WALKING AND TALKING IN MULTIPLE SCLEROSIS:

AN INVESTIGATION OF COGNITIVE-MOTOR DUAL-TASKING

AND CLINICAL RESEARCH PORTFOLIO

VOLUME ONE

(VOLUME TWO BOUND SEPARATELY)

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OCTOBER 2008

Submitted in part fulfilment of the requirements for the degree of Doctorate in Clinical Psychology, Section of Psychological Medicine, University of Glasgow

ACKNOWLEDGEMENTS

I am indebted to my supervisor, Professor Jon Evans, for his guidance, support and encouragement. I am also very grateful to Professor Lynn Rochester, Glasgow Caledonian University, and Dr. Lorna Paul, University of Glasgow for their practical support with equipment and accommodation and valuable input and comments. Many thanks are due also to Danny Rafferty, Glasgow Caledonian University, who generously gave his time to assist with equipment and data collection. I am grateful also to Lianne Scarlett who kindly volunteered her time to assist with data collection.

I am grateful to staff at the Institute of Neurological Sciences, Southern General Hospital, for their support and assistance; in particular Dr. Colin O'Leary, for his assistance with recruitment and collecting medical information for the research; Ms. Mhairi Nellis and Ms. Lynn Cherry for their hard work recruiting research participants; and Dr. John Greene for his assistance regarding research accommodation. Many clinical supervisors have supported me throughout my clinical training; particular thanks to Dr. Sue Copstick for her support with the research described in this portfolio.

Thanks to my family, friends and classmates who have supported me throughout the past three years; particularly my Thursday night study group. Finally, many thanks to my husband, John, for his practical help, support, and kindness.

TABLE OF CONTENTS

Volume One

Appendices

CHAPTER ONE

SYSTEMATIC LITERATURE REVIEW

Walking and Talking:

A Systematic Review of Cognitive-Motor Dual-Tasking in Neurological Conditions*

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Manuscript word count: 4999

Abstract word count: 199

* Manuscript prepared in accordance with the author guidelines of *Journal of International Neuropsychological Society* (see Appendix A).

Abstract

Difficulties performing a concurrent cognitive task while walking have been reported in several neurological conditions. Such difficulties may have significant functional consequences, including increasing the risk of falls. A systematic review of studies investigating the effect of a concurrent cognitive task on walking in neurological conditions was conducted. The aims of the review were 1) to determine the effect of a concurrent cognitive task on walking, 2) to determine the effect of titrating task demand on dual-task performance and 3) develop recommendations for future research. Forty-one articles were identified through electronic and hand search. Sixteen articles met inclusion criteria. Studies were rated using quality criteria, effect sizes were calculated and a narrative review was conducted. Fifteen out of 16 studies reported a disproportionate decrement in walking ability, relative to healthy controls, when performing a concurrent cognitive task in neurological conditions; including Alzheimer's disease, Parkinson's disease, stroke and brain injury. It was only possible to calculate effect size for half of the studies; the median effect size was 0.77. Several methodological issues with the literature were identified. Performing a concurrent cognitive task while walking has a disproportionate effect in a range of neurological conditions. Recommendations are made for future research.

Key words: Adult, attention, memory, neuropsychological tests, gait, nervous system disorders

Introduction

In everyday life we frequently do more than one thing at any one time; e.g. having a conversation while walking, crossing a busy road, and navigating a supermarket. Dual-tasking refers to this ability to do two things at once. Dual-task paradigms compare people's performance when tasks are performed alone (single task) and when two tasks are performed simultaneously (dual-task). The decrement in dual-task performance, compared to single task performance, is thought to reflect the attempt to share limited capacity between the two tasks. Investigations using a dual-task paradigm further our understanding of the organisation of cognitive resources in the brain (Della Sala & Logie, 2001) and the effect of neurological conditions such as Alzheimer's disease, stroke, brain injury and Parkinson's disease on divided attention. This understanding is important because if our ability to do two things at once is impaired, then this has implications for our functioning in everyday life. Though activation studies implicate the pre-frontal and anterior cingulate cortices in dual-tasking (Dreher & Grafman, 2003), it is unclear which anatomical lesions may be responsible for deficits in dual-task performance.

Different types of dual-task combinations are possible; for example demands of both tasks may be principally motor or principally cognitive, or tasks may include both motor and cognitive demands. One type of dual-task is performing a simultaneous cognitive task while walking, something people are frequently required to do in everyday life. In the past walking was generally considered to be an automatic process involving minimal attentional resources (Woollacott & Shumway-Cook, 2002). Recent research however has shown that even in healthy adults walking can be attentionally demanding when a secondary task is performed simultaneously (Woollacott & Shumway-Cook, 2002). In healthy adults the dual-task effect is small and occurs only when quite complex secondary additional tasks are performed, though the dual-task effect increases with age.

Adults with a variety of neurological conditions; including Alzheimer's disease (Cocchini et al., 2004), Parkinson's disease (Yogev et al., 2005), stroke (Hyndman et al.,

2006 and Kemper et al., 2006) and acquired brain injury (Haggard et al., 2000) appear to be disproportionately impaired while walking and simultaneously performing a cognitive task, compared to healthy age-matched controls. For example reduced step length and slower speed have been reported in Parkinson's disease (Rochester et al., 2004) and increased stride duration and poorer cognitive performance are reported in brain injury under dual-task conditions (Haggard et al., 2000). Dual-task walking may therefore uncover deficits not apparent under single task conditions, and may be a more sensitive assessment of everyday walking ability in these neurological groups. This may have implications for the assessment and rehabilitation of walking in physiotherapy settings in brain injury and other neurological conditions (Haggard et al., 2000).

Lundin-Olsson and colleagues reported that older adults who tended to stop walking while talking were more likely to suffer falls (Lundin-Olsson et al., 1997). Subsequent studies have suggested that dual-tasking does not provide independent prediction of falls but significantly affects gait parameters associated with falling (Yogev-Seligman et al., 2008). It has been suggested that this dual-tasking difficulty explains the high risk of falls in Alzheimer's disease (Cocchini et al., 2004), despite the fact that gait and motor function are relatively spared early in the disease (Sheridan & Hausdorff, 2007).

Difficulties performing a concurrent cognitive task while walking may be affected both by motor and cognitive factors in neurological conditions. Sensory/motor deficits as a direct consequence of disease interfere with gait in some conditions, such as Parkinson's disease or stroke. Mulder and colleagues suggest the motor system comprises both a fast mode, involving the automatic control of over-learned movements, and a slow mode, involving direct cognitive control of newly learned or complex movements. They postulate that when the motor system is damaged control of movement is primarily directly cognitive and via this slow mode of control (Mulder et al., 2002). Walking therefore becomes an attention demanding task.

There are therefore three possible explanations for the development of a dual-tasking deficit. One is that a basic deficit in motor functioning means that motor tasks require more conscious attention for successful performance, as described above, and so the limited capacity working memory system is overloaded in the dual-task situation. Another possibility is that in neurological conditions working memory capacity is reduced, so that is overloaded by previously normal loads of motor and cognitive content. A third possibility is that rather than basic working memory capacity being the problem, there is a deficit in the attention control system that allocates attention between concurrent demands (Logie et al., 2004). Baddeley and Hitch's model of working memory suggests that a central executive is responsible for the division of attention between concurrent tasks (Baddeley & Hitch, 1974). From this model a difficulty performing two concurrent tasks is seen as due to a deficit in the ability to allocate attentional resources to competing demands, rather than due to insufficient attentional capacity. Deficits in divided attention are well documented in Alzheimer's disease (Binetti et al., 1996), Parkinson's disease (Dubois & Pillon, 1997) and brain injury (Park et al., 1999). Holtzer and colleagues (2005, 2006) reported that in healthy older adults dual-task performance decrement is predicted both by speed/executive attention factors and memory factors.

It has been argued that in studying dual-tasking it is important to control for the effect of task demand impacting on dual-tasking when comparing a patient group with a healthy control group (Cocchini et al., 2004 and Yogev et al., 2008). In order to determine whether dual-tasking difficulties are specifically caused by a divided attention/dual-tasking process impairment it is suggested that it is necessary to titrate tasks according to performance under single task conditions. Some studies have attempted to do this, while in other studies this issue is not addressed. Cocchini and colleagues (2004) assessed ability to perform a digit span task under single task conditions. The digit span task involves listening to sequences of numbers of varying length and repeating them, e.g. 2-5-1, 5-4-9-2-7-8. Under titrated dual-task conditions participants were required to complete the digit span task at

their individual span length as previously assessed, i.e. some individuals listened to sequences five digits long while others heard sequences seven digits long. In a fixed demand condition all participants would have heard sequences seven digits long, as this is the average digit span in adults. Titrating dual-task demand to single task performance has the advantage of making it clearer whether a divided attention deficit or task demand is responsible for difficulties dual-tasking in neurological conditions, though may be less clinically relevant to the extent that everyday conditions are not titrated to individual performance levels.

Two other factors may influence the performance of a concurrent cognitive task while walking; the prioritisation of performance during dual-tasks and the effect of instruction on task performance. Bloem and colleagues (2001) suggest that healthy adults prioritise performance on walking over cognitive performance, while a recent review of dual-tasking in Parkinson's disease suggest that these patients maintain cognitive performance at the cost of a reduction in walking performance (Bloem et al., 2006). Huitema et al. (2006) report that post-stroke patients also fail to prioritise walking during dual-tasking. Canning (2005) reports that instructing participants to direct their attention to walking improved walking performance while concurrently carrying a tray in Parkinson's disease.

Research on the effect of performing concurrent cognitive tasks on walking in neurological conditions is spread across a variety of literatures; including physiotherapy, gait and cognition; and has employed a number of methodologies. For example some studies have used simple measures of walking, such as number of steps walked within a time limit, while others have used measures such as stride variability and stride duration. Different studies have also employed different cognitive tasks. The extent to which a cognitive task is attentionally demanding will have an effect on study outcomes. This makes it difficult to assess or summarise the findings of the literature. Without an adequate

summary of the literature and its findings it is difficult to evaluate competing explanations of any possible dual-task effects.

There has been one review of the effect of a concurrent cognitive task on walking (Woollacott & Shumway-Cook, 2002).The review covers studies of dual-tasking in both healthy adults and adults with neurological conditions and is helpful in summarising a new and developing literature. It concludes that the attentional demands of dual-tasking varied depending on the complexity of the task and the type of secondary task being performed. The review is now several years old and has some limitations; it is not systematic, both healthy and neurological populations are included and it does not address the task demand issue or the methodological issues of the literature. There is a more recent review of walking and a concurrent task (either cognitive or motor) in patients with Parkinson's disease (Bloem et al., 2006), though this is not systematic nor does it address the above issues in the literature.

The aims of this review are to determine the effect of a concurrent cognitive task on walking in people with neurological conditions and to determine the effect of titrating task demand on dual-task performance. It is hoped that this will allow a more complete analysis of possible explanations for performance on concurrent cognitive and walking tasks in neurological conditions and will lead to suggestions for future research in the area.

Method

A systematic review was conducted. All studies investigating the effect of a concurrent cognitive task on walking in neurological populations over 18 years of age were eligible for inclusion.

Search Strategy and Sensitivity Analysis

Computerised databases searched were MEDLINE (1950 to Week 1 October 2007), Cochrane Database of Systematic Reviews (Issue 3, 2007), British Nursing Index and

Archive (1985 to September 2007), CINAHIL (1982 to Week 1 October 2007) and PsycINFO (1806 to Week 2 October 2007). Search terms used were [dual task] AND [walking] OR [gait] AND [neurological] OR [Alzheimer's] OR [Parkinson's] OR [dementia] OR [Multiple Sclerosis] OR [Stroke] OR [Brain Injury] OR [cognitive]. Other search terms were used, including divided attention, but identified no further articles. On-line abstracts were reviewed and copies of potentially eligible articles were obtained. Reference lists of included articles were hand searched for additional articles. Further electronic search using first authors of included articles was conducted and all first authors of included articles were contacted via email for details of any further articles, though no extra articles were identified .

Data Extraction

Exclusion criteria were (1) performance of the neurological group was not compared to a healthy control group, (2) single and dual-task performance were not compared, (3) the paper involved case report rather than experimental study, (4) the motor task was not walking and (5) the paper was a review paper rather than original research (see Figure 1).

Figure 1 outlines the article selection process for the review. Electronic searches identified 28 relevant studies and hand search identified a further 13. Of these, nine were excluded as the motor task was not walking, and a further 16 were excluded for other reasons (see Figure 1). Sixteen research papers, published between 1997 and 2007, met the inclusion criteria.

[INSERT FIGURE 1 HERE]

Quality Criteria

A quality criteria protocol was compiled (see Table 1) based on the Scottish Intercollegiate Guidelines Network (SIGN) Methodology Checklist 4: Case-control studies (SIGN, 2007), the Consolidated Standards of Reporting Trials (CONSORT) (Altman et al., 2001), York Centre for Reviews and Dissemination (YCRD) guidelines (YCRD, 2007) and the criteria used by Ellis and colleagues (1996). The quality criteria covered six

methodological areas; participants, confounding factors, study design, study description, results and overall assessment (Table 1). Each question on the protocol was answered 'yes', 'partial', 'no' or 'not reported' with scores of 2, 1, 0, and 0 respectively. The total maximum possible score was 38. Two raters assessed the quality of each paper independently using the protocol. Agreement was 87%. A third party arbitrator was available to resolve any disagreements. The quality ratings of included studies are outlined in Table 2. A narrative review of the included studies was also conducted in order to identify issues unique to this particular literature.

[INSERT TABLE 1 HERE]

Effect Sizes

Effect sizes were calculated for each variable under investigation within each particular study, wherever possible. Effect size was calculated regardless of whether a statistically significant difference was found for that variable under dual-task conditions.

Results

Studies Included in Review

Sixteen papers (17 studies as one paper included two studies) were included in the review. Details of the included studies, as well as the quality rating and effect size for each study, are outlined in Table 2. Studies involved participants with four different neurological conditions; Alzheimer's disease (five studies), brain injury (four studies), Parkinson's disease (six studies) and stroke (two studies).

[INSERT TABLE 2 HERE]

Four out of five Alzheimer's disease studies reported a disproportionate decrement in patient performance, relative to controls, in the dual-tasking condition. One study reported a greater combined decrement (of both walking speed and cognitive performance) in

patients. Four out of five of these studies did not measure the effect of dual-tasking on performance on the cognitive task.

Three out of four brain injury studies reported disproportionate dual-task effects for patients on various walking parameters. Three out of four brain injury studies measured cognitive performance. Of these three, one found disproportionate dual-task effects in patients on the number of errors on cognitive tasks.

All of the Parkinson's disease studies reported greater dual-task effects for patients on several different walking parameters. Half of the studies measured cognitive performance. Of these, all found disproportionate dual-task effects on cognitive tasks in patients; primarily in slower response rate and increased error rate.

Both stroke studies reported disproportionate dual-task effects for patients on both walking and cognitive performance.

Quality Ratings

The quality ratings of the studies ranged from 20/38 to 30/38, with a median score of 25/38. Scores of each study on each quality criterion are available in Appendix B1. Few studies reported the percentage of patients and controls that participated, and none of the studies compared participants and those who declined to participate. Only one study reported how sample size was determined. Studies with the lowest overall scores tended not to have reported exclusion criteria, whether the same criteria were applied to cases and controls or to have addressed multiplicity of analyses. Other common reasons for losing points were not taking potential confounders into account and not comparing patients and controls on demographic and clinical characteristics. In particular many studies took account of age and education as potential confounders, but few controlled for fatigue.

It was difficult to determine whether study quality affected findings, due to study differences in factors such as patient group, outcome measures and methodology (see below). For example 15 studies used speed or a proxy of speed (e.g. time, distance) as an outcome measure. Of these seven reported a differential dual-task decrement in the patient

group and eight reported no difference. There was no systematic discrepancy in quality ratings between studies that reported a difference and those that did not. However, studies differed with respect to time or distances walked, cognitive task used and patient group.

Effect Sizes

It was not possible to calculate effect sizes for eight studies. This was primarily because studies reported means and standard deviations for dual-task performance and for single-task performance, but not means and standard deviations for differences between dual and single task performances. For the remaining nine studies effect sizes were calculated for each outcome measure, therefore it was possible to have several different effect sizes for the same study. Calculated effect sizes ranged from 0.46 to 1.2, with a median effect size of 0.77. This is approaching a large effect size (Cohen, 1988).

Methodological Issues

A number of methodological issues make it difficult to compare included studies. First, there is wide variability in the walking tasks employed in the studies (see Table 3).

[INSERT TABLE 3 HERE]

Five studies employed distance walked during a set time, ranging from 30 seconds to 5 minutes, as the measure of walking. Twelve studies employed time to walk a particular distance, ranging from 5 metres to 11 metres (with one study not specifying the distance), as the measure of walking. There are two difficulties with this variability. Greater distances or greater time spent walking may be more taxing for patients and therefore these studies may be more likely to show a dual-task effect, though it is unclear how much of this may be due to the greater effects of fatigue in the patient groups. Patient groups may also be at a disadvantage in studies employing a fixed distance as the measure of walking. Patient groups, compared to healthy controls, may be slower on even simple walking. This means that they will be walking for longer than healthy controls on all tasks involving walking. In comparison, studies that utilise a fixed time as the measure of walking ensure that all participants are dual-tasking for the same duration.

A further difficulty comparing studies is that the studies have measured different parameters of walking and it may be that some of these are more sensitive to the effects of dual-tasking on walking than others (see Table 4). Some studies have used basic measures of walking such as time, distance, velocity or number of steps. Other studies have used electronic equipment, such as electronic walkways, to measure more complex parameters such as stride time, stride length, step width and stride and swing variability. Table 4 summarises the parameters of walking used in different studies.

