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The Relationship Between Spatial Memory and Postural Balance in Seniors with Good and Poor Balance

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Eleanor Riesen

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In

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This dissertation is dedicated to the most important people in my life:

To my children, David and Marie, for filling my life with joy and meaning

To my parents, David and Helene Riesen,
who raised me to believe that I could do anything
and then stood by me while I did

To Francois Forget, for loving me

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Abstract

The purpose of this study is to examine the mutual effects of the concurrent performance of a spatial memory task (spatial span forward and backward of the Wechsler Memory Scale-III) and postural balance task (standing on a compliant surface) in seniors with good and poor balance. Furthermore, the purpose it to determine if these interference effects are similar if using a verbal memory task (letter number sequencing of the Wechsler Memory Scale-III) rather than a spatial memory task, or a finger tapping task rather than a postural balance task. Sixty-one participants were recruited from seniors' residences and the community. Twenty-nine were assigned to the poor balance group (mean age 72.93) and 32 were assigned to the good balance group (mean age 80.78) based on their scores on the Berg Balance Scale. Subjects were asked to conduct the spatial and verbal memory tasks while sitting, standing, and finger tapping. Four measures of balance were computer from Kistler force plate data: range of center of pressure in the anteriorposterior (Range A-P) and the mediolateral (Range M-L) directions; and root means square of center of pressure in the anteriorposterior (RMS A-P) and mediolateral (RMS M-L) directions. Finger tapping rate was measured with an electronic counter. Interference effects differed for the verbal and the spatial memory tasks. Specifically, postural balance was spared interference when paired with the spatial memory task, but not when paired with the verbal memory task. This pattern of interference was different when a finger tapping task was substituted for a balance task, and could not be explained by a unitary model of attentional resources or a multiple resources model. A new model of attentional resources was presented which better explains the results of the current study as well as the results of previous studies.

Introduction

Since the turn of the 20th century there have been remarkable demographic changes in aging in North America, coupled with a substantial increase in life expectancy (Elliot, 1996; Binstock & George, 1996; Statistics Canada, 2004). In 2004 Statistics Canada reported that Canada's 4,141,000 seniors comprised 13% of the population (Statistics Canada, 2004). By the year 2011, seniors are expected to comprise 14.6% of the population, with those over 85 being the fastest growing segment. There are many challenges associated with these demographic changes, one of the most important being: Can older adults look forward not just to a longer life, but also to a higher quality of life, without putting an undue strain upon the financial and health care resources of society? To answer this question, we must look at the many factors that play a role in the ability of older adults to function without assistance in our society. Two of these factors are spatial memory and postural balance, and their possible relationship to each other.

Age related decline in spatial memory skills is a frequently cited finding in aging research (Simon, Walsh, Regnier, & Krauss, 1992; Arbuckle, Cooney, Milne, & Melchoir, 1994; Charness, 1981; Evans, Brennan, Skorpanich, & Held, 1984; Light & Zelinski,1983; Moore, Richards, & Hood, 1984; Park, Puglisi, & Lutz, 1982; Pezdek, 1983; Salthouse, 1991; Salthouse, Babcock, Skovronek, Mitchell, & Palmon, 1990; Wahlin, Backman, Wahlin, & Winblad, 1993). Given the fact that spatial memory is crucial to tasks such as using community services (Simon et al., 1992), finding objects in the home (Uttl & Graf, 1993), and even taking medication properly (Patrick & Howell, 1998), this decline can have major consequences.

In order to gain a better understanding of spatial memory deterioration in older adults, it is important to examine the factors that may be causing it. One of the possible contributing factors suggested by Craik and others (Craik, 1985 Craik & Byrd, 1982) relates to the hypothesis that the quantity of attentional resources diminishes with age. In other words, as people get older they have less attention available to devote to a variety of attentionally demanding tasks, one of which may be spatial memory. As a result, there may be a decline in the performance of any tasks that demand careful attention. This problem leads to yet another question. Do aging adults face any other challenges that may increasingly compete for these limited resources? One such challenge already explored involves the ability of older people to maintain their balance.

