
Three or more times

18. How many falls have you had in the last year?

None
One
More than 1

19. Do you need spectacles?

Yes
No

20. Do you need a hearing aid?

Yes
No

21. How satisfied with your current health status are you?

Satisfied
Unsatisfied

22. Is there anyone in your immediate family who has ever been diagnosed with Alzheimer's disease or dementia?

Yes
No

[redacted]

Appendix D
Participant Information Sheet: Experiment 2

Participant Information Sheet

Project Title

The Association between Gait and Cognition in the ageing process of older adults, using the Dual-task paradigm– Study 2

What is the study about?

Previous research has found that people's gait (the way they walk) is affected both when they walk and think and when they walk and listen to music. I invite you to participate in a research project which will investigate the relationship between walking, reasoning and listening to music. In particular, the project will try to find a sensitive and effective way of measuring this relationship. This project is being conducted as part of Mrs Lin Maclean's PhD Thesis in the School of Psychology at the University of St Andrews

Do I have to take Part?

This information sheet has been written to help you decide if you would like to take part. It is up to you and you alone whether or not to take part. If you do decide to take part you will be free to withdraw at any time without providing a reason. If you do decide to take part, you will be asked to sign a consent form. Even although you sign the consent form, you will still be able to withdraw at any time without having to give a reason.

What would I be required to do?

You will be asked to visit the School of Psychology at the University of St Andrews where you will be given a short questionnaire about your background and lifestyle. You will then be asked to carry out a series of short thinking tasks and calculations. After a refreshment break, you will be asked to walk along a corridor (approximately 35 feet) several times, sometimes carrying out another thinking task. You may be asked to listen to music at certain times during the visit. You should wear comfortable, flat shoes when you carry out the walking tasks. I will ask if we may video record you as well as record your vocal responses. I will ensure that there will be nothing on these recordings that could identify you in person. The research will take approximately one and a half hours in total.

Will my participation be Anonymous and Confidential?

All data collected in the research documentation, videos and voice recordings will be kept confidential. You will be allocated a number during the research and, whilst your face and voice will be seen and heard, only the researcher will be able to cross-reference these to your actual identity. Only the researcher and her supervisor will have access to this data. Your permission maybe sought in the Participant Consent form for the data you provide to be used for future scholarly purposes.

Storage and Destruction of Data Collected

The data we collect will only be accessible by the researcher and supervisor involved in this project, unless explicit consent for wider access is given by means of the consent form. Your data will be stored in a locked filing cabinet, or on a secure computer system, for a period of at least 10 years before being destroyed by shredder and/or deletion.

What will happen to the results of the research study?

The results will be finalised by 2012 and written up as part of the researcher's PhD Thesis.

Reward

There is no monetary reward for taking part in this project but the results may impact on future research into healthy ageing and may inform future health policy and clinical practice.

Are there any potential risks to taking part?

I do not anticipate any health risks from taking part in this study. You may find some aspects of the research tiring but you will be given plenty of opportunity to take breaks. I do not anticipate any adverse effects from taking part in the study. However, if you wish to complain, or have any concerns about any aspect of the way you have been approached or treated during the course of the study, you should inform Dr Arlene Astell, in the first instance, and follow the complaints procedure outlined below, thereafter.

Questions

You will have the opportunity to ask any questions in relation to this project before giving completing a Consent Form.

Consent and Approval

This research proposal has been scrutinised and been granted Ethical Approval through the University ethical approval process.

What should I do if I have concerns about this study?

A full outline of the procedures governed by the University Teaching and Research Ethical Committee is available at ://www.st-andrews.ac.uk/utrec/complaints/

Contact Details

Researcher: Mrs Lin Maclean
Contact Details: lmm18@st-andrews.ac.uk
Telephone: 01334 461990

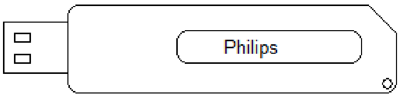
Supervisor: Dr Arlene Astell
Contact Details: aja3@st-andrews.ac.uk
Telephone: 01334 462056

Appendix E
'DataGait' Operating Instructions
Quick guide Philips Pi-Node usage – Version 2.4

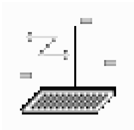
Before following this quick guide, please ensure that the software is fully installed on your laptop and that the batteries in both the Pi-node and laptop are fully charged (please see full manual for details).