[INSERT TABLE 4 HERE]

Thirdly, there is variability in the cognitive tasks employed by studies (see Table 3). Six studies employed some form of verbal fluency task, either reciting names in a particular category or producing exemplars from a category. One study employed a digit span task. Seven studies used tasks which involved a level of mental manipulation; such as subtracting serial numbers or reciting the days of the week backwards. One study employed the Stroop, which was projected onto a wall while participants walked. Two studies required participants to answer 'autobiographical questions', though the nature of the questions is unclear. Two studies required participants to repeat sentences, while one study required participants to learn and recall a seven item shopping list. Some studies used more than one cognitive task, therefore the total cognitive tasks exceeds the total number of studies.

The extent to which cognitive tasks are attentionally demanding may influence the size of any dual-task effect found. It is questionable whether some of the tasks employed were difficult enough to induce a dual-task effect. Two studies have compared cognitive tasks of varying levels of difficulty. Campbell and colleagues (2003) found that a dual-task effect was evident in their high demand task (days of the week backwards) but not in their low demand task (repeating sentences). Similarly, Yogev and colleagues (2005) found a greater dual-task effect during a complex listening task compared to a simple listening task.

Fourth, six studies did not measure performance on the cognitive task (Camicioli et al., 1997; Campbell et al., 2003; Catena et al., 2007; Parker et al., 2005; Rochester et al., 2004). Of the 10 studies that did measure performance on the cognitive task, six found that dual-tasking had a differential effect. The failure of some studies to measure cognitive task performance makes it difficult to comprehensively evaluate dual-task decrements in these studies. In dual-task conditions some participants may sacrifice performance on the walking task, while others maintain walking performance but sacrifice performance on the cognitive task. If performance on both tasks is not evaluated then a full picture of performance under dual-task conditions will not be achieved.

A related issue is the use of combined decrement scores. Cocchini and colleagues (2004) calculated combined decrement scores in order to evaluate dual-task effects. The combined decrement score is a single score for the overall combined decrement for both dual-tasks (cognitive and walking). It averages the percentage change in each task under dual-task, compared to single task, conditions to give an overall percentage change score. It assumes both tasks have equal importance. This approach takes into account any variability in the relative emphasis that different participants give the two tasks when performing them simultaneously (Nebes et al., 2001). That is, a participant may trade off performance on one of the tasks in order to maintain better performance on the other task. Thus two participants may have a similar combined dual-task decrement, though one may have sacrificed performance on the cognitive task while the other has sacrificed performance on the walking task. In the studies reviewed here only one study adopted this approach, and as previously mentioned several did not measure cognitive task performance, making it more difficult to compare dual-task effects across participants and across studies.

There is another issue in comparing the dual-task performance of a patient population to that of healthy control participants: differences in single-task performance can confound interpretation of dual-task performance. Those participants who have difficulty carrying

out a task by itself will find the dual-task condition proportionately more difficult than will subjects for whom the single-task condition is fairly easy, because the poorer performers are operating closer to their performance limit under the single-task condition (Baddeley et al., 1986). Some studies have dealt with this problem by titrating the difficulty level of each cognitive task to the individual's performance level under single-task conditions (Logie et al., 2004; Nebes et al., 2001). This ensures that the amount of decrement produced when subjects have to combine the two tasks is not confounded by individual differences in performance on the single-task condition. In this review however, only one study titrated cognitive task difficulty, and found no difference between dual and single task performance (Cocchini et al., 2004).

Discussion

The findings of this review suggest that a concurrent cognitive task has a disproportionate effect on walking in people with Alzheimer's disease, Parkinson's disease, brain injury and stroke. Traditionally walking has been considered an automatic task, requiring few higher cognitive resources (Woollacott & Shumway-Cook, 2002). The findings indicate that there are significant demands on attentional resources when walking whilst performing a concurrent cognitive task. There is a disproportionate effect in several neurological conditions, with a variety of both walking and cognitive parameters disproportionately affected under dual-task conditions. This has a number of real life implications for individuals living with these conditions. We can expect that for these individuals, performance on many everyday tasks will be poorer where concurrent cognitive and walking demands are present.

It has been suggested that disproportionate impairment on dual-tasks is related to the risk of falls (Yogev et al., 2005; Lundin-Olsson et al., 1997; Bloem et al., 2006). Falls are common in many neurological diseases and are difficult to predict as clinical tests assess

single components of postural control while everyday falls mechanisms are typically more complex (Bloem et al., 2006). Dual-task walking may therefore be a more sensitive assessment of walking ability in these neurological groups. The relative contribution of dual-task effects in predicting falls is still under investigation. Recognition of dual-task effects and their impact on fall risk may lead to the development of strategies, including physiotherapy and cognitive rehabilitation strategies, which these groups could use to ensure safer walking and to minimise the impact of dual-task demands. A recent study using randomised control trial methodology reported that a cognitive-motor training programme, involving walking with simultaneous cognitive tasks of gradually increasing demand, may lead to improvements in walking and talking in people with brain injury (Evans et al., submitted).

The current review identified several methodological issues. It was possible to calculate effect size for only half of the studies, and these effect sizes were approaching large. Considerable variability in the methods studies used, particularly in the types of tasks and their measurement, made studies difficult to compare. It would have been helpful to compare effect sizes across different methodologies to determine whether this influenced findings. This was not possible however as only half the studies contained enough information to calculate effect sizes. Only one study evaluated the effect of titrating task demand, therefore it was not possible to investigate the effect of this on outcome. Whilst this type of research has several inherent limitations, based on the findings of this review a number of recommendations for future studies are made.

Recommendations for Future Studies

Study design.

1. Methodological rigour could be increased by stating how sample size was determined. Sample size should be based on power calculations.

2. Study design should take account of potential confounders; in particular age, education and fatigue. The possible effects of fatigue on performance on experimental

trials can be controlled for by i) comparing participants performance on a timed walk before and after the experimental trials ii) counterbalancing experimental trials and iii) participants completing a fatigue questionnaire that measures general fatigue levels.

3. Studies comparing the effects of fixed and titrated demand cognitive tasks are needed, in order to control for individual differences in single task performance.

Measurement issues.

1. Walking a fixed time rather than distance is preferable as it ensures all participants are exposed to dual-tasking for the same duration. Though this cannot take account of the fact that walking may be more physically effortful for patient groups than for controls, it ensures that both groups are dual-tasking for the same duration.

2. It is not clear if a 30 second walk is long enough to elicit a dual-task effect or indeed the optimum length of time required. Haggard and colleagues (2000) found that the dual-task effect was most apparent in the last 30 seconds of a 60 second walk. This suggests that at least a 60 second walk should be considered.

3. It is important that the cognitive task is attentionally demanding and without floor or ceiling effects. Tasks such as verbal fluency, digit span and serial sevens are more likely to be attentionally demanding than listening tasks or tasks involving answering autobiographical questions. Verbal fluency is a task that is self-titrated, rather than having fixed and titrated demand versions.

4. Performance on the cognitive task should be measured. Measurement could include number of responses or percent of correct responses.

5. Performance on both motor and cognitive tasks should be compared in single and dual-task conditions.

6. Means and standard deviations for difference scores, i.e. the mean difference between single and dual-task performance and the standard deviation of the difference, should be reported, to allow calculation of effect sizes.

7. Combined decrement scores should be calculated and reported as in the dual-task some participants will have greater decrement on cognitive performance and others will have greater decrement in walking performance. A combined decrement score allows comparison of the overall decrement in the dual-task, regardless of whether the effect is on cognitive or walking performance. Cocchini and colleagues used Baddeley et al.'s (1997) formulae:

$$\text{Percentage of change task A} = \frac{\text{Single task A-Dual task A}}{\text{Single task A}} \times 100$$

$$\text{Combined decrement} = 100 - \frac{\text{Percentage of change task A+ Percentage of change task B}}{2}$$

Questions for Future Research

Studies to date have generally been limited in their exploration of possible mechanisms of and explanations of dual-task effects. There are a number of ways in which this future research could address this issue. First, if studies adopted the approach of reporting difference scores it should be possible to compare dual-task effects between different neurological conditions. This might provide greater information about the different mechanisms at work.

Second, in their review of dual-tasking in Parkinson's disease Bloem and colleagues (2006) identified that patients adopted a 'posture second' strategy, in which cognitive performance was maintained while motor performance decreased in dual-task conditions. Improved measurement in studies, as outlined above, would allow similar analyses of strategies in other patient groups. Better knowledge of the mechanisms of poor dual-task performance would lead to the development of improved assessment and rehabilitation strategies.

Third, it would be helpful to examine of the relationship between executive function and performance under dual-task conditions. Recent studies have begun to examine this. Yogev and colleagues (2005) compared performance of Parkinson's disease patients and controls on executive and memory tasks. Patients performed worse on the executive tasks than controls and performance on the executive tasks correlated with dual-task performance. The executive tests used focus primarily on set shifting and response inhibition. This suggests that a divided attention impairment results in poor walking and talking performance, rather than poor performance simply being a result of increased task demand in dual-task conditions. Yogev-Seligman and colleagues (2008) discuss the possible impact of executive functions; including volition self-awareness, planning, response inhibition, response monitoring and divided attention; on gait and review findings of studies examining executive function and gait. They conclude that assessment of executive function and dual-task walking should become a part of the routine examination among neurological patients in order to more fully evaluate gait abnormalities and fall risk. Sheridan and Hausdorff (2007) review the role of executive function in gait and its possible relation to falls, in Alzheimer's disease. They suggest several possible mechanisms whereby impaired cognition influences gait in Alzheimer's disease; disintegration of higher cortical sensory function leads to breakdown of automaticity of walking, poor control of timing in the cerebellum leads to variability of stepping and subsequent gait unsteadiness, and impairment of working memory which is necessary for sequential ordering of movement leads to instability of an automatic walking program. They suggest a treatment approach that specifically targets executive function in order to reduce the rate of falls. Future studies could routinely include standard measures of executive function and attempt to use them to explain mechanisms of dual-task performance.

Conclusions

The findings suggest that a concurrent cognitive task has a disproportionate effect on walking in Alzheimer's disease, Parkinson's disease, brain injury and stroke. It was not possible to determine the effects of titrating task demand. Effect size could only be calculated for half the studies, with a large median effect size. This meant that meta-analytic review was not possible. Analysis of study quality identified a number of methodological issues, which future studies could address.

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Table 1

Quality Criteria Protocol

CRITERION
PARTICIPANTS
Cases are clearly defined and differentiated from non-cases
It is clearly established that controls are non-cases
Exclusion criteria are sufficiently described
The same exclusion criteria are used for cases and controls
The disease state of cases is reliably assessed and validated
Cases & controls are taken from similar populations
The % of cases and controls that participated are described
Participants and non-participants are compared
CONFOUNDING FACTORS
Potential confounders are identified and taken into account in design and analyses
STUDY DESIGN
Measures are appropriate e.g. have sufficient reliability , no floor or ceiling effects
STUDY DESCRIPTION
Settings and location of data collection described
How sample size determined is outlined & power is sufficient
Objectives and hypotheses outlined
Outcome measures described
Precise details of intervention and how and when administered described
RESULTS
Demographic and clinical characteristics of each group described & compared
Number of participants in each analyses described
Appropriate statistical analyses performed
Multiplicity of analyses is addressed
TOTAL QUALITY SCORE

Note. For each criterion a score of 2 (yes), 1 (partial) or 0 (no or not reported) was awarded

Table 2

Summary and Quality Ratings of Studies Included in Review

Reference	Quality score	Effect Size	Participants		Walking task	Cognitive task	Outcome measures	Results in patient group compared to control
ALZHEIMER'S	DISEASE							
Camicioli 1997	25/38	0.74 0.83 ns 0.54 ns 0.46 ns	AD Old old Young old	n=15 n= 20 n= 23	30 foot (9.14 metres) walk	Reciting names	Walking - Time taken - No. of steps Cognitive task not measured	-Increased walking time in dual task -No difference in steps taken
Cocchini 2004a	25/38	0.84	AD Controls	n= 15 n= 15	30 second walk	Association fluency	Walking - Distance walked Cognitive task - No. of words	-No differences in distance or no. of words -Greater combined dual-task decrement scores in AD
Cocchini 2004b	25/38	0.55ns	AD Controls	n= 15 n= 15	30 second walk	Titrated digit span	Walking - Distance walked Cognitive task - % digit span correct	-Reduced distance in dual task -No difference in decrement scores
Petterson 2005	23/38	1.2 0.7	Controls MCI AD OD	n= 33 n= 59 n= 22 n= 26	10 metre walk	TUG task. Cognitive task not described	Walking - Time taken Cognitive task not measured	-Both AD & OD greater reduction in speed in dual task

Reference	Quality score	Effect Size	Participants	Walking task	Cognitive task	Outcome measures	Results in patient group compared to control
Petterson 2007	27/38	1.2	Controls n= 25 MCI n=6 AD n= 6	10 metre walk	Reciting names	Walking - Time taken Cognitive task not measured	-AD greater reduction in speed in dual task
BRAIN	INJURY						
Cantena 2007	28/38		Concussed n= 14 Controls n= 14	8 metre walk	Mini-mental tasks; DLROW, continuous subtraction or months backwards	Walking - gait velocity - stride time - stride length - step width Cognitive task - Measured but not indicated how	- No decrement differences found in walking or cognitive tasks

Reference	Quality score	Effect Size	Participants	Walking task	Cognitive task	Outcome measures	Results in patient group compared to control
Haggard 2000	20/38		Patients n=50 (mixture of traumatic brain injury and stroke) Controls n=10	60 second walk	1) Category fluency and 2) Mental arithmetic and 3) VPA monitoring and 4) Visuospatial task	Walking - No. of strides - Median duration - Variability in stride duration Cognitive tasks - No. of errors	- Dual task decrement in stride duration for all cognitive tasks, no difference in gait variability - Increased errors in word generation, mental arithmetic, VPA monitoring but not visuospatial tasks in dual task conditions - Decrement in dual task word generation confined to last 30s - Dual task performance correlated with ADL. Standard gait measures did not correlate with ADL
Parker 2005	22/38		Concussed n= 10 Controls n= 10	10 metre walk	Serial sevens or DLROW or months backwards	Walking - gait velocity - step width - stride length & time - Whole body CoM motion & velocity Cognitive task not measured	- Increased medio-lateral CoM sway while walking in dual-task condition in patients but not controls

Reference	Quality score	Effect Size	Participants		Walking task	Cognitive task	Outcome measures	Results in patient group compared to control
Vallee 2006	25/38		TBI Controls	n= 9 n= 9	11 metre walk	Stroop	Walking - speed - stride length - foot clearance margin Cognitive task - reading time	- Stride length decreased in dual task, no difference in speed decrement - No difference in reading time decrement
PARKINSON'S	DISEASE							
Camicioli 1998	22/38	1.2 0.8	PD-NF PD-F Controls	n=9 n=10 n=19	30 foot (9.14 metres) walk	Reciting names	Walking - Time taken - No. of steps Cognitive task not measured	-PD-F group increased number of steps, but not time during dual tasking
Campbell 2003	23/38		PD Controls	n= 9 n= 10	6 metre walk	1) Repeating a sentence (low cognitive demand) 2) Reverse days of week (high cognitive demand)	Walking - time taken - no. of steps Cognitive task not measured	- In high (but not low) cognitive demand dual task increased time and steps

Reference	Quality score	Effect Size	Participants		Walking task	Cognitive task	Outcome measures	Results in patient group compared to control
Galletly 2005	21/38	0.6	PD Control	n= 16 n=16	10 metre walk	1) backwards counting in threes 2) verbal fluency	Walking - velocity - stride length - cadence Cognitive task - Correct response rate	- Decreased stride length in dual task - Slower correct response rate in dual task
OShea 2002	30/38 0.9 0.9 0.7	0.9 0.9 0.7	PD Controls	n= 15 n=15	10 metre walk	Subtracting serial 3's	Walking - speed - stride length - cadence - double support duration Cognitive task - response rate - no of errors	- Greater decrement in stride length, speed and cadence in dual task conditions, no difference in double support duration - Controls improved response rate during dual tasking, PD did not - Increased error rate during dual tasking compared to controls
Rochester 2004	29/38		PD n=20 Controls n=10		Distance unspecified	Answering autobiographical questions	Walking - speed - step length - step frequency Cognitive task not measured	- Greater decrement in speed & step length in dual task

Reference	Quality score	Effect Size	Participants		Walking task	Cognitive task	Outcome measures	Results in patient group compared to control
Yogev 2005	28/38		PD Controls	n=30 n=28	2 minute walk	1) listening to text (simple task) and 2) listening to text and counting word occurrences (complex task) and 3) serial sevens	Walking - velocity - stride time and variability - swing time and variability - speed Cognitive task - listening comprehension - subtraction errors	- No difference between groups in dual-task decrement in speed - Gait variability differentially affected in patients in dual-task - Decrement in performance on serial sevens in dual task - Gait variability during dual task correlated with tests of executive function, gait variability during normal walking did not
STROKE								
Hyndman 2006	21/38	0.5	Stroke Controls	n=36 n=24	5 metre walk	Remembering 7 item shopping list	Walking - time taken - stride length - velocity Cognitive task - no of items recalled	- Increased walking time in dual task - Fewer items recalled in dual task

Reference	Quality score	Effect Size	Participants		Walking task	Cognitive task	Outcome measures	Results in patient group compared to control
Kemper 2006	23/38		Stroke Controls	n=10 n=10	3-5 minute walk	Answering autobiographical questions	Walking - errors while walking - steps per second Cognitive task - language fluency - grammatical complexity - language content	- Decreased time on task in dual task, no effect on walking errors - Fluency, grammatical complexity and content decreased in dual task for stroke but not controls

Note. AD= Alzheimer's disease, MCI= Mild Cognitive Impairment, OD= Other dementia, PD= Parkinson's disease, PD-F= Parkinson's disease freezing, PD-NF= Parkinson's disease no freezing, Reh. =Rehabilitation, Phys.=Physical, n.s= not statistically significant in study analysis