The ability to maintain one's balance is critical to maintaining independence in old age in that it is necessary for safe mobility and the prevention of falls (Dunn, Rudberg, Furner, & Cassel, 1992; Lipsitz, Jonsson, Kelley, & Koestner, 1991; Bonar, Tinetti, Speechley, & Cooney, 1990). It has been well documented that falls in older adults occur frequently (Luchies, Wallace, Pazdur, Young, & deYoung, 1999), often resulting in fractures (Nevitt, Cummings, & Hudes, 1991; Tinetti, Speechley, & Ginter, 1988) that are very costly to the health care system (Schneider & Guralnik, 1990) and have a particularly negative impact on the ability of seniors to remain independent (Kosorok, Omenn, Diehr, Koepsell, & Patrick, 1992). As is the case with spatial memory, postural balance has been found to decline with age (Ansley, Stankov, & Lord, 1993; Era & Heikkinen, 1985).

Not only do spatial memory and balance both tend to decline with age, but there is some evidence that they tend to decline together. One study (Soulodre & McComas,

2000) found a relationship between spatial memory and postural balance. Specifically, those people with poorer postural balance scores also tended to have poorer spatial skill scores when age was statistically controlled.

As was suggested by Craik's hypothesis (Craik, 1985), one possible explanation for this is a competition between balance and spatial memory for a finite quantity of attentional resources. In other words, perhaps both postural balance and spatial memory require attention. If attention is limited in quantity then two attentionally demanding tasks would be in competition for this limited resource.

In order to explore this possibility further, several questions must be answered. What are attentional resources and what theoretical framework can be used to guide a study of this concept? Second, what are spatial memory and postural balance and how can they be defined? Third, what research paradigm allows the empirical investigation of attentional resources as they relate to spatial memory and postural balance? Fourth, what evidence is there that postural balance and spatial memory require attentional resources? Finally, what studies have already been conducted that examine the relationship between spatial memory and balance within an attentional framework? Each of these questions will be addressed.

Attentional Resources

The concept of attentional resources was first defined by Kahneman (1973) as a limited reservoir of cognitive processing capacity. Tasks requiring attentional resources compete for this limited resource, which can be subdivided between concurrent tasks in any way that the individual chooses. Not only is this resource limited in quantity, but it is also believed that the quantity diminishes with age (Craik, 1985; Craik & Byrd, 1982).

Kahneman (1973) proposed a theory that assumes that mental work is effortful, and that there is a limit to the human capacity to perform mental work. Furthermore, the theory suggested that there is freedom and choice in the manner in which attention is allocated to tasks that are performed either individually or concurrently with other tasks. Specifically, he noted that an allocation policy exists which determines the quantity of resources that are directed towards any given task. This allocation policy determines the number of resources available and the amount needed for a given task to be accomplished. Kahneman's (1973) conceptualization of attentional resources and the theoretical model which he proposed will be discussed in greater detail.

According to Kahneman (1973), different mental activities require different amounts of attention. Thus, these mental activities impose different demands on limited capacity attentional resources. An easy task demands little effort and a more difficult task demands more effort. When the demands of the tasks exceed the supply of attention available, task performance will suffer or possibly cease altogether. In other words, task performance can fail either because there is insufficient capacity to meet demands or because the available attentional resources are channeled elsewhere.

The two most critical elements of the model are the *allocation policy* and the *evaluation of demands* on the limited capacity. The allocation policy determines which activities will receive limited capacity resources. The evaluation of demands is the system that determines the quantity of resources to be allocated to each activity. There are four factors that control the allocation policy:

1) *Enduring dispositions* that determine the rules of involuntary attention such as a novel signal, or a sudden movement.