SETUP:

1) Plug the Philips USB stick in the USB-port of the computer:

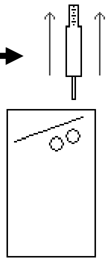


2) Wait for the red LED in the Philips USB stick to flash
3) Start the Philips Pi-Node software by double clicking the desktop icon as showed below:



Plug

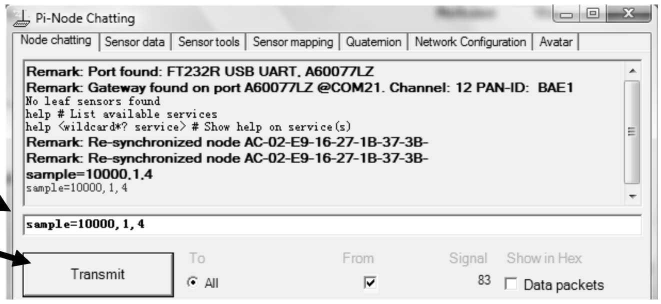
Sensor



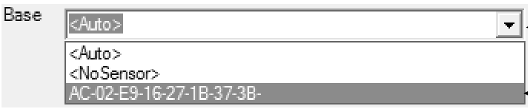
4) Unplug the Philips Pi-Node sensor:
5) Wait for the LED to flash green on the sensor as well as inside the USB stick
6) Go to the *Node* chatting-tab and type *sample=10000,1,4* into the text entry box (white input box) and press *Transmit*:

Text Entry Box

Transmit button



7) Go to the *Sensor mapping*-tab and assign the sensor to the *base* in the drop-down menu:



Drop Down Menu

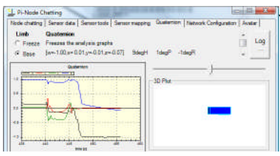
Select Sensor

PLACING:

8) Palpate the top of the iliac crest on both sides
9) Imagine a horizontal line between these two points
10) Follow the imaginary line with two fingers until you reach the spine and you are over the 4th Lumbar Vertebrae which represents the Centre of Mass
11) Stick the Pi-Node sensor with double adhesive tape over the spine in line with the top of the iliac crest (Orientation of sensor on body does not matter)

RECORDING:

12) Go to the *Quaternion*-tab and press the '*Log…*' button on the right side, assign a location and file name and press '*Save'* to start recording
13) When done recording press the '*Log…*' button ONCE to STOP recording
14) Repeat step 12 & 13 to record



'*Log…*'-button

another measurement

Leg Length:

1) Let the participant lie down
2) Palpate the anterior superior iliac spine & medial malleolus
3) Measure and record the distance between both anatomical landmarks in centimetres

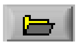
Walking Distance over Time

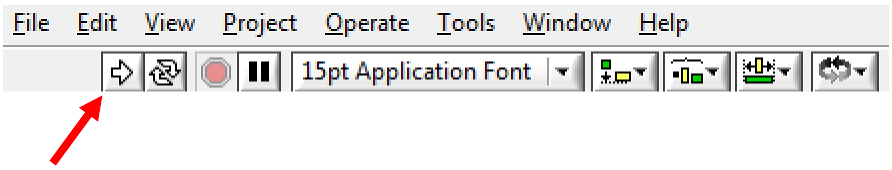
1) Depending on your protocol, record the time it takes the participant to walk the predetermined distance (e.g. 10 meters)
2) Or record the distance the participant covered in a predetermined time (i.e., 2 minutes)

D. Instructions for valid data analysis

Now you've collected data it's time to start analysing the data to create an understandable outcome for the measurements. This standard operation procedure is meant for DataGait analysis program version 2.1

D1 Starting & Setting up Program:

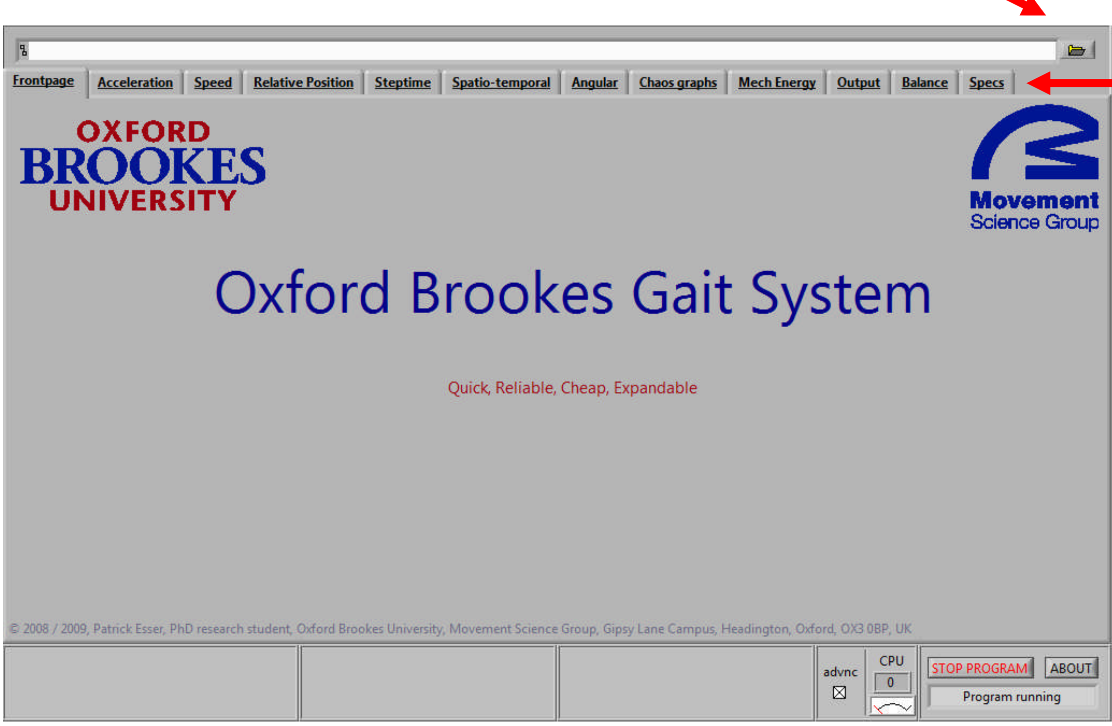
1. Open the DataGait analysis software
2. Select the measurement file by clicking the  button once (right top corner)
3. Select the raw measurement file and click "**OPEN**" in the pop-up screen
4. Press the single arrow to start the program located in the left top corner of your screen