Table 3

Walking and Cognitive Tasks Employed in Studies

Task	**Studies using this task**	**Number of studies that found a dual-task effect in this task**
WALKING TASKS		
30-60 second walk	Cocchini et al. (2004a & b), Haggard et al. (2000)	2/3
120 second walk	Yogev et al. (2005)	1/1
3-5 minute walk	Kemper et al. (2006)	1/1
5 metre walk	Hyndman et al. (2006)	1/1
6 metre walk	Campbell et al. (2003)	1/1
8 metre walk	Cantena et al. (2007)	0/1
9-11 metre walk	Camicioli et al. (1997, 1998), Pettersson et al. (2005, 2007), Parker et al. (2005), Vallee et al. (2006), Galletly et al. (2005), OShea et al. (2002)	7/7
Unspecified	Rochester et al. (2004)	1/1
COGNITIVE TASKS		
Verbal fluency task	Camicioli et al. (1997), Cocchini et al. (2004a)Pettersson et al. (2005, 2007), Haggard et al. (2000), Camicioli et al. (1998), Galletly et al. (2005)	7/7
Digit span task	Cocchini et al. (2004) B	1/1
Subtracting serial numbers, reciting days of week backwards, spelling	Cantena et al. (2007), Haggard et al. (2000), Parker et al. (2005), Campbell et al. (2003), Galletly et al. (2005), OShea et al. (2002)	5/6

Task	Studies using this task	Number of studies that found a dual-task effect in this task
WORLD backwards		
STROOP	Vallee et al. (2006)	1/1
Autobiographical questions	Rochester et al. (2004), Kemper et al. (2006)	2/2
Repeating sentences	Campbell et al. (2003)	0/1
Simple listening task	Yogev et al. (2005)	1/1
Learning seven item shopping list	Hyndman et al. (2006)	1/1
Verbal monitoring task	Haggard et al. (2000), Yogev et al. (2005)	2/2
Visuospatial task	Haggard et al. (2000)	1/1

Table 4

Walking Parameters Used in Included Studies

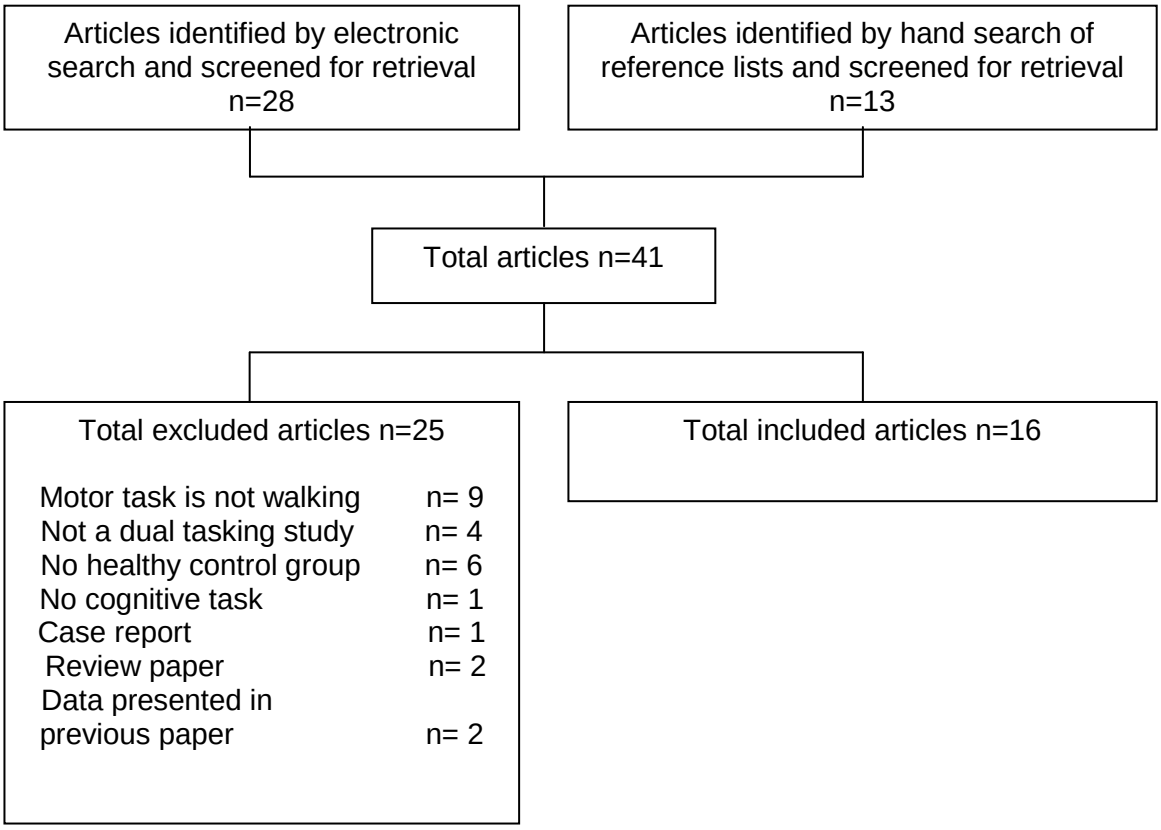
Walking parameter	**Studies using this parameter**	**Number of studies that found a dual-task effect in this parameter**
Time taken	Camicioli et al. (1997), Camicioli et al. (1998), Pettersson et al. (2005), Pettersson et al. (2007), Campbell et al. (2003), Hyndman et al. (2006)	5/6
Distance walked	Cocchini et al. (2004a & b)	1/2
Number of steps	Camicioli et al. (1997), Camicioli et al. (1998), Campbell et al. (2003), Rochester et al. (2004), Kemper et al. (2006)	3/5
Velocity	Cantena et al. (2007), Parker et al. (2005), Vallee et al. (2006), Galletly et al. (2005), OShea et al. (2002), Rochester et al. (2004), Yogev et al. (2005)	2/7
Stride time	Cantena et al. (2007), Parker et al. (2005)	0/2
Stride length	Cantena et al. (2007), Parker et al. (2005), Vallee et al. (2006), Galletly et al. (2005), OShea et al. (2002), Rochester et al. (2004), Hyndman et al. (2006)	4/6
Step width	Cantena et al. (2007), Parker et al. (2005)	0/2
Stride variability	Yogev et al. (2005)	1/1
Swing variability	Yogev et al. (2005)	1/1
Median duration	Haggard et al. (2000)	1/1
Variability	Haggard et al. (2000)	0/1

Walking parameter	Studies using this parameter	Number of studies that found a dual-task effect in this parameter
Whole body Centre of Mass motion & velocity	Parker et al. (2005)	1/1
Foot clearance margin	Vallee et al. (2006)	0/1
Cadence/Step frequency	Galletly et al. (2005), OShea et al. (2002), Rochester et al. (2004)	1/3
Double support duration	OShea et al. (2002)	1/1
Walking errors	Kemper et al. (2006)	0/1

Figure Captions

Figure 1. Flowchart of article selection process.

Figure 1


Articles identified by electronic search and screened for retrieval n=28
Articles identified by hand search of reference lists and screened for retrieval n=13
Total articles n=41
Total excluded articles n=25
Motor task is not walking n= 9
Not a dual tasking study n= 4
No healthy control group n= 6
No cognitive task n= 1
Case report n= 1
Review paper n= 2
Data presented in previous paper n= 2
Total included articles n=16

CHAPTER TWO

MAJOR RESEARCH PROJECT

Walking and Talking in Multiple Sclerosis:

An Investigation of Cognitive-Motor Dual-Tasking[†]

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Abstract

Problems with walking and attention are known to be prevalent in Multiple Sclerosis (MS), though no studies have reported how these two difficulties might interact. The study aimed to investigate the effects of performing a concurrent cognitive task when walking in MS and determine the effects of task demand on dual-task performance. Eighteen MS participants and 18 healthy controls took part. Participants completed walking and cognitive tasks under single and dual task conditions. MS participants, compared to healthy controls, had greater decrements in dual-task performance; including decrements in cognitive task performance, walking speed and swing time variability. Dual-task decrements were evident in titrated and fixed demand conditions. Dual-task decrements were related to fatigue, cognitive functioning and self-reported cognitive errors, but not to measures of disease severity or duration. MS participants perform differentially poorly on walking and talking dual-tasks compared to healthy controls. This may lead to difficulties in everyday life and increase the risk of falls in MS. Clinicians should independently assess dual-task walking in MS patients. The role of task demand in dual-tasking decrements remains unclear and needs further investigation. Future studies should replicate the current findings and develop practical clinical tools to assess walking and talking ability.

Key words: Adult, attention, memory, neuropsychological tests, gait, nervous system disorders

Introduction

Problems with walking and cognition are common in Multiple Sclerosis (MS). Cognitive impairment affects about 50% of people with MS (NICE, 2004). One of the most frequently impaired cognitive domains is attention (Calabrese, 2006), with 22-25% of people with MS reporting attentional problems (Sullivan, et al., 1990 and Arnett, 2003). In a recent review of neuropsychological impairment in MS, Calabrese (2006) concluded that impairment of attention appears to occur early in the disease and may contribute to subsequent dysfunction in memory and abstract reasoning.

Despite apparently being a common difficulty there are only a few studies investigating attention in MS (Calabrese, 2006). McCarthy et al. (2005) investigated divided and sustained attention in MS. They reported that MS participants were slower and less accurate on both types of attention compared to controls and that divided attention was more impaired than sustained attention. D'Esposito et al. (1996) used a dual-task paradigm with people with MS, asking participants to perform two cognitive tasks simultaneously in the dual-task condition. They found that, compared to healthy controls, MS participants had a greater reduction in performance in the dual-task condition compared to the single task, suggesting a differential impairment in divided attention.

Up to 50% of people require assistance walking within 15 years of MS onset (Ruddich, 1999). Walking has traditionally been considered automatic or reflex controlled, requiring minimal attentional resources (Woollacott & Shumway-Cook, 2002). A recent review however suggests that control of walking can be attentionally demanding (Woollacott & Shumway-Cook, 2002). In healthy young adults this is detectable only when quite complex additional secondary tasks are performed in addition to walking, while in healthy older adults performing a secondary task appears to have a more deleterious effect.

Dual-tasking refers to the ability to do two things at once. Recent studies have investigated the effects of a particular type of dual-tasking in neurological conditions;

performing concurrent cognitive tasks while walking. Studies of people with Alzheimer's (e.g. Cocchini et al., 2004) and Parkinson's disease (e.g. Yogev et al., 2005) have suggested that speed and accuracy of walking is affected by simultaneously performing a cognitive task. The research suggests that in these neurological conditions performing concurrent tasks has a disproportionate effect on walking, compared to healthy controls (Hamilton et al., chapter one this volume; Woollacott & Shumway-Cook, 2002). As well as having implications for everyday life, where we are frequently required to do two things at once, dual-tasking difficulties may help explain the high risk of falls (Cocchini et al., 2004) and may have implications for the assessment and rehabilitation of walking (Haggard et al., 2000) in several neurological conditions. A recent study using randomised control trial methodology reported that a cognitive-motor training programme, involving walking with simultaneous cognitive tasks of gradually increasing demand, may lead to improvements in walking and talking in people with acquired brain injury (Evans et al., submitted).

There are three possible explanations for the development of a dual-tasking deficit (Hamilton et al., chapter one this volume). One is that basic deficits in motor functioning mean that motor tasks require more conscious attention for successful performance. Mulder and colleagues, for example, postulate that when the motor system is damaged control of movement is primarily directly cognitive (Mulder et al., 2002) and under a 'slow mode' of control. Walking becomes an attention demanding task. The limited capacity working memory system is therefore overloaded in the dual-task situation. Another possibility is that in neurological conditions working memory capacity is reduced, so that is overloaded by previously normal loads of motor and cognitive content. A third possibility is that rather than basic working memory capacity being the problem, there is a deficit in the attention control system that allocates attention between concurrent demands (Logie et al., 2004). Baddeley and Hitch's working memory model suggests that a central executive is responsible for dividing attention between concurrent tasks (Baddeley &

Hitch, 1974). From this model a difficulty performing two concurrent tasks is seen as due to a deficit in the ability to allocate attentional resources to competing demands, rather than due to insufficient attentional capacity. Deficits in divided attention are well documented in a variety of neurological conditions.

It has been argued (e.g. Cocchini et al., 2004 and Logie et al., 2004) that in studying dual-tasking it is important to control for this task demand effect when comparing a patient group with a healthy control group. In order to determine whether dual-tasking difficulties are specifically caused by a divided attention/dual-tasking process impairment they suggest that it is necessary to titrate tasks according to performance under single task conditions. Logie et al. (2004) for example investigated the effects of manipulating task demand on performing two simultaneous cognitive tasks in patients with Alzheimer's disease and healthy controls. It was reported that there was a greater dual-task decrement in patients with AD, compared to healthy controls, independent of overall task demand, suggesting a divided attention impairment, rather than a capacity issue. Titrating dual-task demand to single task performance therefore has the advantage of making it clearer whether a divided attention deficit is responsible for difficulties under dual-tasking conditions, though may be less clinically relevant to the extent that everyday conditions are not titrated to individual performance levels.

Difficulties both with walking and attention are known to be prevalent in people with MS, though no studies have investigated how these two difficulties might interact as in other neurological conditions. The present study seeks to investigate the effects of performing a simultaneous cognitive task when walking in MS. In order to determine whether dual-tasking difficulties are specifically caused by a divided attention/dual-tasking process impairment both titrated and fixed demand tasks will be used.

The aims of this study were; to investigate whether cognitive-motor dual-tasking is impaired in MS, relative to healthy controls; to investigate whether any cognitive-motor dual-tasking impairment in MS is due to increased task demand or a divided attention

deficit; and to identify any association between self-reported attentional difficulties, self-reported fatigue and dual-task performance.

It was expected that MS participants would perform differentially poorly on dual-tasks compared to controls. Specifically, it was hypothesised that performance on measures of walking and an additional cognitive task would be disproportionately impaired in dual-task conditions compared to single-task conditions (in MS participants compared to controls).

Method

Ethical Approval

The study was granted ethical approval by the local NHS Research Ethics Committee.

Participants

Power calculations indicated that a sample size of n= 20-26 per group was needed (see Appendix C1, page 111). Participants were people with MS and healthy controls. MS participants were recruited from MS clinics by two research nurses and a consultant neurologist specialising in MS. Controls were recruited via MS participants and via recruitment posters placed throughout the hospital in which the study was being conducted.

Inclusion criteria for MS participants were; a diagnosis of relapsing-remitting MS and an Expanded Disability Status Scale (EDSS) score (Kurtzke, 1983) up to 5.5. Relapsing-remitting MS refers to clearly defined disease relapses with either full recovery or with residual deficit upon recovery; periods between relapses are characterised by a lack of disease progression (NICE, 2004). Diagnosis of MS was made by a consultant neurologist specialising in MS using the Poser (Poser et al., 1983) and McDonald (McDonald et al., 2001) criteria i.e. at least two clinical attacks and abnormal MRI consistent with MS, either with or without abnormal CSF consistent with MS. An EDSS

score up to 5.5 indicates minimal or moderate impairment in up to four functional systems and an ability to walk at least 100 meters unaided. EDSS scores were assessed by a consultant neurologist. Healthy controls were matched for age. Exclusion criteria for both MS participants and healthy controls were; major psychiatric disorder, history of brain injury or neurological disease (other than MS) and a history of falls in the past month. Healthy controls with a history of any disorder affecting walking were also excluded.

Design

A cross sectional design was used comparing the performance MS and control participants under single and dual task conditions.

Materials

Baseline assessment

Pre-morbid intellectual functioning was assessed using the Weschler Test of Adult Reading (WTAR) (Weschler, 2001). Reliability and validity have been reported as good; with internal consistency coefficients of 0.87 to 0.95, test-retest correlation coefficients of 0.90 and correlation coefficients of 0.73 with the Weschler Adult Intelligence Test Full Scale IQ score (Spreen et al., 2003).

General cognition was assessed using the Addenbrooke's Cognitive Examination-Revised (ACE-R), a brief cognitive test designed to screen for dementia. It has not been validated with MS but was used in this study to describe basic cognitive function of patients and controls. In the general population sensitivity of 0.94 and specificity of 0.89 have been reported at a cut-off of 88/100 (Hodges, 2007).

Cortical vision was screened using the Cortical Vision Screening Test (CVST) (James et al., 2001). This test includes ten sub-tests each designed to evaluate a different aspect of early visual processing and identifies visual problems with a cortical cause.

Anxiety and depression were screened using the Hospital Anxiety and Depression Scale (HADS) (Zigmund and Snaith, 1983). The HADS is a self-report instrument designed for use with non-psychiatric hospital patients. The reliability and validity of the

HADS is described as good to very good with internal consistency coefficients of 0.8, concurrent validity of 0.6 to 0.8 and both sensitivity and specificity of 0.8 (Bjelland et al., 2002).

Fatigue was assessed using the Modified Fatigue Impact Scale (MFIS) (Multiple Sclerosis Council for Clinical Practice Guidelines, 1998). The MFIS is a 20-item self-report instrument. It is the recommended measure for fatigue in MS (Multiple Sclerosis Council for Clinical Practice Guidelines, 1998) with good reliability (e.g. internal consistency coefficients 0.92, intra-class correlation coefficient 0.91) and validity (convergent validity coefficient 0.67) reported in MS patients (Kos et al., 2005).

Self-rated attention was measured using the Cognitive Failures Questionnaire (CFQ) (Broadbent, 1982). Good reliability, with internal consistency coefficients of 0.76 to 0.86, and construct validity have been reported (Wallace et al., 2002).

Disease severity of MS was assessed using Kurtzke's EDSS (Kurtzke, 1983).

The following *demographic information* was recorded; age, gender, history of mental health problems, medical history, disease type (MS participants) and years of illness (MS participants).