2) *Momentary intentions* that allow you to make voluntary decisions about how to devote attention or divide attention.

3) *Evaluation of demands* that assesses the quantity of attentional requirement and makes decisions about how to divide attention if the demands exceed the capacity available.

4) *Effects of arousal,* which vary by the intensity of arousal. In situations of high arousal, attention is focused on the dominant aspects of the situation. High arousal impairs ability of the individual to discriminate between relevant and irrelevant aspects of the task. Thus high arousal generally leads to a decrement in performance, particularly in tasks requiring fine discrimination.

According to this model, variations in physiological arousal accompany variations of effort, thus implying that the limited capacity system and arousal system must be closely related. The wavy line in Figure 1 (see Figure 1 below) suggests that capacity and arousal may vary together depending upon the changing demands of the activities that are being performed.

The process of prioritizing attentional allocation is most evident when dangerous tasks, complex tasks, or multiple tasks are conducted. For example, many older adults can walk and have a conversation. However, if they are walking on a very slippery street, it may be that they participate less in the conversation, or terminate the conversation altogether. In these situations, arousal may be high as there is potential danger, the evaluation of the demands may be high, and all available attentional capacity may be directed towards maintaining balance. When all attention is focused on the most critical task (maintaining balance) there may be an obvious decrement or complete failure in performance of other tasks such as maintaining a conversation. Furthermore, information that might normally be gathered such as spatial information relevant to wayfinding, may be deemed irrelevant in these situations, thus leading to a further decrement in spatial memory task performance.

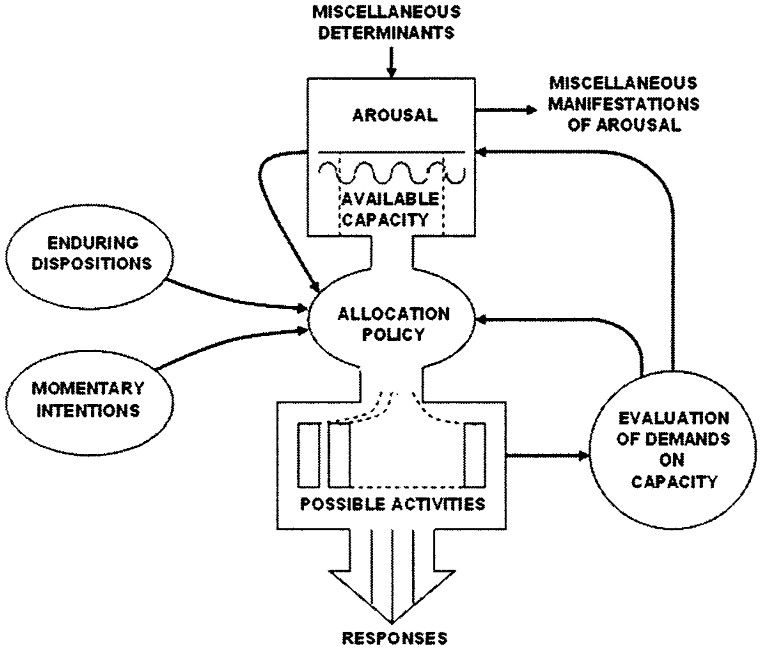

Figure 1. Kahneman's Capacity Model of Attention (Kahneman, 1973, p. 10)

Spatial Memory

The study of spatial cognition has origins in psychology as well as in geography and architecture. In psychology, Tolman (1947) first suggested that rats in a maze learned much more than when to turn right and left to find food—that they had an overall mental picture of the maze that guided their path. This finding was in contrast to the perspective of the time that memory was based in language, and that the spatial world was also reduced to words and descriptions (Tversky, 2000). Since that time, perspectives have changed. Researchers have examined people's memory for direction and distance, with vision and without vision, with actual navigation and with imagined navigation, and with direct experience and without direct experience (Tversky, 2000).