Run program

When started the "**Acceleration**" tab will open once the file is loaded

Open File



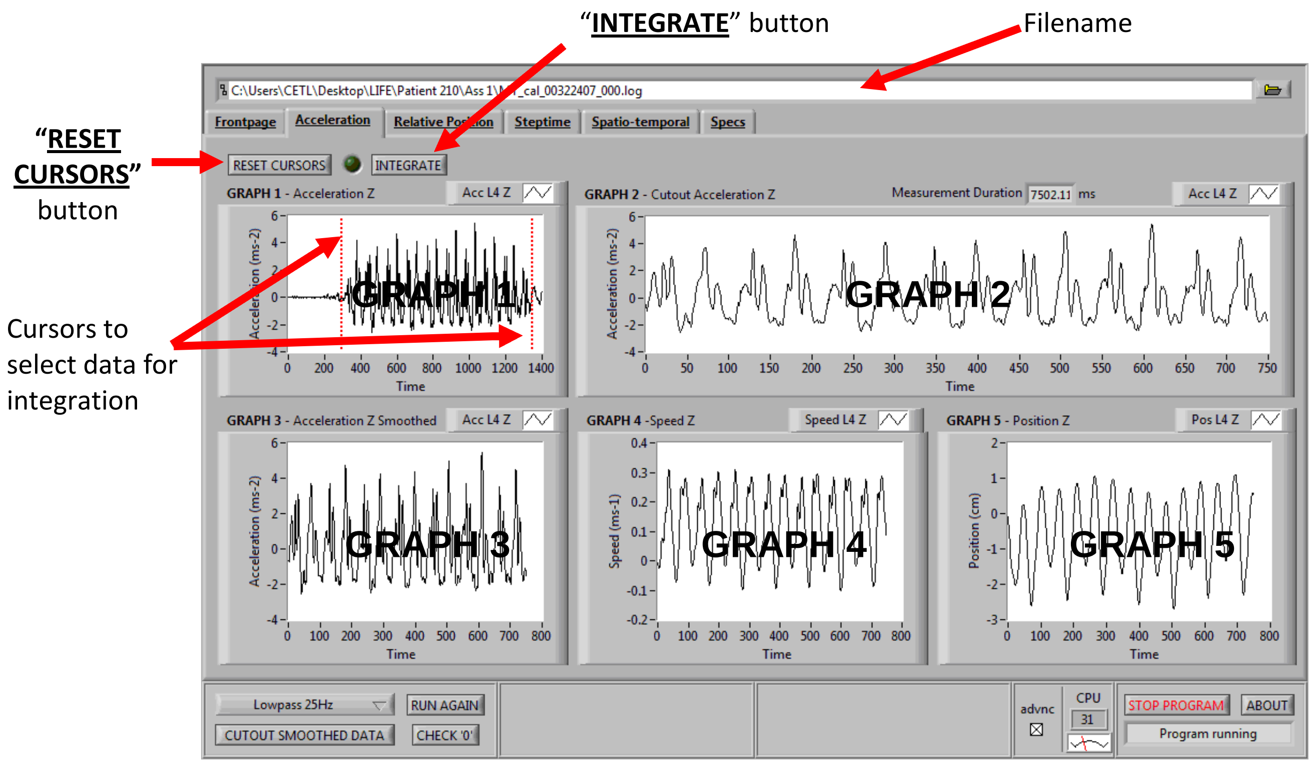
Tabs

D2 Data selection and integration:

This window shows the raw data. It is important that the data analysis is done on walking data. Currently this has to be manually selected before proceeding. As pointed out in the screenshots of the window below only the steady state during walking is selected. In order to make a data selection, follow the steps below.

1. Select walking data (steady state walking preferred, similar peaks/through) by dragging the **red vertical cursors** on the **top left graph** (**GRAPH 1**) in range.
2. Once the data is selected press the "**INTEGRATE**" button ONCE (Above **GRAPH 1**)
   You will see that the bottom three graphs will show
   GRAPH 3: Selected filtered vertical projected centre of mass acceleration profile
   GRAPH 4: Selected vertical projected centre of mass velocity profile
   GRAPH 5: Selected vertical projected centre of mass movement profile

Once you see the screen similar to below you're ready to proceed to the next page.