An individual *digit span assessment* (see Appendix C2) was completed using Cocchini et al.'s method (2004). Participants listened to a string of digits and repeated them back (e.g. 3-2-5). Cocchini et al. presented the digits at the rate of two per second, in the current study however digits were presented at the rate of one per second.Three trials were given at each sequence length. If two out of three trials at a given length were correct the participant was deemed to have passed that sequence length and the length was increased by one digit. Each participant's digit span was determined as the last sequence length at which two out of three trials were correct.

Gait assessment

The GAITRite System was used to measure walking parameters. The GAITRite system is a flexible electronic walkway providing automated measurement of the spatial

and temporal parameters of gait using a carpet embedded with sensors which detect footfalls. It has been shown to give valid and reliable data (van Uden & Besser, 2004). The carpet is 457cm long with an active area of 366cm and a sampling rate of 32.3-38.4Hz. The GAITRite was placed so that it formed part of a circuit of approximately 18 metres.

During all walking trials participants walked unaided around the circuit continuously for 90 seconds until told to stop. They were instructed to walk at their preferred speed. Participants performed between three and six repetitions of the circuit during each trial. Walking speed, step length, step frequency, step time, swing time and double limb support time variability were automatically calculated by computer software designed for GAITRite and recorded on disc for later analysis. Distance walked during each trial was measured manually by the researcher.

Cognitive tasks

There were two cognitive tasks; a fixed and a titrated demand task. During each task participants listened to sequences of digits, played aloud on a CD player, and were required to repeat each sequence in order. During the fixed demand task all participants were presented with sequences that were seven digits in length, since this is the average digit span in adults (Miller, 1956). During the titrated demand task participants were presented with sequences at their own digit span length; as assessed in the baseline digit span assessment. Participant responses were recorded by a pocket sized digital voice recorder with portable microphone worn by the participant. The percentage of digit sequences correctly recalled was later calculated by the researcher. Development of the CD version of cognitive tasks is described in Appendix C3.

Procedure

All participants provided written informed consent. Participants first completed the baseline assessment measures as described. Participants then completed walking and cognitive tasks under both single and dual task conditions. In total each participant

completed five trials; walking alone, fixed digit task alone, titrated digit task alone, walking with fixed digit task and walking with titrated digit task. Each trial lasted 90 seconds. Trials were counter-balanced to ameliorate order effects. To control for fatigue effects, counter-balancing was blocked to ensure two walking tasks did not occur together. Immediately before and after the protocol, participants completed three repetitions of a timed 10metre walk to determine any impact of fatigue on walking performance.

Data Analysis

Descriptive statistics are reported as mean $\pm$ standard deviation or, where indicated, medians (95% confidence intervals). Student's t, Mann Whitney U and chi-square tests were used as appropriate to compare MS and control participants on demographic and baseline clinical characteristics. Decrement scores, i.e. percentage change from single to titrated and fixed demand dual-task performance, were calculated for each outcome measure. Combined decrement scores, i.e. a single score for the overall combined change in cognitive task and walking task performance under titrated and fixed demand dual-task conditions, were calculated for cognitive task and each walking outcome measure. Decrement and combined decrement scores for MS and control participants were compared on each outcome measure using Student's t and Mann Whitney U tests as appropraite. Since specific predictions were made regarding findings and effect sizes (r) are reported Bonferroni corrections were not applied, due to the risk of Type II errors.

The relation between education, pre-morbid ability, general cognition and self-reported depression, anxiety, cognitive errors, fatigue and dual-task decrement scores was investigated using Pearson correlation coefficients (r). Association between measures of disease severity (EDSS score, years since diagnosis) in the MS group only and dual-task decrement scores was also investigated using Pearson correlation coefficients (r). Logistic regression was used to explore the relative ability of dual-task decrement and measures which correlated with dual-task decrement to predict whether a participant was from the MS or control group.

Results

Descriptive Characteristics

Eighteen people with MS and 18 healthy controls took part. The basic demographic and clinical details of each group are outlined in Table 1. MS participants were in remission and did not use walking aids. Of the 18 healthy controls, five were recruited via MS participants and 13 were recruited using posters. Both groups were similar with respect to age and gender. There were statistically significant differences in pre-morbid ability and education, with controls on average having 1.76 years more education. MS participants performed more poorly on the ACE-R; five MS participants scored in the possible dementia range compared to none of the controls. MS participants reported greater levels of fatigue, everyday cognitive errors and (non-clinically significant) anxiety and depression. None of the controls reported falling in the past 6 months, while MS participants reported an average of 0.8 falls. There was no difference between MS and control participants in assessed digit span with an average digit span of 6.39 (range 4-9) in MS participants and 6.5 (range 5-9) in controls. When time to walk 30 metres after experimental trials were completed was subtracted from time to walk 30 metres prior to experimental trials there was no difference between MS and control participants.

[INSERT TABLE 1 HERE]

The data were analysed to determine percentage correct in the digit task, walking speed, step frequency, step time, step length, swing time variability and double support time variability for each task alone and in titrated and fixed demand dual-task conditions. Step frequency, step time and step length were highly correlated with walking speed ($r = 0.958, -0.929, -0.925$ respectively, $p<0.001$) and were therefore excluded from further analyses. The performance of MS and control participants for each task alone and in titrated and fixed demand dual-task conditions is presented in Table 2 and Figure 1.

[INSERT TABLE 2 HERE]

[INSERT FIGURE 1 HERE]

Comparison of Single and Dual-Task Performance for Titrated and Fixed Task Demand

Percentage change (decrement) from single to dual task performance was calculated using Baddeley et al.'s (1997) formula (as cited in Cocchini et al., 2004):

$$\text{Percentage of change task A} = \frac{\text{Single task A} - \text{Dual task A}}{\text{Single task A}} \times 100$$

The percentage changes, or decrements, in digit task, walking speed, swing time variability and double support time variability from single to dual task for titrated and fixed task demand are outlined in Table 3 and Figures 2 and 3. Since neither pre-morbid ability nor education correlated with primary outcome measures (see Table 5) in dual-task conditions they were not included as covariates in analyses.

[INSERT TABLE 3 HERE]

Digit task performance

There was a statistically significant difference between MS and control participants in digit task performance *decrement* in fixed demand (t (df 34) = -2.219, p = 0.033 two-tailed, r = 0.36), but not titrated demand (t (df 34) = -1.564, p = 0.127 two-tailed, r = 0.26), dual-tasks. The percentage of digit span tasks performed correctly by MS participants reduced by 14% and 17% in titrated and fixed demand dual-tasks respectively, compared to 3% and 0% for controls. The small-medium effect size (r = 0.26) in the titrated demand dual-task suggests the study may have lacked power to detect this effect.

Walking speed

There were statistically significant differences between the groups for walking speed *decrement* in both titrated (t (df 25.913) = -3.959, p = 0.001 two-tailed, r = 0.61) and fixed (t (df 34) = -4.467, p < 0.001 two-tailed, r= 0.61) demand dual-tasks. This was a large effect size with average walking speed decreasing by 9% and 11% in titrated and fixed demand dual-tasks respectively for MS participants, compared to 2% and 2% for controls.

Swing time variability and double support time variability[‡]

Change in swing time variability between single and dual-task conditions was statistically significantly different for MS participants compared to controls in the fixed demand dual-task (U (N 36) = 96, p = 0.037 two-tailed, r = 0.35). MS participants increased swing time variability by an average of 19% in fixed demand dual-tasks, compared to a 7% decrease for controls. In the titrated demand dual-task there was a trend towards a significant difference between the groups, (U (N=36) = 104, p = 0.068, r = 0.31), the medium effect size indicating that failure to reach significance is a result of a power issue. MS participants increased swing time variability by 30% in titrated demand dual-tasks, compared to 5% for controls. There were no statistically significant differences between MS and control participants for double support time variability in either fixed (U (N=36) = 124, p = 0.239, r = 0.200) or titrated (U (N=36) = 141, p = 0.521, r = 0.11) demand dual-tasks.

[INSERT FIGURES 2 & 3 HERE]

Combined Decrement from Single to Dual-Task Performance for Fixed and Titrated Task Demand

A single score for the overall combined change in cognitive task and walking task performance under dual-task conditions was calculated using the following formula (Baddeley et al., 1997):

$$\text{Combined decrement score} = \frac{\text{Percentage change task A} + \text{Percentage change task B}}{2}$$

A combined decrement score was calculated for cognitive task and each of walking speed, swing time variability and double support time variability. Combined decrement scores for MS and control participants in both titrated and fixed demand dual-tasks are outlined in Table 4.

[‡] See Appendix C4, page 123, for definitions of swing time and double support time and brief overview of gait cycle.

[INSERT TABLE 4 HERE]

Cognition and walking speed

There were statistically significant differences between MS and control participants for combined cognition and walking speed decrement in both titrated (t (df 34) = -2.418, p = 0.021 two-tailed, r = 0.38) and fixed (t (df 34) = -3.274, p = 0.002 two-tailed, r = 0.49) demand dual-tasks. On average MS participants overall performance decreased by 12% in the titrated demand dual-task and 14% in the fixed demand dual-task, compared to 2% and 1% respectively for controls.

Cognition and swing time variability

Combined cognition and swing time variability decrement was statistically significantly different between MS and control participants in both titrated (U (N=36) = 98, p = 0.044 two-tailed, r = 0.34) and fixed demand (U (N=36) = 81, p = 0.010, r = 0.43) dual-tasks. Overall performance by MS participants decreased by 23% in the titrated demand dual-task and 20% in the fixed demand dual-task, compared to a 3% decrease and 9% improvement respectively for controls.

Cognition and double support time variability

There was a statistically significant difference between MS and control participants for combined cognition and double support time variability decrement in the fixed demand dual-task (U (N=36) = 100, p = 0.051, r = 0.330), with performance of the MS group reducing by 20% compared to 1% for controls. There was no statistically significant difference between the groups in the titrated demand dual-task (U (N=36) = 118, p = 0.171, r = 0.23), the overall performance of the MS group decreased by 16% compared to 3% in controls.

Exploratory Analysis of Possible Factors Affecting Dual-Task Differences in MS and control Participants

Exploratory correlational analysis was conducted to determine if pooled MS and control participants' differences in dual-task decrement scores could be explained by other

factors. The difference between each participant's assessed digit span and the fixed demand digit span was calculated (e.g. the participant's assessed digit span might be 5 while fixed digit span is 7 resulting in a difference of -2). There was no association between difference between assessed and fixed digit span and either cognitive task decrement for titrated (r= -0.126, p = 0.464) and fixed (r = 0.091, p =0.595) demand dual-tasks or walking speed decrement for titrated (r = -0.090, p = 0.607) and fixed (r = 0.051, p = 0.769) demand dual-tasks. There was a large effect size for the difference in time taken to walk 30 metres before and after experimental trials and dual-task decrement in walking speed in both titrated (r = -0.540, p = 0.001) and fixed (r = -0.508, p = 0.002) demand dual-tasks.

The relation between education, pre-morbid ability, general cognition and self-reported depression, anxiety, overall cognitive errors, cognitive errors as reported on CFQ Question 9, fatigue and dual-task decrements was explored in pooled MS and control participants. CFQ Question 9 was selected for this analysis as this CFQ question most closely relates to dual-tasking ability; 'Do you fail to hear people speaking to you when you are doing something else?' The results are outlined in Table 5. Self-reported fatigue and performance on a cognitive screening test (ACE-R) were related to decrement in walking speed in fixed demand dual-tasks (r = 0.387, -0.385, p = 0.020, 0.020 respectively). Decrement in walking speed in the titrated demand dual-task was related to cognitive errors as reported on CFQ Question 9, while in fixed demand dual-task conditions this association approached statistical significance (r = 0.332, 0.320, p = 0.048, 0.057 respectively). Further analysis, shown in Table 6, indicated there was no association between measures of disease severity in the MS group (EDSS score or years since diagnosis) and dual-task decrements.

[INSERT TABLES 5 & 6 HERE]

Logistic regression was used to explore the relative ability of self-reported fatigue, performance on a cognitive screening test (ACE-R), cognitive errors (CFQ Question 9),

difference in time taken to walk 30 metres before and after experimental trials and decrement in walking speed under fixed demand dual-task conditions to predict whether a participant was from the MS group or control group. Independent variables were centred to prevent multi-collinearity. Interactions of independent variables were also included in the model. Using the forward conditional entry method a significant model emerged (X^2 (df 1) = 9.982, p = 0.002). The results are shown in Tables 6 and 7. Performance on the ACE-R, CFQ Question 9 and difference in time taken to walk 30 metres before and after experimental trials did not enter the model as they did not increase the predictive ability of the model. The odds of being from the MS group increased by 1.3 for every 1% change in walking speed from single to dual task and by 1.1 for every 1 point increase in MFIS score. The overall predictive ability of the model was 73% (Nagelkerke R^2 = 0.728).

[INSERT TABLES 7 & 8 HERE]

Discussion

Consistent with hypotheses, the main findings were that MS participants, compared to healthy controls, had greater decrements in dual-task performance; including decrements in digit task performance, walking speed and swing time variability in fixed demand dual-tasks and in walking speed in titrated demand dual-tasks. The study may have lacked power to detect similar differences with smaller effect sizes in titrated demand dual-tasks. Differences between MS and control participants in dual-tasks remained when cognitive task decrements and decrements on gait measures were combined. Effects sizes were medium to large where statistically significant differences were found.

Fatigue (both self-reported fatigue and physical fatigue from experimental trials) and performance on a cognitive screening measure (ACE-R) showed significant relationships with dual-task decrement in walking speed during fixed demand conditions. Score on CFQ Question 9 showed a significant relationship with dual-task decrement in walking speed

during titrated demand conditions and approached statistical significance in the fixed demand dual-task condition. There were no significant relationships between dual-task decrement in MS participants and measures of disease severity.

The Effect of Dual-Tasking in MS

The findings are consistent with those of D'Esposito et al. (1996), who reported differential dual-task decrements in MS participants, compared to controls, when performing two cognitive tasks simultaneously. There are several possible explanations for the current findings including; reduced working memory capacity, task demand, use of different strategies, confounding factors and a divided attention deficit.

A titrated demand condition was designed in case MS participants had lower assessed digit spans than control participants; in this event a fixed demand task would have put MS participants at a disadvantage. This was not the case however, there being no difference in assessed digit span between groups, suggesting that differential dual-task decrements in MS participants are not due to reduced working memory capacity. Thus the fixed demand condition simply represents a small increase in demand for both groups.

In some ways the finding of differential dual-task effects in MS under both demand conditions differs from that of Cocchini et al. (2004) who found that dual-task differences between people with Alzheimer's disease and healthy controls disappeared when task demand was titrated. The present study differs from Cocchini et al. in three important ways however. First, the present study presented the digits at the rate of one per second, which is less challenging than the rate of two per second that Cocchini et al. presented them at. Second, Cocchini et al. did not include digit span as the cognitive task in both demand conditions. Instead their titrated demand condition used the digit span task similar to the present study, but their fixed demand task used verbal fluency, a self-titrated task, as the cognitive task. Third, the dual-task difference between Alzheimer's participants and healthy controls, reported by Cocchini et al., in the fixed demand condition was quite small

and only evidenced when a combined decrement score was used, not with individual decrement scores.

The results of the present study are more consistent with those of Logie et al. (2004) and D'Esposito et al. (1996), suggesting that task demand is not a prime determinant of dual-task performance. Logie et al. (2004) reported that manipulating task demand did not ameliorate greater dual-task decrements in Alzheimer's patients, compared to healthy controls, suggesting a divided attention deficit rather than an overall capacity issue. D'Esposito et al. (1996) did not directly manipulate task demand but reported no difference in dual-task decrement between easy and difficult conditions. In the present study however the role of task demand remains unclear, as there was no difference in assessed digit span between patients and controls. If, as Mulder et al. (2002) suggest, walking becomes attention demanding in MS then the patient group use some of their limited working memory capacity for walking, while the control group do not. Therefore, in dual-tasking conditions working memory capacity is overloaded in MS participants but not in controls. In order to test this it would be necessary to manipulate task demand and investigate dual-tasking performance when task demand was at assessed level, below assessed level and above assessed level. If dual-tasking deficits were not a result of capacity issues one would expect to find that differential dual-tasking decrements remained across all demand conditions. The lack of association between assessed and fixed digit span difference and dual-task decrement scores in this study suggests that differential dual-task decrements in MS participants are not simply due to task demand.

The use of decrement and combined decrement scores allows comparison of MS and control dual-task strategies; for example control participants might have prioritised the walking task at the expense of the cognitive task while the patient group may have done the opposite as, has been reported in Parkinson's disease (Bloem et al., 2001). The fact that differences between MS and control participants remained when decrements in the

cognitive task were combined with decrements on gait measures suggests that differential dual-task decrements in MS participants are not due to different prioritisation of tasks.

MS and control participants differed with respect to several baseline characteristics. Of these, fatigue (both self-reported fatigue and physical fatigue from experimental trials) and general cognitive functioning were associated with dual-task decrements, suggesting that the other characteristics were not confounding dual-task decrement differences in MS and control participants. Fatigue (both self-reported fatigue and physical fatigue from experimental trials), CFQ Question 9 score, general cognitive functioning and dual-task decrement score were entered into a model to predict MS or control group membership. Self-reported fatigue and dual-task decrement score were included in the final model, suggesting that these separately contributed to MS or control group membership. This suggests that neither physical fatigue from experimental trials, CFQ Question 9 score nor general cognitive functioning alone can predict dual-task decrement. This is consistent with the findings of D'Esposito et al. (1996) who reported no association between dual-task decrement and mood or fatigue for MS or control participants.

The lack of association between measures of disease severity and duration and dual-task decrement also rule this out as an explanatory factor. D'Esposito et al. (1996) also reported no association between disease duration or EDSS score and dual-task decrement.