The concept of spatial memory can be further discussed in terms of spatial memory as a component of working memory and spatial memory as a part of long-term memory. Working memory is a short-term memory system that is necessary for tasks that require concurrent retention and processing (Baddeley, 1986). According to Baddeley's theoretical framework, working memory is made up of three components, the phonological loop, which holds verbal information, the visuospatial sketchpad, which holds visual and spatial information, and the central executive. The central executive is responsible for the control and distribution of the limited attentional resources.

It has been demonstrated that in order for spatial information to be stored in long-term memory it must first be stored in working memory. Evidence for this has been demonstrated in patients who have suffered brain trauma. Amnesic patients who have experienced damage to the hippocampal formation have been found to have normal short-term memory function but severely impaired long-term memory ability (Cave & Squire, 1992). However, the opposite has not been demonstrated to be true (Baddeley, Papagno, & Vallar, 1982). In other words, the prevalent current understanding of how spatial information is remembered, be it in small-scale space or large-scale space, is that first it is remembered in the visuospatial sketchpad of the working memory system, from which it can be retrieved for only a short time. Afterwards it may or may not be transferred to long-term memory, where it can be retrieved at a later time.

Spatial memory is a complex construct that is defined in the research literature in many different ways. The term is used to refer to small-scale environments or large-scale environments. For the purposes of this paper, spatial memory will be defined as memory for the location of items or places in space. In ecologically valid terms, it may include finding a specific article in the newspaper, finding items in the house, or remembering the location of a building in the city (Pezdek, 1983).

Postural Balance

Posture and balance involve the ability to maintain stability, the ability to recover from instability and anticipate and move in ways that proactively avoid instability. There is no universally accepted definition of postural balance in the research literature. However, Shumway-Cook and Woollacott (2001) provide a widely accepted definition and description of postural balance, which will be discussed.

Postural control involves maintaining the body's position in space for two purposes: stability and orientation (Shumway-Cook & Woollacott , 2001). Postural stability, also known as postural balance, is the ability to maintain the body in a state of static equilibrium when the body is at rest, or dynamic equilibrium when the body is in motion. Postural orientation is the ability to maintain the appropriate relationship between the various parts of the body, and between the body and environment.

For most tasks, people maintain a vertical orientation of the body. In order to do so, multiple sensory references and associated sensory systems are involved. These sensory references include gravity, which relies on the vestibular system, the support surface, which relies on the somatosensory system, and the relationship of the body to the environment, which for most people relies on the visual system.

An individual is considered stable when his or her center of mass (COM) is maintained over his or her base of support (BOS). The COM is the point at the center of the body mass and the BOS is the area of the person that is in contact with the support surface. In order to maintain postural balance, an individual continually produces muscular forces to control the COM. The vertical projection of these muscular forces that direct COM motion is called the center of pressure (COP). When an individual is quietly standing, there is a different COP under each foot and a net COP that lies between the feet and is determined by the weight that is supported by each limb.

During quiet stance, there is a small amount of spontaneous postural sway. This postural sway can be detected by changes in the COP primarily in the anterioposterior direction but also in the mediolateral direction. The perceived limits of stability are the distances that a person is willing and able to sway in either direction without losing postural balance and taking a step.

For the purposes of this paper, postural balance will be defined as the ability to maintain the body in a state of equilibrium during quiet stance. Postural balance, defined in this way, can be monitored by changes in the position of COP in both the mediolateral and anterioposterior directions.

The Dual Task Paradigm

The dual task paradigm is the most widely used methodological approach employed to determine whether or not attentional resources are required by a given task. There are several basic assumptions that underlie this approach (Kramer & Larish, 1996). First, attentional resources available at any given time are of a finite quantity. When two tasks requiring attentional resources (i.e., effortful tasks) are performed simultaneously, there is a cost. In cases where the attentional demands of the two tasks exceed the quantity of attentional resources available, there is a decline in performance of one or both tasks. If a task does not require attentional resources (i.e., it is automatic) then simultaneous performance of effortful secondary tasks will not interfere with performance on either task. It is possible to assess the attentional cost of a given task by comparing the performance of these tasks when performed together with performance when each task is performed on its own.