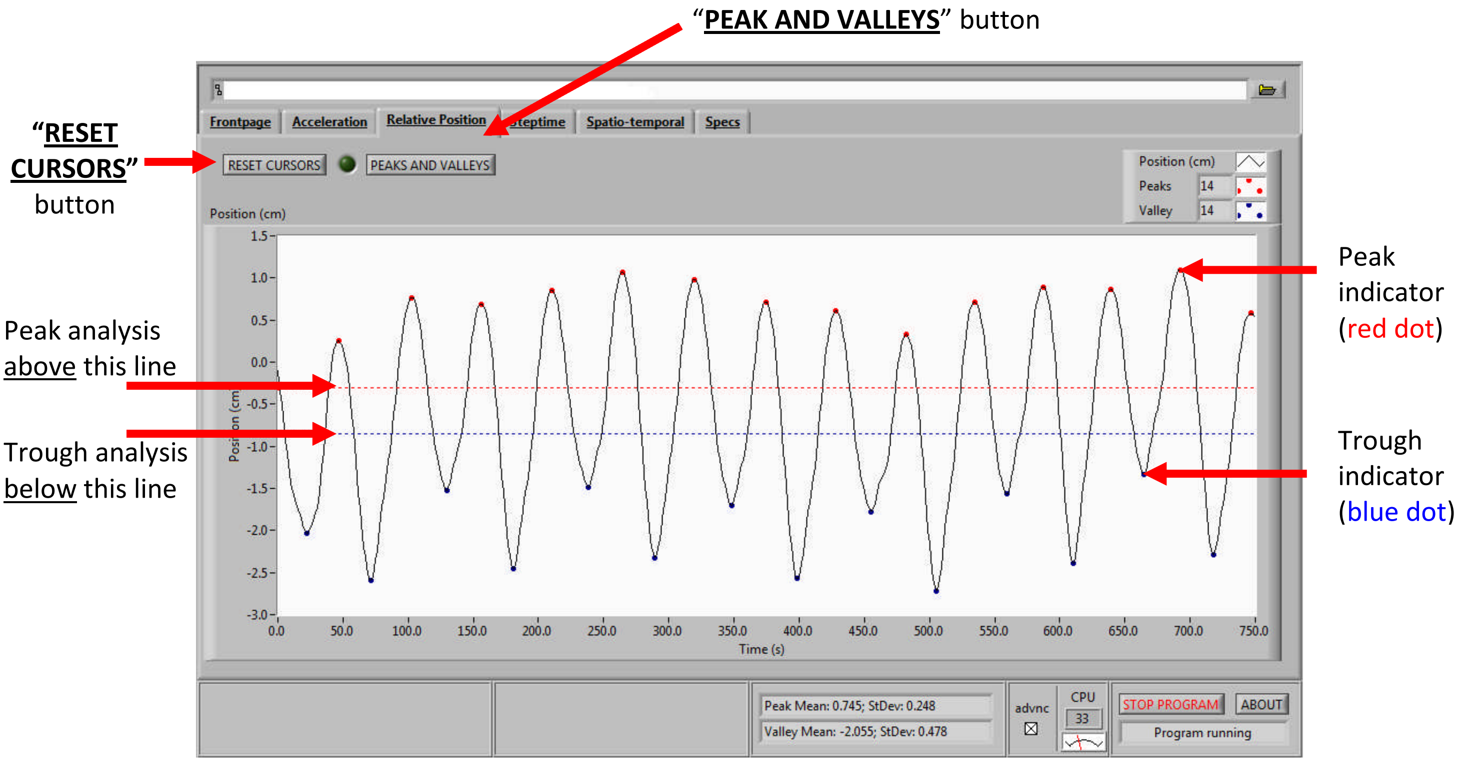
D3 Selecting peak and troughs on vertical centre of mass excursion data

In this tab you will define the data points (peaks and troughs) of the measurement that will be used to model the timing aspects of human gait.

Select the "**Relative Position**" tab

This part will select all the data needed to drive the gait models later on in a further stage of the program. This will be achieved by:

A. Resetting the cursors by clicking the "**RESET CURSORS**" button **twice!**
B. Set red line below all peaks and blue line above all valleys
C. Click "**PEAKS AND VALLEYS**" button (next to the "**RESET CURSORS**" button)
D. Confirm that all the peaks are marked by a red dot as well as valleys which should be marked by a blue dot as indicated on the figure below



WELL DONE!

You have now selected all critical points which will be taken on to the next part of the analysis.