The results suggest that MS participants have a differential dual-task impairment; which can be partially explained by fatigue and general cognitive functioning but which is not due to reduced working memory capacity or use of different strategies. The role of task demand remains unclear, for reasons outlined, making it difficult to determine whether the dual-task impairment is due to a divided attention deficit or capacity issues. This may be less clinically important in that task demands in everyday life are not titrated to individual performance levels.

Everyday and Clinical Implications

The findings suggest that people with MS will have everyday difficulties walking and talking, with performance on both decreasing when the two tasks are attempted at once. This has implications for everyday life where we are frequently required to walk while attending to cognitive tasks simultaneously; such as having a conversation while walking, crossing a busy road, and navigating a supermarket. Decrease in walking speed may not in itself cause undue difficulty but Yogev et al. (2005) suggest increased gait variability during dual-tasking may explain some of the high fall risk in Parkinson's disease patients. Gait variability during usual walking is independently associated with fall risk in community living older adults (Hausdorff et al., 1997; Maki, 1997), Alzheimer's disease patients (Nakamura et al., 1996) and Parkinson's disease patients (Hausdorff et al., 2001, Schaafsma et al., 2003). Increased gait variability in MS patients while walking and talking may therefore increase fall risk.

Raising awareness, among both professionals and people with MS, of potential walking and talking difficulties is important so that it is taken into account in everyday activities, clinical assessment and treatment planning. The study findings suggest that assessing walking ability alone will not necessarily relate to everyday walking ability, where people may be required to attend simultaneously to other tasks. Walking under dual-tasking conditions should therefore be separately assessed. The study results also suggest a clinical challenge in assessing dual-tasking in MS. Dual-task decrements were not predicted by MS disease severity or years since diagnosis, and while general cognitive ability, fatigue and a high score on Question 9 of the CFQ are associated with dual-task decrements none of these are predictive of group membership. This suggests that dual-tasking ability needs to be independently assessed. To date no clinical measures have been developed to do this. A paradigm where performance on walking and cognitive tasks under both single and dual task conditions is compared would suffice, though from a practical perspective this may not be ideal in clinical situations.

Evans et al. (submitted) have described a rehabilitation programme that may lead to improvements in walking and talking in people with acquired brain injury. This presents the possibility of developing treatment strategies for walking and talking impairments in MS, but as with other treatments any effects may be time-limited in a degenerative neurological condition such as MS.

Limitations

The present study has several limitations. While power was sufficient to detect effect sizes that were medium to large as predicted, it was insufficient for two analyses where the effect size was smaller (small to medium) than predicted from studies with other neurological groups. In the present study the digit span task was scored by giving one point if an entire digit sequence (e.g. 5-6-1-7) was correct and zero points if any digit in the sequence was incorrect. Since an average of seven digit sequences was performed in each condition this made the scoring system less sensitive than preferable. In future studies a more sensitive scoring system might be preferable, for example giving one point for each digit in the correct place in a sequence.

Future Work

Since there are no published studies investigating walking and talking in MS the present study needs to be replicated. In addition to the comments above regarding limitations, future studies could explore the effect of manipulating task demand on dual-task decrements, in order to determine if impairments are due to capacity issues or a divided attention deficit. Finally developing a practical clinical tool for the assessment of walking and talking ability must be a priority for future work.

Conclusions

Initial hypotheses that MS participants perform differentially poorly on walking and talking dual-tasks compared to healthy controls were confirmed. It is suggested that fatigue

and general cognitive ability contribute to this. The role of task demand in dual-tasking deficits remains unclear and needs further investigation. Clinicians should independently assess dual-task walking in MS. Future studies should replicate the current findings and develop practical clinical tools to assess walking and talking ability.

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Table 1

Basic Demographics and Clinical Characteristics of Participants

	MS participants n=18	***Healthy participants n=18***	***P value***
Demographic variables			
Age (years)	**39.23 ± 8.15**	**39.25 ± 11.42**	**0.944**
Gender			
Female	**16**	**12**	
Male	**2**	**6**	**0.228**
Years of education	**15.06 ± 2.9**	**16.82 ± 1.78**	**0.051***
Clinical variables			
WTAR score (Standard score)	**105.22 ± 14.40**	**114.18 ± 8.97**	**0.043***
ACE-R score	**91.17 ± 6.49**	**96.70 ± 2.64**	**0.002***
Assessed digit span	**6.39 ± 1.19**	**6.50 ± 1.12**	**0.900**
CFQ	**53.50 (43-62)**	**35.00 (30-41)**	**0.004***
MFIS	**44.00 (42-55)**	**14.00 (6-32)**	**<0.000***
HADS			
Anxiety	**8.28 ± 3.79**	**5.65 ± 2.57**	**0.015***
Depression	**6.50 (2- 9)**	**1.50 (0-4)**	**0.001***
Number of falls in past six months	**0.83 ± 1.2**	**0 ± 0**	**0.003***
Time to walk 30 metres (after experimental trials- before experimental trials)	**1.00 (0-5)**	**1.00 (0-3)**	**0.210**
MS participants only			
EDSS score	**2.74 ± 1.59**		
Years since diagnosis	**4.00 (1-7)**		

Note. Values are mean ± standard deviation, median (95% confidence intervals) or n.* Statistically significant difference for MS versus healthy participants.

Table 2

Performance of MS and Control Participants for Each Task Alone and in Titrated and Fixed Demand Dual-Task Conditions

Task	*Participant Type*	*Digit Task (% correct)*	*Walking Speed (cm/second)*	*Swing Time Variability (%)*	*Double Limb Support Time Variability (%)*
D^{A-T}	**MS**	**64.89 ± 22.78**			
	Healthy controls	**70.78 ± 19.56**			
D^{A-F}	**MS**	**46.11 ± 29.14**			
	Healthy controls	**61.22 ± 20.91**			
W^{A}	**MS**		**108.76 ± 15.75**	**3.03 (2.40 to 3.65)**	**5.65 (3.90 to 6.45)**
	Healthy controls		**139.57 ± 19.47**	**3.40 (2.75 to 4.55)**	**7.78 (5.65 to 9.90)**
W^{+T}	**MS**	**50.50 ± 27.94**	**99.57 ± 16.10**	**3.93 (3.05 to 4.60)**	**5.55 (3.20 to 10.00)**
	Healthy controls	**67.94 ± 23.03**	**136.72 ±19.63**	**3.23 (2.70 to 3.70)**	**7.38 (5.45 to 9.70)**
W^{+F}	**MS**	**29.28 ± 26.57**	**97.35 ± 16.98**	**4.00 (2.75 to 6.35)**	**6.45 (4.25 to 9.20)**
	Healthy controls	**62.78 ± 27.32**	**135.74 ± 19.28**	**3.00 (2.30 to 3.60)**	**6.93 (6.30 to 8.45)**

Note. **Values for digit task and speed are mean ± standard deviation, values for swing time and double support time variability are median (95% confidence intervals). Abbreviations: D^{A-T}, digit task alone-titrated demand; D^{A-F}, digit task alone-fixed demand; W^{A}, walking alone; W^{+T}, walking with titrated demand digit task; W^{+F}, walking with fixed demand digit task.**

Table 3

Percentage Change in Performance from Single to Dual-Task for Titrated and Fixed Task Demand.

Note For digit task and speed positive signs indicate a decrease in performance from single to dual task, whilst for swing time and double support time variability negative signs indicate a decrease in performance from single to dual task (i.e. an increase in variability).

Task	*Participant Type*	*Digit Task*	*Walking Speed*	*Swing Time Variability*	*Double Limb Support Time Variability*
W^{+T}	**MS**	**14.39 ± 22.44**	**8.62 ± 6.67**	**-29.51 (-57.58 to 06.02)**	**1.25 (-46.47 to 20.00)**
	Healthy controls	**2.83 ± 21.89**	**1.57 ± 3.55**	**-4.46 (-13.00 to 32.29)**	**2.85 (-25.83 to 32.86)**
P value		**0.127**	**0.001***	**0.068**	**0.521**
Effect size (r)		**0.26**	**0.61**	**0.31**	**0.11**
W^{+F}	**MS**	**16.83 ± 27.95**	**10.72 ± 6.65**	**-18.94 (-100.00 to 25.00)**	**-6.07 (-64.29 to 9.66)**
	Healthy controls	**-1.56 ± 21.32**	**2.12 ± 4.83**	**7.36 (-23.77 to 35.09)**	**1.85 (-25.45 to 33.84)**
P value		**0.033***	**<0.000***	**0.037***	**0.239**
Effect size (r)		**0.36**	**0.61**	**0.35**	**0.20**

Note. Values for digit task and speed are mean ± standard deviation, values for swing time and double support time variability are median (95% confidence intervals). Abbreviations: W^{+T}, walking with titrated demand digit task; W^{+F}, walking with fixed demand digit task. * Statistically significant difference for MS

Table 4

Combined Percentage Change in Performance from Single to Dual Task for Titrated and Fixed Demands for Cognitive Task Change and Each Gait Variable

Note. Positive signs indicate a decrease in performance from single to dual task for all variables.

Task	*Participant Type*	*Walking Speed*	*Swing Time Variability*	*Double Limb Support Time Variability*
W^{+T}	**MS**	**11.50 ± 11.29**	**22.89 (05.09 to 44.06)**	**15.73 (-8.21 to 40.26)**
	Healthy controls	**2.41 ± 11.27**	**3.24 (-15.01 to 20.45)**	**2.97 (-10.93 to 18.91)**
P value		**0.021***	**0.044***	**0.171**
Effect size (r)		**0.38**	**0.34**	**0.23**
W^{+F}	**MS**	**13.80 ± 13.99**	**19.91 (02.63 to 65.73)**	**20.45 (-2.13 to 39.82)**
	Healthy controls	**-0.51 ± 10.03**	**-9.31 (-16.50 to 13.93)**	**0.75 (-19.84 to 13.10)**
P value		**0.002***	**0.010***	**0.051***
Effect size (r)		**0.49**	**0.43**	**0.33**

*Note.*Values for speed are mean ± standard deviation, values for swing time and double support time variability are median (95% confidence intervals). Abbreviations: W^{+T}, walking with titrated demand digit task; W^{+F}, walking with fixed demand digit task. * Statistically significant difference for MS versus healthy participants.

Table 5

Correlation Between CFQ, MFIS, HADS-A, HADS-D, ACER, WTAR, Education and Decrement Scores

	CFQ	***CFQ Question 9^***	***MFIS***	***HADS-A***	***HADS-D***	***ACE-R***	***WTAR***	***Education***
Digit task								
W^{+T}	**0.119**	**-0.028**	**0.120**	**0.150**	**0.181**	**-0.147**	**0.052**	**-0.090**
P value	**0.490**	**0.872**	**0.162**	**0.386**	**0.289**	**0.393**	**0.768**	**0.603**
W^{+F}	**0.150**	**-0.068**	**0.238**	**0.109**	**0.310**	**-0.045**	**-0.035**	**-0.120**
P value	**0.382**	**0.692**	**0.486**	**0.546**	**0.066**	**0.793**	**0.841**	**0.485**
Walking speed								
W^{+T}	**0.167**	**0.332**	**0.209**	**0.228**	**0.173**	**-0.187**	**-0.130**	**-0.032**
P value	**0.332**	**0.048***	**0.222**	**0.182**	**0.313**	**0.274**	**0.458**	**0.852**
W^{+F}	**0.200**	**0.320**	**0.387**	**0.194**	**0.136**	**-0.385**	**-0.233**	**-0.314**
P value	**0.243**	**0.057**	**0.020***	**0.256**	**0.427**	**0.020***	**0.179**	**0.062**

Note. Values are Pearson's r. ^ CFQ Question 9 'Do you fail to hear people speaking to you when you are doing something else?' Abbreviations: W^{+T}, walking with titrated demand digit task; W^{+F}, walking with fixed demand digit task. * Statistically significant correlation.

Table 6

Correlation Between Measures of Disease Severity in MS Participants and Decrement Scores

	Digit task W^{+T}	***Digit task*** W^{+F}	***Walking speed*** W^{+T}	***Walking*** W^{+F}
EDSS score	**0.278**	**-0.002**	**0.069**	**-0.296**
P value	**0.280**	**0.993**	**0.791**	**0.248**
Years since diagnosis	**0.240**	**-0.207**	**0.008**	**-0.069**
P value	**0.337**	**0.410**	**0.974**	**0.785**

Note. Values are Pearson's r. Abbreviations: W^{+T}, walking with titrated demand digit task; W^{+F}, walking with fixed demand digit task

Table 7

Logistic Regression Analysis for Pooled Data from MS and Control Participants

Predictor	*B*	*S.E. B*	*Wald's* X^2	*df*	*P value*	e^B *(odds ratio)*	*95% C.I. for* e^B
W^{+F} Decrement in walking speed	**0.263**	**0.106**	**6.220**	**1**	**0.013**	**1.301**	**1.058 to 1.600**
MFIS score	**0.096**	**0.036**	**7.312**	**1**	**0.007**	**1.101**	**1.027 to 1.180**
Constant	**0.217**	**0.570**	**0.146**	**1**	**0.703**	**1.243**	**NA**

Test	X^2	*df*	*P value*
Overall model evaluation			
Omnibus tests of model coefficients	**9.982**	**1**	**0.002**
Goodness of fit test			
Homer & Lemeshow	**2.730**	**7**	**0.909**

Note. Cox and Snell $R^2 = 0.546$. Nagelkerke $R^2 = 0.728$. Abbreviations: NA, not applicable.

Table 8

The Observed and the Predicted Frequencies for MS Group or Control Group by Logistic Regression

		Predicted		*Percentage correct*
Observed	***MS group***		***Control group***	
MS group	**15**		**3**	**83.3**
Control group	**2**		**16**	**88.9**
Total	**18**		**17**	**86.1**

Figure Captions

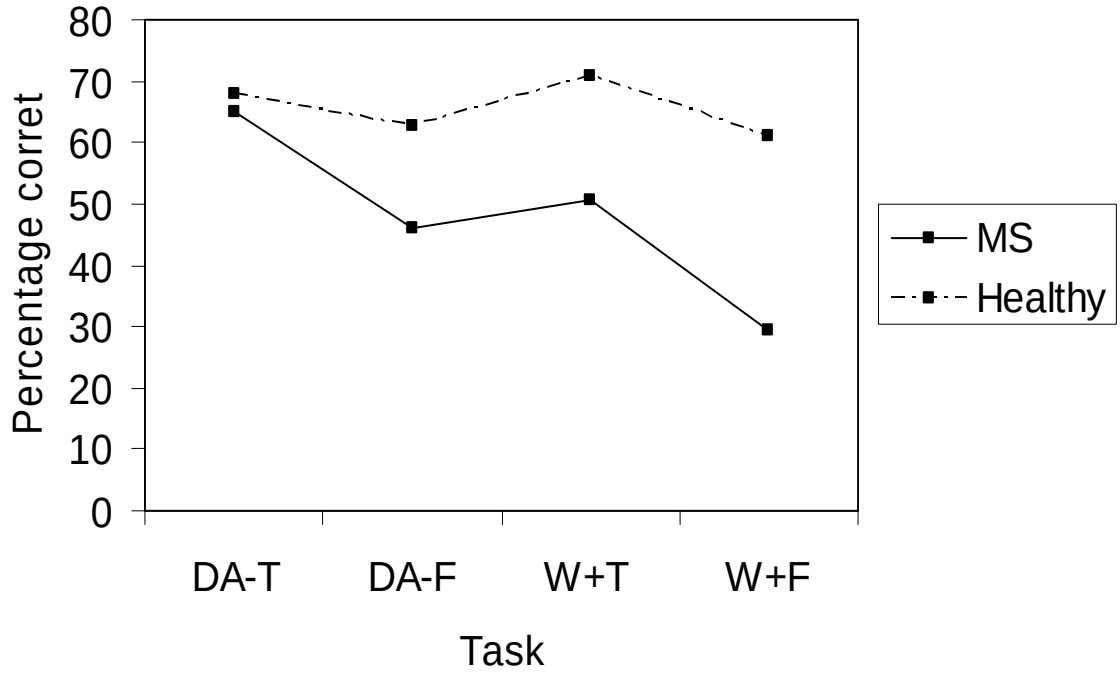
Figure 1. Performance of MS and control participants on (A) digit task % correct (B) walking speed (C) swing time variability and (D) double support time variability in single task conditions and titrated and fixed demand dual-task conditions.

Figure 2. The mean percentage change ± SD in (A) digit task and (B) walking speed for MS and control participants for single task minus dual-task performance in both titrated and fixed demand conditions. *Note.* Positive signs indicate a decrease in performance from single to dual task i.e. fewer digit task correct or slower speed in dual-tasks compared to single tasks.

Figure 3. The median percentage change ± 95% CI in (A) swing time variability and (B) double support time variability for MS and control participants for single task minus dual-task performance in both titrated demand and fixed demand conditions. *Note.* Negative signs indicate a decrease in performance from single to dual-task i.e. greater variability in dual-tasks compared to single tasks.

Figure 1 (A & B)

A Digit tasks (% correct)



B Walking speed

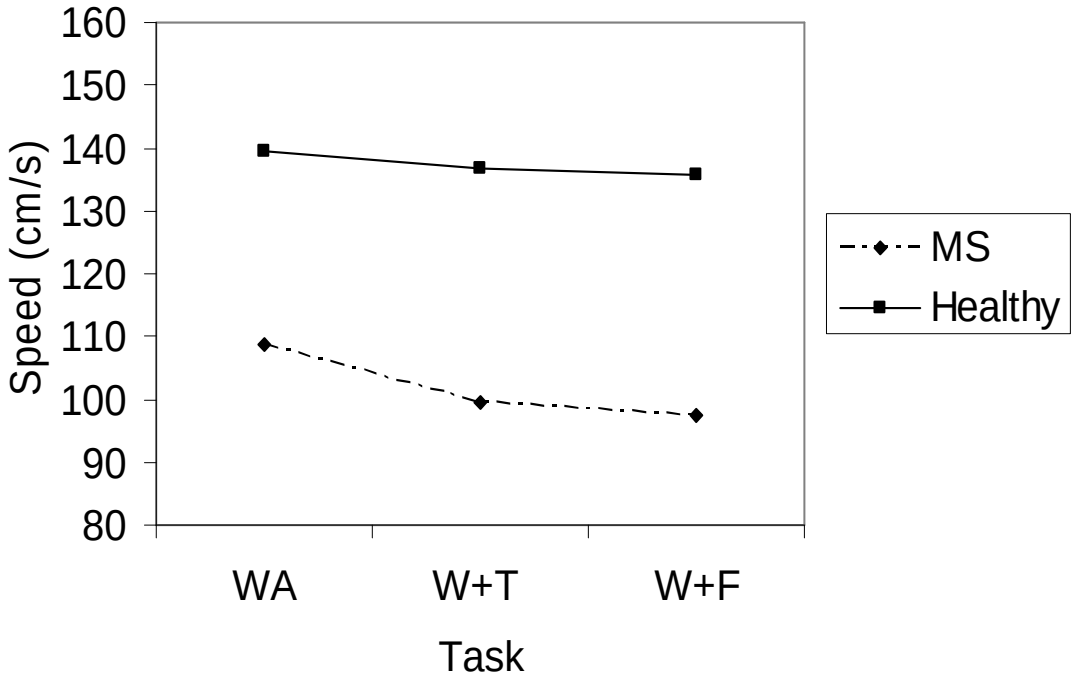
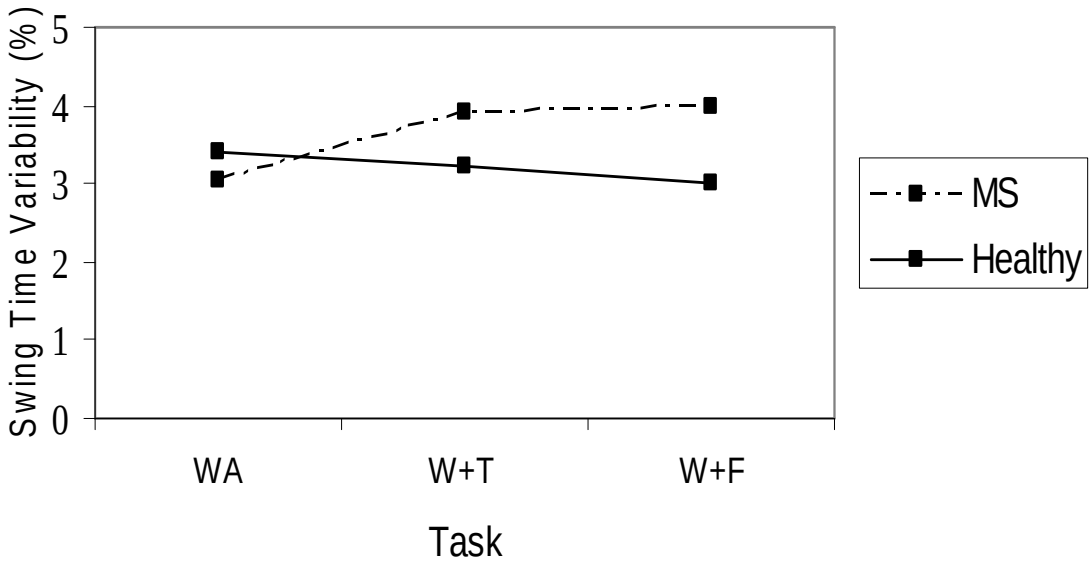
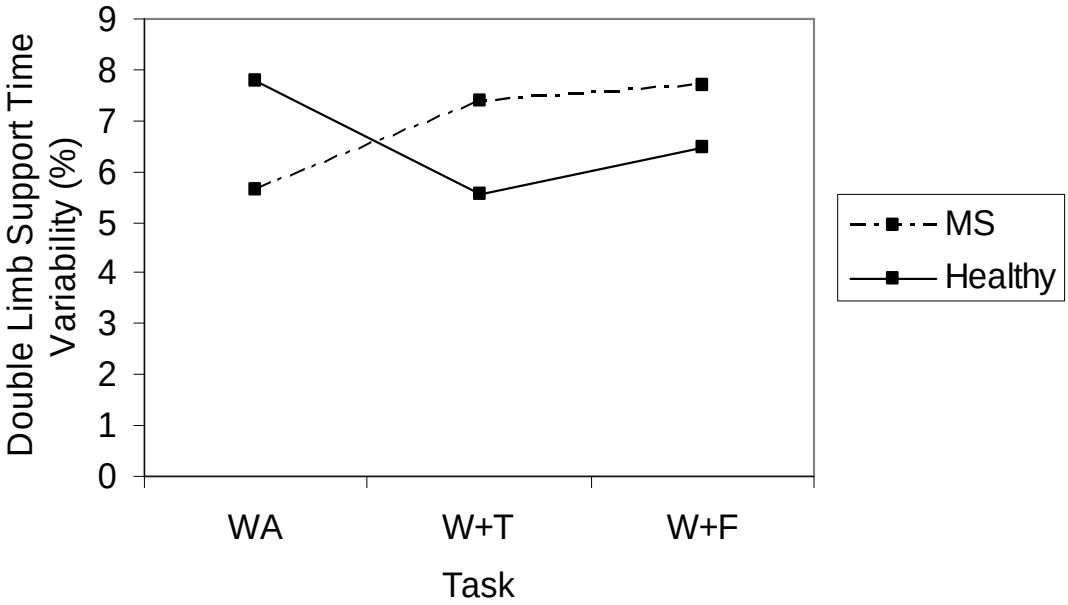


Figure 1 (C & D)

C Swing time variability



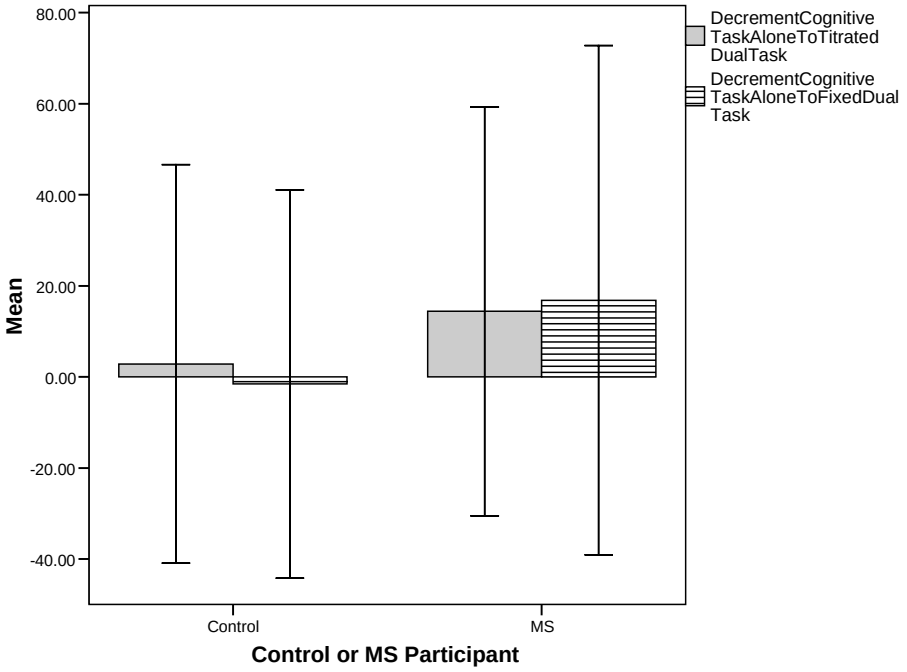
D Double support time variability



Abbreviations. D^{A-T} , digit task alone-titrated demand; D^{A-F}, digit task alone – fixed demand; W^{A}, walking alone; W^{+T}, walking with titrated demand digit task; W^{+F}, walking with fixed demand digit task.

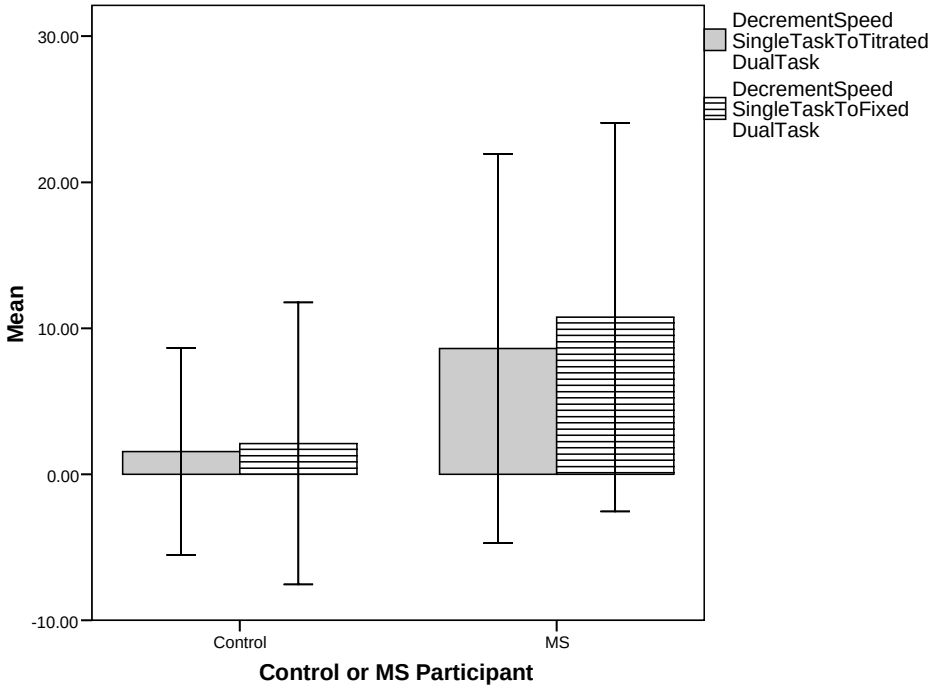
Figure 2

A Digit task



Error Bars: +/- 2 SD

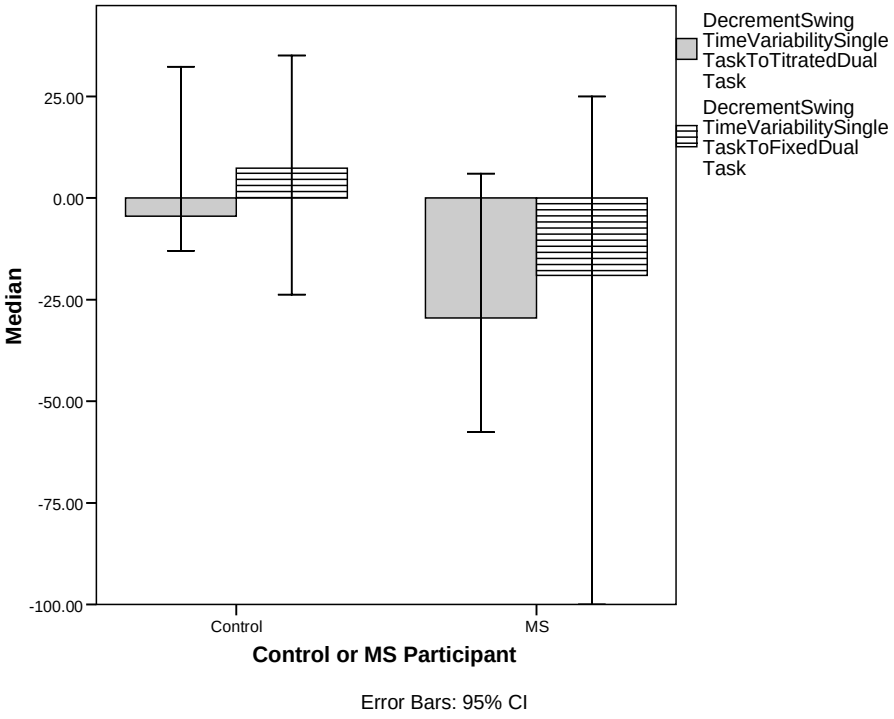
B Walking speed



Error Bars: +/- 2 SD

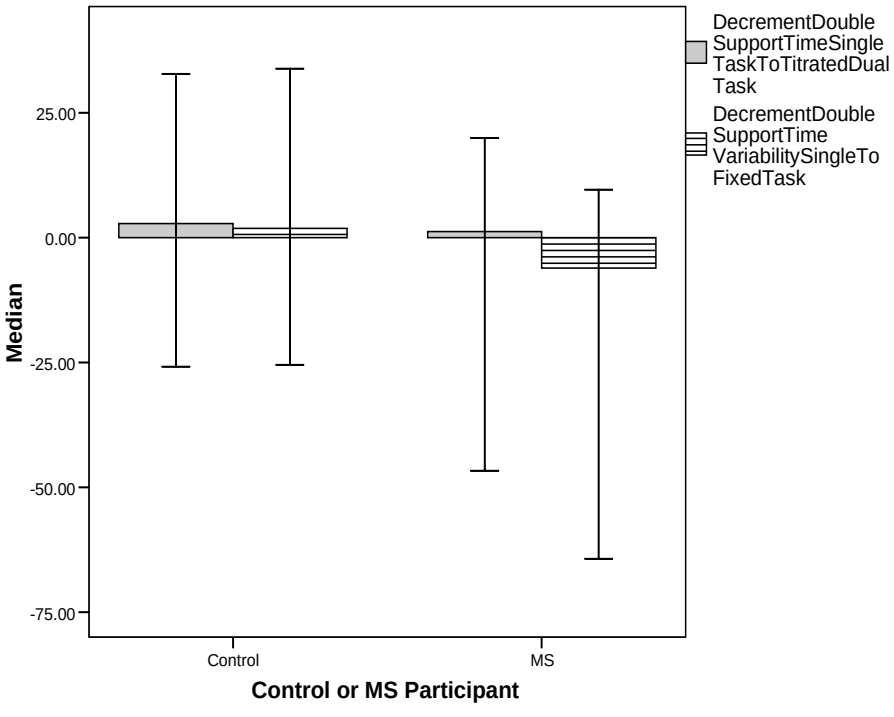
Figure 3

A Swing time variability



Error Bars: 95% CI

B Double support time variability



Error Bars: 95% CI

CHAPTER THREE

ADVANCED PRACTICE I REFLECTIVE CRITICAL ACCOUNT

Advanced Practice I Reflective Critical Account:

Learning to Make Decisions in Complex Clinical Situations

ABSTRACT

Decision-making in complex situations where there is an absence of all the information is a key competency in doctoral training. Yet decision making in these circumstances can be extremely complex. This reflective account describes the process of learning to make these decisions in a third year specialist neuropsychology placement. The account describes relevant learning experiences, my changing thoughts and feelings about my practice through the course of the placement, and the influences on my practice, thoughts and feelings. The subsequent reflective review dissects this learning process and relates it to relevant literature. The skills I developed through learning to make these judgments are related to National Occupational Standards for Psychologists. The key learning points relate to evaluating evidence, the assessment process, awareness of the limit's of evidence and of my own competence, and managing the emotional impact of decision-making. The utility of reflective practice is discussed.

CHAPTER FOUR

ADVANCED PRACTICE II REFLECTIVE CRITICAL ACCOUNT

Advanced Practice II Reflective Critical Account:

Working Psychologically in Teams

ABSTRACT

Working with teams and developing team effectiveness are increasingly important parts of psychologists' roles. In my current placement I am working in two mental health teams with very different team approaches and this has presented many learning opportunities. I have therefore chosen to write this reflective account about 'working psychologically with teams'. Kolb's Theory of Experiential Learning is used to reflect on key learning experiences. Key learning points were about the process of becoming a team member, working psychologically with teams at several different levels, formulating team dynamics and thinking about the management of psychological services at systems level. The lessons I learned and the skills I developed are in line with National Occupational Standards for Psychology which describe the provision of psychological systems, services and resources as a key competency for psychologists. I discuss how I hope to use these skills and develop them further as a qualified clinical psychologist.

APPENDICES

APPENDIX A

Journal Author Guidelines

Appendix A1: Author Guidelines for Journal of International Neuropsychological Society

Instructions for Contributors

Manuscript Submission and Review

The *Journal of the International Neuropsychological Society* uses online submission and peer review. Authors who are not able to submit their manuscripts online are asked to contact the editorial office at: jins@unm.edu. The website address for submissions is: http:00mc.manuscriptcentral.com0cup0jins, and complete instructions are provided on the website. Prior to online submission, please consult http:00www.ncbi.nlm.nih.gov0entrez0query.fcgi?db5mesh for 6 keywords or mesh terms that are different from words in the title. Accurate mesh terms will increase the probability that your manuscript will be identified in online searches. Please follow the instructions carefully to avoid delays. The menu will prompt the author to provide all necessary information, including the manuscript category, the corresponding author including phone number, fax number and e-mail address, and suggested reviewers. The website will automatically acknowledge receipt of the manuscript and provide a manuscript reference number. The Editor-in-Chief will assign the manuscript for review to an Associate or Department Editor and at least two other reviewers. Every effort will be made to provide the author with a review within 6 to10 weeks of manuscript assignment. *Rapid Communications* will be reviewed within 6 weeks. If the Editor requests that revisions be made to a manuscript before publication, a maximum of 3 months will be allowed for preparation of the revision, except in unusual circumstances.

Manuscript Length

In order to increase the number of manuscripts that can be published in the *JINS*, please adhere to the following length requirements. Please provide a word count on the title page

for abstract and for manuscript (not including abstract, tables, figures, or references). Manuscripts will be returned if they exceed length requirements.

Regular Research Articles: Maximum of 5,000 words (not including tables, figures, or references) and a 200 word abstract.