D4 Temporal gait analysis

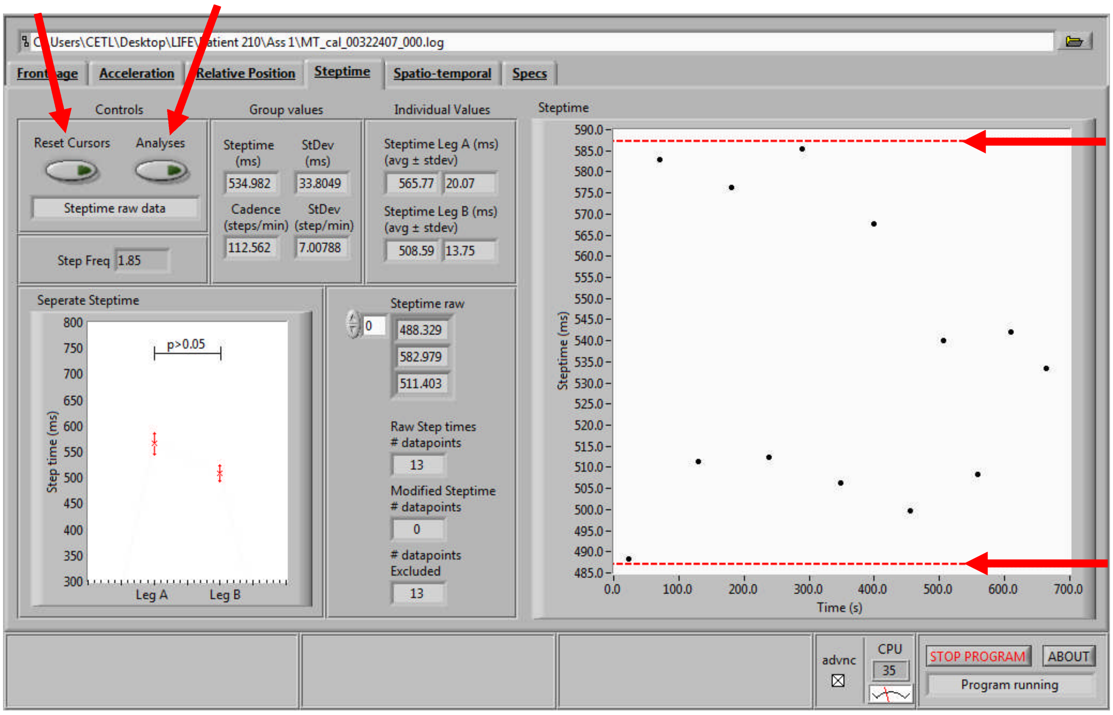
You are now ready to analyse the first bits of temporal data from the recorded files. Cadence and step frequency will be calculated for both legs. In order to model these temporal parameters:

Select the "**Steptime**" tab

A. Click the "**Reset Cursors**" button
B. Look at step time values
C. If step time analysis is within 2 standard deviations,
   i. Analysis mode should indicate: *"step time raw data"* to include all data points
D. If there are outliers (greater than 2 standard deviations)
   i. Click the "**Analyses**" button (next to "**Reset Cursors**" button)
   ii. Analysis mode will change to *"step time modified data"*
   iii. Exclude outlier by dragging red cursors to define range

Reset Cursors

Step time excluding mode



Upper step time limit

Lower step time limit

WELL DONE!

Once you have placed analysed this data according to the rules above, proceed to the next step (next page)

NOTE:

For example, when established by taking a mean (520.149ms) with the standard deviation (23.456ms) we can see that all data points are within two standard deviations when being in range of 567ms and 473ms. Therefore we can selected the "*step time raw data*" and NOT the "*step time modified data*".