Critical Reviews: Maximum of 5,000 words (not including abstract, tables, figures, or references) and a 200 word abstract. ***Critical Reviews*** **must be pre-approved by the Department Editor. Please e-mail your abstract to jins@unm.edu in order to receive prior approval.**

Manuscript Preparation and Style

The entire manuscript should be typed double-spaced throughout using any word processing program. Unless otherwise specified, the guideline for preparation of manuscripts is the *Publication Manual of the American Psychological Association* (5th edition) except for references with 3 or more authors (see References section). This may be ordered from: APA Order Dept., 750 1st St. NE, Washington, DC 20002-4242, USA. Pages should be numbered sequentially beginning with the Title Page. The Title Page should contain the full title of the manuscript, the full names and affiliations of all authors, a contact address with telephone and fax numbers and e-mail address, and the word count for abstract and for manuscript (excluding title page, abstract, references, tables, and figures). At the top right provide a short title of up to 45 characters preceded by the lead author's last name. Example: Smith-Memory in Parkinson's Disease. This running headline should be repeated at the top right of every following page. The Abstract and Mesh terms (Keywords) on *page 2* should include a brief statement of the problem, the method, the key findings, and the conclusions. Six mesh or key words should be provided (see http:00www.ncbi.nlm.nih.gov0 entrez0query.fcgi?db5mesh for list), and they should not duplicate words in the title. The full text of the manuscript should begin on *page 3.* For scientific articles, including *Regular Research Articles, Brief Communications, Rapid*

Communications, and *Symposia*, the format should include an Abstract, Introduction, Method, Results, and Discussion. This should be followed by References, Appendixes, Acknowledgments, Tables, Figures, and Figure Legends. The use of abbreviations, except those that are widely used, is strongly discouraged. They should be used only if they contribute to better comprehension of the manuscript. Acronyms should be spelled out at first mention. Metric system (SI) units should be used.

Figures

High quality digital images (600 dpi or higher) should be provided in PDF, EPS, or TIFF formats. If a digital image is not available, please scan in the image. Figures should be numbered consecutively as they appear in the text. Any indication of features of special interest should also be included. Figures should be drawn or composed on computer to about twice their intended final size and authors should do their best to construct figures with notation and data points of sufficient size to permit legible photo reduction to one column of a two-column format. As a guide, no character should be smaller than 1 mm wide following reduction. Tables and figures should be numbered in Arabic numerals. The approximate position of each table and figure should be provided in the manuscript: [INSERT TABLE 1 HERE]. Tables and figures should be on separate pages. Tables should have short titles and all figure legends should be on separate pages. Color figures can be accepted. All color graphics must be formatted in CMYK and not in RGB, because 4-color separations cannot be done in RGB. However, the extra cost of printing these figures must be paid by the author, and the cost typically ranges from $700 to $1500 per figure.

References

References should be in American Psychological Association, 5th Edition, style (see the examples presented below). Text references should be cited as follows: “. . . Given the

critical role of the prefrontal cortex (PFC) in working memory (Cohen et al., 1997; Goldman-Rakic, 1987; Perlstein et al., 2003a) . . .” with multiple references in alphabetical order. Another example is: “For example, Cohen et al. (1994, 1997), Braver et al. (1997), and Jonides and Smith (1997) demonstrated . . .” If multiple works by Perlstein et al. (1977) are cited, use a, b, c, in the order these appear in the text, even if the subsequent authors are different. References cited in the text with three or more authors should state et al. (e.g., Smith et al.) even at first mention (**this deviates from the APA 5th Edition style**). However, in the reference section all authors should be listed. Reference entries should be alphabetically listed in the reference section with all authors being cited.

APPENDIX B

Systematic Literature Review

Appendix B1: Table Showing Scores of Each Study on Each Quality Criterion

Criterion / Study	**PARTICIPANTS**	Cases & non-cases defined	Controls are non-cases	Exclusion criteria defined	Exclusion criteria same for cases & controls	Disease state reliably assessed	Cases & controls from similar populations	% cases & controls that participated reported	Participants and non-participants compared	**CONFOUNDING FACTORS**	Confounders identified & taken into account	**STUDY DESIGN**	Appropriate measures	**STUDY DESCRIPTION**	Data collection settings & location described	How sample size determined outlined & sufficient power	Objectives & hypotheses outlined	How & when intervention administered described	Outcome measures described	**RESULTS**	Demographic & clinical characteristics of groups described	No. in each analysis described	Appropriate statistical analyses	Multiplicity of analyses addressed	**TOTAL SCORE**
Camicioli 1997		2	2	1	0	2	2	0	0		1		2		0	1	2	2	2		2	1	2	1	25
Cocchini 2004a		2	2	1	0	2	2	0	0		1		2		0	1	1	2	2		2	1	2	2	25
Cocchini 2004b		2	2	1	0	2	2	0	0		1		2		0	1	1	2	2		2	1	2	2	25
Petterson 2005		2	2	0	0	2	2	0	0		1		1		2	1	1	2	1		1	1	2	2	23
Petterson 2007		2	2	2	2	2	0	1	0		1		1		2	1	1	2	2		1	1	2	2	27
Cantena 2007		2	2	2	2	2	2	0	0		1		2		1	0	1	2	2		2	1	2	2	28
Haggard 2000		1	1	2	0	0	0	0	0		1		2		2	1	1	2	2		1	2	2	0	20

Criterion	Parker 2005	Vallee 2006	Camicioli 1998	Campbell 2003	Galletly 2005	OShea 2002	Rochester 2004	Yogev 2005	Hyndman 2006
Study									
PARTICIPANTS									
Cases & non-cases defined	2	2	2	1	1	2	2	2	1
Controls are non-cases	2	2	2	1	1	2	2	2	1
Exclusion criteria defined	1	2	0	2	1	2	2	2	2
Exclusion criteria same for cases & controls	0	0	0	2	0	2	2	2	0
Disease state reliably assessed	2	2	2	2	1	2	2	2	0
Cases & controls from similar populations	2	1	2	2	2	2	0	0	1
% cases & controls that participated reported	0	0	0	0	0	1	0	0	1
Participants and non-participants compared	0	0	0	0	0	0	0	0	0
CONFOUNDING FACTORS									
Confounders identified & taken into account	1	1	1	1	2	1	2	1	1
STUDY DESIGN									
Appropriate measures	1	2	1	1	2	2	1	2	2
STUDY DESCRIPTION									
Data collection settings & location described	0	0	2	0	0	2	2	1	0
How sample size determined outlined & sufficient power	1	1	1	1	1	1	1	2	1
Objectives & hypotheses outlined	2	2	1	2	2	1	2	1	2
How & when intervention administered described	2	2	2	2	2	2	2	2	2
Outcome measures described	2	2	2	2	2	2	2	2	2
RESULTS									
Demographic & clinical characteristics of groups described	1	1	1	1	1	1	2	2	1
No. in each analysis described	1	1	1	1	1	1	1	1	1
Appropriate statistical analyses	2	2	2	2	2	2	2	2	2
Multiplicity of analyses addressed	0	1	0	0	0	2	2	2	0
TOTAL SCORE	22	25	22	23	21	30	29	28	21

Criterion Study	**PARTICIPANTS**	Cases & non-cases defined	Controls are non-cases	Exclusion criteria defined	Exclusion criteria same for cases & controls	Disease state reliably assessed	Cases & controls from similar populations	% cases & controls that participated reported	Participants and non-participants compared	**CONFOUNDING FACTORS**	Confounders identified & taken into account	**STUDY DESIGN**	Appropriate measures	**STUDY DESCRIPTION**	Data collection settings & location described	How sample size determined outlined & sufficient power	Objectives & hypotheses outlined	How & when intervention administered described	Outcome measures described	**RESULTS**	Demographic & clinical characteristics of groups described	No. in each analysis described	Appropriate statistical analyses	Multiplicity of analyses addressed	**TOTAL SCORE**
Kemper 2006		2	2	2	0	1	0	0	0		1		2		1	1	2	2	2		2	1	2	0	23

Note. 2= Full Score, 1=Partial Score 0=Not present or not reported.

APPENDIX C

Major Research Project

Appendix C1: Major Research Project Proposal

MAJOR RESEARCH PROJECT PROPOSAL

Title: Cognitive Motor Dual-Tasking in Multiple Sclerosis

Researcher:

Fiona Hamilton, Doctorate in Clinical Psychology Programme, Department of Psychological Medicine, University of Glasgow

Research Supervisor:

Professor Jon Evans, Department of Psychological Medicine, University of Glasgow

Collaborators:

Dr. Colin O'Leary & MS Team, Institute of Neurological Sciences, Southern General Hospital, Glasgow

Professor Lynn Rochester, HealthQWest, School of Nursing Midwifery and Community Health, Glasgow Caledonian University

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ABSTRACT

Background: Up to 50% of individuals with MS experience some level of cognitive impairment and this can contribute to the disability experienced in everyday life. One cognitive domain frequently thought to be impaired in MS is attention, in particular divided attention. The present study seeks to investigate divided attention in people with MS using a dual-task paradigm.

Aims: The aim of the study is to investigate dual-tasking, doing two things at once, in MS, specifically 'walking while talking'. It is hoped that the findings will add to the understanding of divided attention in MS as well as to the general understanding of cognition-motor relationships.

Methods: Both MS participants and controls will perform cognitive tasks and motor tasks under both single and dual task conditions. It is hypothesised that walking will be differentially impaired while performing concurrent cognitive tasks in MS participants compared to controls.

Applications: Since impairment of both attention and mobility appear to effect a significant number of people with MS an investigation of cognitive–motor interference may have practical implications for assessment and rehabilitation in MS, as well as adding to the general understanding of divided attention in the brain.

INTRODUCTION

Multiple Sclerosis (MS) is the most common neurological disease affecting young and middle aged adults (Arnett, 2003). The impairments arising from MS can lead to significant disability. MS is estimated to cost in the region of 1.4 billion GBP per annum in the UK (Kobelt et al., 2000), compared with an estimated 7 billion per annum for stroke (National Audit Office, 2005), which has a prevalence of 700 per 100, 000 (NICE, 2004).

Physical impairments in MS include impairment to sensory and motor systems, with problems with fatigue and mobility common. Cognitive impairment is thought to affect about 50% of people with MS (NICE, 2004). The most frequently impaired cognitive domains in MS are memory, mental flexibility, visuo-construction, information processing speed and attention (Calabrese, 2006).

When surveyed 22-25% of people with MS report impairment of attention (Sullivan, Edgley & Dehoux, 1990 & Arnett, 2003), though there appear to be only a few studies investigating attention in MS (Calabrese, 2006). In a recent review of neuropsychological impairment in MS, Calabrese (2006) concluded that impairment of attention appears to occur early in the disease course and may be one reason for subsequent dysfunction in memory and abstract reasoning. McCarthy et al. (2005) investigated the performance of MS and control participants on measures of divided and sustained attention. The results suggested that MS participants were slower and less accurate on both measures of attention compared to controls and that divided attention was more impaired than sustained attention. D'Esposito et al. (1996) used a dual-task paradigm with people with MS, asking participants to perform two cognitive tasks simultaneously in the dual-task condition. They found that the MS participant's had greater decrement in performance in the dual-task compared to healthy controls, suggesting a differential impairment in divided attention.

Dual-tasking refers to the ability to do two things at once. Investigations using a dual-task paradigm further our understanding of both the organisation of cognitive resources in the brain (Della Sala & Logie, 2001) and the effect of neurological conditions such as Alzheimer's disease, stroke, brain injury and Parkinson's disease on divided attention. This understanding is important because if one's ability to do two things at once is impaired then this has implications for people's ability to function in everyday life where one is frequently required to attend to more than one thing at any one time.

The control of posture and gait has traditionally been considered automatic or reflex controlled, requiring minimal attentional resources (Woollacott & Shumway-Cook, 2002). A recent review suggests that control of walking can be attentionally demanding (Woollacott & Shumway-Cook, 2002). In healthy young adults this dual-task effect appears to be small and is detectable only when quite complex additional secondary tasks are performed, while in healthy older adults performing a dual-task appears to have a more deleterious effect.

Recent studies have investigated the effect of performing concurrent cognitive tasks on walking in adults with various neurological conditions. Studies of people with Alzheimer's (Cocchini et al., 2004) and Parkinson's disease (Yogev et al., 2005) have suggested that speed and accuracy in walking is affected by simultaneously performing a cognitive task. The research suggests that in these neurological conditions performing concurrent tasks has a disproportionate effect on walking, compared to healthy controls (Woollacott & Shumway-Cook, 2002).

One possible reason why a concurrent cognitive task may impact on walking is that performing two tasks simply reflects an increase in task demand and once this demand exceeds attentional capacity a decrement in performance on one of the tasks occurs. In

neurological conditions one might expect that this attentional capacity is reduced making it more likely that a dual-task performance decrement will occur. An alternative explanation is that that performing two tasks makes demands on divided attention and that in these neurological conditions there is damage to some executive co-ordination function required to divide attention between concurrent demands (Logie et al., 2004). It has been argued (e.g. Cocchini et al., 2004 & Logie et al., 2004) that in studying dual-tasking it is important to control for this task demand effect when comparing a patient group with a healthy control group. In order to determine whether dual-tasking difficulties are specifically caused by a divided attention/dual-tasking process impairment they suggest that it is necessary to titrate tasks according to performance under single task conditions. This has the advantage of making it clearer whether a divided attention deficit is responsible for difficulties under dual-tasking conditions, though may be less clinically relevant to the extent that everyday conditions are not titrated to individual performance levels.

Regardless of the reason for dual-tasking difficulties there are implications for everyday life. It has been suggested that difficulty doing two things at once may explain the high risk of falls in Alzheimer's disease (Cocchini et al., 2004) and may have implications for the assessment and rehabilitation of walking in physiotherapy settings in a brain injured population (Haggard et al., 2000). The present study seeks to investigate the effects of performing a simultaneous cognitive task when walking in MS. This has not previously been investigated in a MS population but the procedures have been widely used with other neurological populations. Since impairment of both attention and mobility appear to affect a significant number of people with MS an investigation of cognitive–motor interference may have practical implications for assessment and rehabilitation in MS, as well as adding to the understanding of divided attention in MS. In order to determine whether dual-tasking difficulties are specifically caused by a divided attention/dual-tasking process impairment both a fixed and a titrated demand task will be used.

AIMS AND HYPOTHESES

Aims

- To investigate whether cognitive-motor dual-tasking is impaired in MS
- To investigate whether any cognitive-motor dual-tasking impairment in MS is a result of increased task demand or whether it is a divided attention impairment
- To add to the understanding of cognition-gait relationships

Hypotheses

It is expected that MS participants will perform differentially poorly on dual-tasks compared to controls. Specifically it is hypothesised that walking and an additional cognitive task will be disproportionately impaired in dual-task conditions compared to single task conditions (in MS participants compared to controls).

PLAN OF INVESTIGATION

Participants

Participants will be individuals with MS and, consistent with previous studies of dual-tasking in neurological conditions, a control group of healthy individuals. The purpose of the control group is to compare the effect of dual-task conditions on walking in those with and without MS. Previous studies, as mentioned above, have found that the performance of healthy controls decreases under dual-task conditions, but that this performance decrement is significantly smaller than that found in the various neurological conditions studied. Inclusion of a control group allows one to evaluate any dual-task decrement in MS participant's performance in light of the performance of healthy controls, making it possible to consider what dual-task decrement is normal and what may be attributed to MS.

A control group of individuals with orthopaedic conditions was considered, as this would allow one to control for musclo-skeletal contributions to dual-task performance

decrements. This consideration was discounted however. First obtaining an orthopaedic control group would present practical difficulties in the timeframe available. In addition it would be difficult to ascertain what was an appropriate orthopaedic control, for example how the level of physical impairment in the MS group (which in this study would be mild due to the inclusion criteria) could be matched to levels of impairment in an orthopaedic group. Second since there is very little previous dual-task research with MS it was thought preferable to first compare MS participants with healthy participants to establish whether MS participants dual-task performance decrement is greater than that of healthy controls. The key issue is a clinical one, i.e. whether dual-tasking is a difficulty in an MS population compared to a healthy one, regardless of the contribution of physical and cognitive factors to this. As the first study to investigate cognitive-motor dual-tasking in an MS population, it was considered preferable to first establish whether there is a cognitive-motor dual-tasking problem in this population.

Inclusion & Exclusion Criteria

MS participants will be included if they meet the following criteria; a diagnosis of relapsing-remitting sub-type of MS and an Expanded Disability Status Scale (EDSS) score (Kurtzke, 1983) up to 5.5. Relapsing-remitting MS refers to clearly defined disease relapses with full recovery or with sequelae and residual deficit upon recovery; periods between relapses are characterised by a lack of disease progression (NICE, 2004). An EDSS score up to 5.5 includes individuals with mild and moderate MS. It indicates minimal or moderate impairment in up to 4 functional systems and an ability to walk at least 100 meters unaided. A Consultant Neurologist will assess patients using the EDSS and confirm their ability to do the physical demands of the task.

Healthy controls will be matched for age and pre-morbid ability as described below. Individuals, either MS participants or healthy controls, with major psychiatric disorder will

be excluded otherwise anxiety and depression will be screened for (see under 'Measures' below). Individuals with a history of brain injury or neurological disease (other than MS) will be excluded. Individuals with a history of falls in the past month will be excluded.

Recruitment Procedures

Recruitment of MS participants will be undertaken in conjunction with Dr. Colin O'Leary, Consultant Neurologist at the Neurology Department in the Southern General Hospital (SGH), Glasgow. Potential MS participants will be identified by the neurologist in outpatient appointments and provided with an information pack about the study. After two weeks a Research Nurse unconnected with the study will contact those provided with information packs to determine if they wish to take part. Individuals who wish to take part will then be contacted by the researcher, Fiona Hamilton. Controls will be recruited by including requests for suitable controls in information packs to MS participants. It is anticipated that controls will therefore be relatives and friends of MS participants.