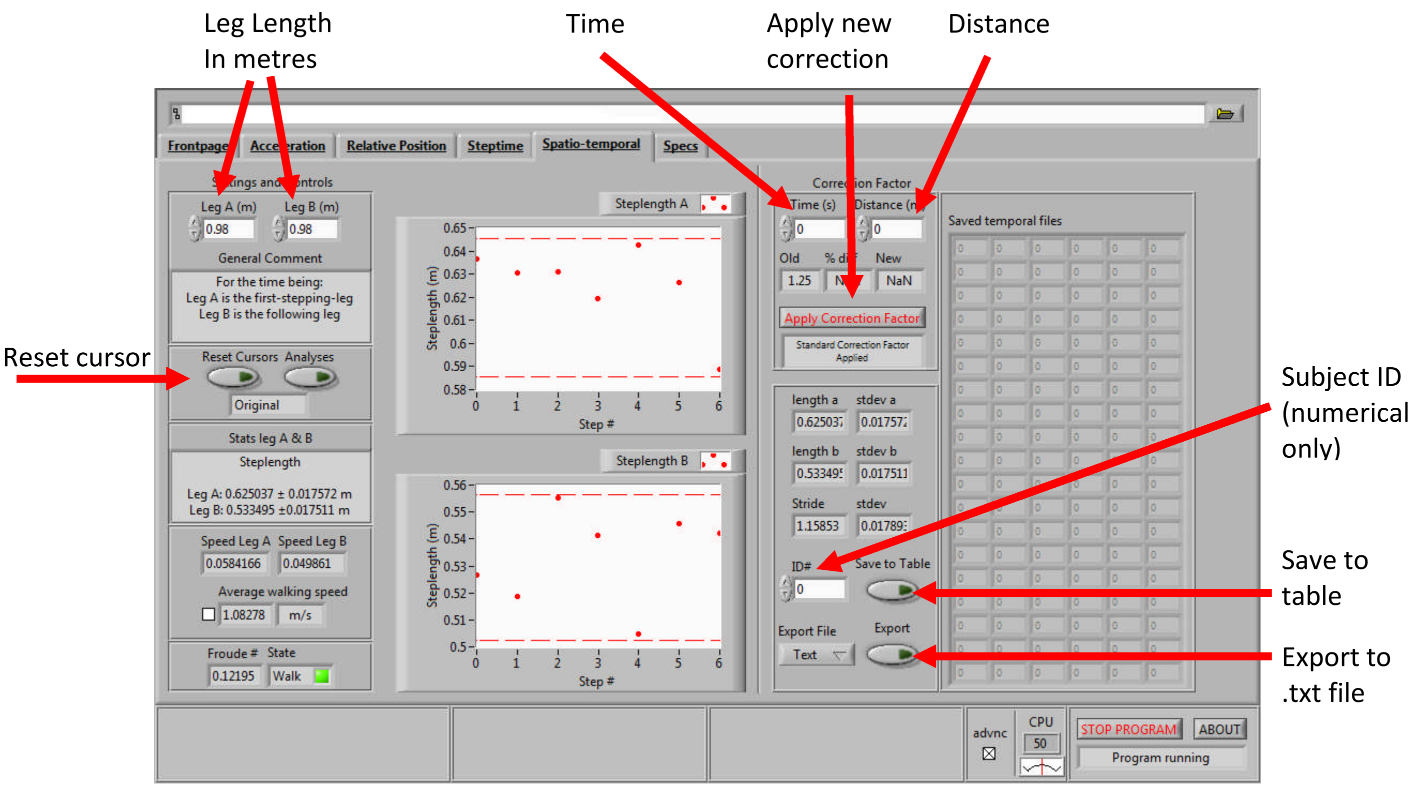
This process will be automated in the near future.

D5 Selecting peak and troughs on vertical centre of mass excursion data

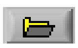
You've derived the temporal aspects of the gait measurements, the spatial parameters. These parameters will include individual step and stride length, walking speed and the Froude number. In order to derive these parameters follow the next few steps:

go to the **"Spatio-temporal"** tab

A. Enter leg length in metres for leg A (left) and leg B (right) as previously recorded
B. Press the button labelled **"Reset Cursors"** (above leg length input Box)
C. Enter walking time (seconds) over walking distance (metres), on the right side of the graphs in the "**Correction Factor**" box and hit **ENTER** on the keyboard
    i. press **"Apply Correction Factor"** to automatically correct the gait models used in throughout the data analysis
D. Enter "**ID#**" for participants (numerical value only)
    i. **"Save to Table"** will put average&stdev values in a table
    ii. The **"Export"** button will export files in a .txt file



Note that the **"Saved temporal files"** table will only be cleared by stopping the program.

A. When analysing another file:
    i. go back to the **"Acceleration"** tab
    ii. select the new file by pressing the  button ONCE
    iii. click **"RUN AGAIN"** button located on the left bottom of the screen
    iv. Follow Steps in order from section **D2, point 1**
B. When finished with data analysis make sure that:
    i. You've exported the data by clicking the **"Export"** button located under the **"Save to Table"** button. Click **"Proceed"** to proceed saving
    ii. Once you've exported the data click **"STOP PROGRAM"** to stop.