Measures

The screening measures described below will be used. The purpose of these measures is to ensure participants meet the inclusion criteria (EDSS), to adequately describe the population being studied, to match participants and controls (WTAR) and to identify any association between self-reported attentional difficulties (CFQ) and dual-task performance and self-reported fatigue (MFIS) and dual-task performance in the current study.

Pre-morbid ability:	Weschler Test of Adult Reading (WTAR) (Weschler, 2001).
General cognition:	Addenbrooke's Cognitive Examination (ACE) (Mathuranath, 2000).
Vision :	The Cortical Vision Screening Test (CVST) (James,

	Plant & Warrington, 2001).
Anxiety & depression:	Hospital Anxiety and Depression Scale (HADS) (Zigmund & Snaith, 1983).
Fatigue	Modified Fatigue Impact Scale (MFIS) (Multiple Sclerosis Council for Clinical Practice Guidelines, 1998)
Self-rated attention:	Cognitive Failures Questionnaire (CFQ) (Broadbent, 1982).
Disease severity:	Kurtzke Expanded Disability Status Score (EDSS) (Kurtzke, 1983) and Multiple Sclerosis Functional Composite Scale (Cutter et al.., 1999). These will be completed by the neurologist.
Demographic information:	Age, gender, history of brain injury or neurological disease, disease type (MS participants) and years of illness (MS participants).

Dependent and independent variables will be measured as follows;

Walking

Previous studies have used both simple and computerized systems for measuring walking and gait, though these studies were conducted in other neurological populations. After consulting with physiotherapists and a bioengineer with interests in dual-tasking the GAITRite System for measuring walking parameters was chosen. The GAITRite system in a flexible electronic walkway providing an automated means of measuring the spatial and temporal parameters of gait using a carpet embedded with sensors which detect footfalls. It has been shown to give valid and reliable data (van Uden & Besser, 2004). The carpet is 457cm long with an active area of 366cm and a sampling rate of 32.3-38.4Hz. Walking speed, step length, step frequency, step time and double limb support time variability will be automatically calculated by computer software designed for GAITRite and recorded on disc for later analysis.

First participants will be assessed for risk of falls. A timed test of balance will be completed for each participant. Participants will be asked to perform a single leg stance on each leg and tandem stance with right and left leg in front. Ability to maintain position without losing balance for up to 30s will be recorded.

For each trial participants will be asked to walk unaided around a circuit of approximately 25m at their preferred walking speed continuously for 90 seconds. Distance walked will be one measure of walking. This duration was chosen 1) to ensure that total distance walked does not exceed 100 metres, since ability to walk at least 100 metres is part of the inclusion criteria, 2) so as not to induce significant fatigue and 3) this time length was thought long enough to induce a dual-tasking effect since it has been used in several other studies. In order to ensure that difficulties initiating walking do not influence the results timing of walking will commence after the individual has walked 5 metres (as in Cocchini et al., 2004). An instrumented walkway (GAITRite) will be used to collect data on gait parameters as outlined above. It will be placed so that it forms part of the circuit and positioned so that individuals do not initiate and terminate walking immediately before and after it in order to avoid the effects of acceleration and deceleration. It is anticipated that participants will perform up to 4 continuous repetitions of the circuit during each trial resulting in a maximum of 20 repetitions over the walkway. A rest will be given between each trial to avoid the effects of fatigue. Data will be stored on disc for later analysis. Immediately before and after the protocol, baseline walking speed will be measured using the 10m walk test during which subjects perform 3 repetitions of the 10m walk to determine any impact of fatigue on gait performance.

Cognitive tasks

We propose to use two cognitive tasks and to compare performance under single and dual task conditions (i.e. when paired with walking) for each task. An important distinction is that between tasks where difficulty is titrated according to the individual's performance in single task performance, so that the dual-task is a 'true' measure of the ability to do two things at once rather than merely representing an increase in task demand, and tasks where the dual-task has a fixed demand. One task will be a fixed demand task (i.e. same task for all participants) and the other will be a titrated task where the form of the task used will be titrated in terms of each participant's level of performance under single task conditions.

The fixed demand task will be a fixed digit span task. Participants will listen to sequences of digits, played aloud on a CD player, and will be required to repeat each sequence in order. All participants will be presented with sequences that are seven digits in length, since this is the average digit span in adults (Miller, 1956). The dependent variable will be percentage of digits correctly recalled in the correct position in one minute.

The titrated task will involve a digit span task that under dual-task conditions is titrated to the individual's level of single task ability. The titration procedures are those used by Cocchini et al. (2004) and Logie et al. (2004). First a digit recall assessment will be performed. The participant will listen to sequences of digits and will be required to repeat each sequence. The sequence of digits will be increased in length by one digit at a time until the participant fails two out of three sequences of a particular length. Digit span will be taken to be one digit less than the length at which the individual failed (e.g. if the participant was successful at length six but failed two out of three sequences at length seven then their digit span would be considered to be sequence length six). Once an individual's digit span is ascertained the titrated digit span task will consist of listening to sequences of digits at their span length for immediate serial ordered recall. Digit sequences

will be played aloud on a CD player. The dependent variable will be percentage of digits correctly recalled in the correct position in one minute.

Design

The design will involve comparing performance people with MS and healthy controls in terms of decrement from single to dual task conditions for the walking task and the two cognitive tasks.

Research Procedures

All participants will complete the digit span titration assessment before completing experimental trials. Experimental trials will involve participants completing both motor and cognitive tasks in single task conditions for the purpose of control. Motor and cognitive tasks will then be combined in dual-task conditions. In total this means each participant will complete 5 trials; walking alone, fixed digit task alone, titrated digit task alone, walking with fixed digit task and walking with titrated digit task. Each trial will last a maximum of 90 seconds. Trials will be counter-balanced to take account of order effects. Counter-balancing will be blocked to ensure two walking tasks do not occur together, this is to control for fatigue effects. Table 1 overleaf outlines the different permutations of counter-balancing. All experimental trials will be videotaped to assist scoring of walking and digit span tasks.

Table 1 outlining counter-balancing of trials

Permut-ation	**Trial 1**	**Trial 2**	**Trial 3**	**Trial 4**	**Trial 5**
1	Walking alone	Fixed digit task alone	Fixed digit & walking	Titrated digit task alone	Titrated digit & walking
2	Walking alone	Fixed digit task alone	Titrated digit & walking	Titrated digit task alone	Fixed digit & walking
3	Walking alone	Titrated digit task alone	Fixed digit task & walking	Titrated digit task alone	Titrated digit & walking
4	Walking alone	Titrated digit task alone	Titrated digit & walking	Fixed digit task alone	Fixed digit task & walking

Sample Size

Studies of divided attention have found large effect sizes when two cognitive tasks have been examined (e.g. D'Esposito (1996) d=0.79 (N=51) with MS patients) and when a cognitive task and motor task have been combined (e.g. Camiocioli (1997) d= 0.73 and d=0.83 (N=38) and Cocchini et al. (2004) d= 0.86 (N=30), both with patients with Alzheimer's disease). In the absence of studies investigating cognitive-motor dual-tasking in MS effect size will be estimated based on cognitive-motor dual-tasking studies in Alzheimer's disease. Assuming a similar effect size for cognitive-motor dual-task combinations in MS would suggest that for alpha 0.05 (two tailed), power =0.8, a sample size of n=26 per group would be needed, or for alpha =0.05 (1 tailed), n=20 per group. In order to allow for potential drop-outs 25 people per group will be recruited.

Settings & Equipment

The Gait-Rite System will be borrowed from Glasgow Caledonian University, for the purpose of the study. Blank CD's will be required to record digit span sequences. A CD player will be needed to play the CD's for the cognitive task. A video-recorder will be required to tape experimental trials. The research will be conducted in a movement lab at the Southern General Hospital. This space will be provided by Glasgow Caledonian University.

Data Analysis

The dependent variables will be performance decrement from single to dual-task conditions for the walking task and the two cognitive tasks. A composite decrement score averaging the decrement on the walking and cognitive tasks (walking and fixed digit task; walking and titrated digit task) will be calculated. Independent variable will be participant group (MS participants and healthy controls). If standard assumptions are met, t-tests will be used to compare means.

Secondary correlational analysis of dual-task decrement score and the Cognitive Failures Questionnaire score will be performed. This analysis is designed to evaluate whether dual-task performance decrement correlates with self-reported dual tasking and general attentional difficulties in everyday life. A secondary correlational analysis of dual-task decrement score and the Modified Fatigue Impact Scale Score will be performed in order to assess whether individuals who experience greater fatigue on a day-to-day basis have greater difficulties with cognitive motor dual-tasking.

HEALTH AND SAFETY ISSUES

Researcher Safety Issues

There are no apparent risks to the researcher from carrying out this study. The study will be carried out in a hospital setting that the participants routinely attend and where there are health and safety procedures in place. The patient group is not known to be aggressive. The research procedures are not known to cause significant distress.

Participant Safety Issues

One possible risk is a risk of MS participants falling while walking since this is a group with some physical limitations. This will be addressed by the inclusion criteria, of an EDSS score of less than 5.5, which sets a safe level of physical impairment for inclusion and will be judged by the neurologist. Participants will also be asked as part of the initial screening if they have fallen within the past month. Regular fallers will be excluded.

Risk of falls will be identified by the use of screening and the timed balance test as outlined in the method section. When walking participants will be issued with instructions regarding what to do if they think they may fall, these instructions will be based on advice from the physiotherapist. The researcher will walk a couple of steps behind each participant as they complete walking tasks. In addition the research will be conducted in a hospital setting that participants routinely attend where procedures are in place to minimize risk and where medical help is readily available.

If a participant falls the following procedure will be adhered to, this is based on the NHS GG&C Falls Management Policies & Guidelines (2006). If there is no obvious injury or discomfort the participant will be moved to a safe place to rest, such as seating in the gait lab. If there is obvious injury or the participant complains of discomfort the participant will be referred to medical staff for assessment. In either case an incident/accident form will be completed.

ETHICAL ISSUES

It will be necessary to ensure that the procedures to approach and recruit participants are free from any pressure to participate. Participants will be provided with adequate information to make an informed decision to participate including; the purpose of the study, what would be involved in taking part (including time), any benefits or risks to taking part, the option to withdraw at any time, whether participant expenses will be covered (e.g. travel expenses) and that participation or non-participation will not effect their medical treatment at the hospital. In addition participants will be briefed on how information obtained will be used and that their individual results remain confidential. Steps will be taken to ensure data are safely stored in a confidential manner and in the data analysis stages, anonymous. Research procedures will be designed to ensure the safety of the participants (see Health & Safety Issues above).

Ethical & Management Approval Submissions

Ethics application will be made to the SGH ethics committee. Dates for committee meetings are as follows:

Date of Meeting	*Cut off date for meeting*
16.01.2007	04.01.2007
27.02.2007	13.02.2007
27.03.2007	13.03.2007
24.04.2007	10.04.2007
29.05.2007	15.05.2007
26.06.2007	12.06.2007
31.07.2007	17.07.2007

Application will also be made to the NHS Management Approval System; this will include a Health & Safety Assessment.

FINANCIAL ISSUES

See Appendix for breakdown of estimated costs.

TIMETABLE

A provisional timetable is as follows:

January –March 2007:

- Prepare and submit Draft MRP Proposal and full MRP Proposal; including finalizing research design and procedures
- Initiative Research Logbook
- Prepare and submit Systematic Review Outline
- Sit in on Neurology clinics for MS patients at SGH
- Consult with Physiotherapy Department at SGH re: measures of gait and possible space for performing study

April-July 2007

- Prepare and submit ethics and management approval submissions
- Source and finalise research and recruitment procedures, space and materials on site
- Finalize planned statistical analysis of data

August-September 2007

- Begin participant recruitment

October-December 2007

- Data collection
- Research Progress Meeting

January-April 2008

- Data Collection
- Research Progress Meeting

April-May 2008

- Data analyses
- Research Progress Meeting

June-July 2008

- Submit MRP drafts to supervisor
- Bind and submit MRP

PRACTICAL APPLICATIONS

It is hoped the findings of the study will have practical implications for assessment and rehabilitation of cognitive-motor dual-tasking in MS, as well as adding to the general understanding of divided attention and cognition-motor relationships in the brain. There is anecdotal evidence that cognitive-motor dual-tasking may be an issue in this population, for example clinicians report that patients often stop walking while they are talking to them. In addition, in other neurological populations cognitive-motor dual-tasking difficulties have been linked to risk of falls (Cocchini et al., 2004). In particular it is hoped the findings of the study will further understanding of everyday functioning in MS as many everyday activities require dual-tasking, such as walking while talking and walking while negotiating a busy environment with many distractions, e.g. crossing the street. It is possible that people with MS avoid these situations for fear of falling or becoming unsteady. It is hoped that the current study will identify if cognitive-motor dual-tasking is a common problem in MS populations, identify if cognitive-motor dual-tasking problems can be assessed and suggest whether there is potential for rehabilitation strategies to address this issue.

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Appendix C2: Individual Digit Span Assessment

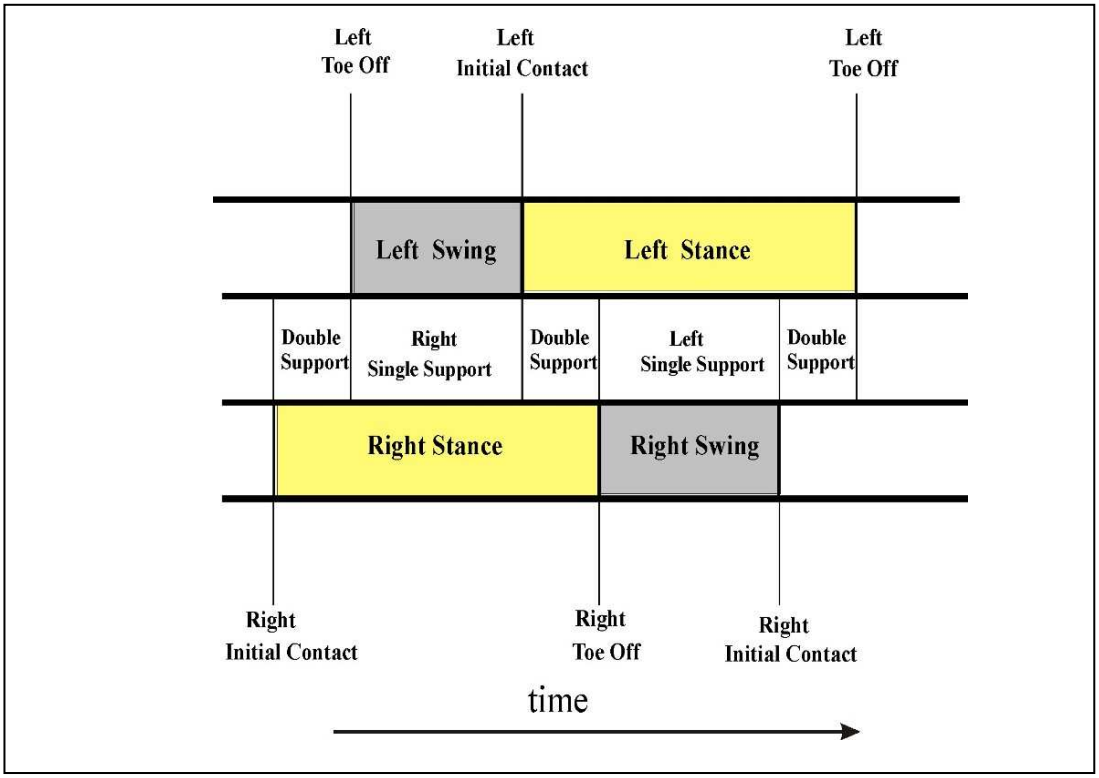
Digits	Answer
6-1	
1-9	
3-5	
5-1-9	
4-5-2	
6-3-1	
2-9-1-5	
6-5-1-9	
8-5-4-7	
8-2-9-6-1	
5-8-7-4-9	
4-1-8-7-2	
4-5-3-8-6-2	
3-9-5-2-4-6	
9-7-8-1-2-6	
4-3-6-7-1-2-5	
5-9-8-4-6-1-2	
3-4-1-6-5-8-2	
3-5-8-7-2-6-4-1	
6-2-7-1-4-5-6-9	
4-9-8-2-7-3-1-5	
5-2-1-4-7-3-6-9-8	
4-1-8-7-2-3-9-5-6	
3-6-5-9-2-4-7-1-8	

Appendix C3: Description of Development of Digit Span Task

Digit sequences of lengths varying from two digits to ten digits long were generated using Microsoft Word Excel random numbers function. A CD was compiled with 18 tracks. On each track the researcher was recorded reading digit sequences of a particular length for 90 seconds. The digits in each sequence were read at the rate of one per second. After each digit sequence was read there was a pause for the participant response before the next digit sequence was read. Two different tracks were recorded at each digit sequence length (i.e. two tracks where all sequences were two digits long, two tracks where all sequences were three digits long etc).

Appendix C4: Definitions of Swing Time and Double Support Time and Overview of Gait Cycle

Figure: Timing During a Single Gait Cycle (from Whittle, 2007, page 54)



Stance Phase: Part of the gait cycle for one side in which the foot is on the ground (from Whittle, 2007, page 240).

Swing Phase: Part of the gait cycle for one side in which the foot is off the ground, moving through the air (from Whittle, 2007, page 240).

Double Support Time: Period in the gait cycle in which both feet are on the ground (from Whittle, 2007, page 235).

Swing Time: Duration of the swing phase, between toe off and initial contact (from Whittle, 2007, page 240).

Initial Contact: Event in the gait cycle when first contact is made between the foot and the ground, made by the heel in normal gait (from Whittle, 2007, page 236).

Toe Off: Event in the gait cycle when the foot (generally the toe) leaves the ground (from Whittle, 2007, page 240).