Abernethy (1988) further elaborated upon the methodological issues associated with dual task paradigms. In some studies in which tasks are performed concurrently, there is a task designated as the primary task and a task designated as the secondary task. The primary task is the one for which the attentional demand is assessed. The secondary task is then conducted simultaneously and performance changes are measured. The attentional priority that participants give each task can be altered by the instructions provided. Participants may be asked to attempt to keep the primary task performance constant, thus making the primary task the attentional priority. The performance in the secondary task is then measured and compared to secondary task performance alone. The decrement in performance thus speaks to the amount of attention required to conduct the primary task. Alternatively, participants may be asked to perform both tasks to the best of their abilities. In this case, neither task is primary and performance on both tasks is measured to determine if there are performance changes.

Another assumption of the dual task paradigms is that the more attentionally demanding the tasks, the larger the decrement in task performance. When the performance of the primary task is held constant, the change in performance of the secondary task is believed to be indicative of the attentional requirements of the primary task. When neither task is primary nor secondary the interpretation of results is more difficult because it is left up to the individual to determine how resources should be allocated. However, there are some advantages in not specifying which task takes priority, in terms of ecological validity.

In a further discussion of methodological issues associated with dual task paradigms, Abernethy (1988) suggested that laboratory conditions are all too frequently applied to studies that utilize dual task paradigms involving motor skills. As a result, it is unknown whether these findings may be generalized to real world conditions in which individuals must actually perform multiple tasks simultaneously. Such is the case when one task is arbitrarily defined as primary and the other arbitrarily defined as secondary. In real world conditions when two tasks (motor, cognitive, or otherwise) are performed simultaneously, the determination of which task, if any, requires primary attention is made by each individual based on his or her needs, skills, available resources, and evaluation of the situation. Thus, in studying the mutual effects of concurrent task performance, the interpretive challenges posed by not prioritizing tasks may be balanced by the ecological validity of the results.

Postural Balance and Attentional Resources

Studies involving dual task paradigms have been used to examine whether postural balance is attentionally demanding or automatic. Bard, Teasdale, & Fleury (1992) found evidence to support the notion that even highly practiced postural tasks can be attentionally demanding, with more complex postural tasks such as walking requiring more attentional resources than sitting or standing. A study of 6 young adults aged 20 to

30 years examined the attentional demands of sitting, standing, and walking. A dual task paradigm was employed using sitting, broad based standing, and walking as the primary task conditions and reaction time to an auditory stimulus as the secondary task. Reaction times were found to be significantly longer in the standing than the sitting condition, and longest in the walking condition. These results indicate that standing is more attentionally demanding than sitting, and walking is more attentionally demanding than standing.

A similar study involving 8 young adults and 9 elderly adults examined the attentional demands of postural balance (Teasdale, Bard, LaRue, & Fleury, 1993). Participants were asked to stand in a stable upright position or an unusual less stable position in four conditions (eyes open/firm surface, eyes open/compliant surface, eyes closed/firm surface, eyes closed/compliant surface). Reaction time to an auditory stimulus, the secondary task, was measured in each of these conditions. When the postural task increased in difficulty, the reaction time increased for both groups. However, this increase in reaction time was significantly exaggerated in the older group. These results indicate that maintaining postural balance is attentionally demanding and that the attentional requirements of postural tasks increase with both task complexity and age.

A further study of the relationship between postural balance and attentional resources involved 15 young adults (mean age 25.3 years) and 10 healthy older adults (mean age 78.74 years), all of whom were exposed to a series of balance disturbances (Brown, Shumway-Cook, & Woollacott, 1999). A dual task paradigm was employed here with postural recovery serving as the primary task and counting backwards serving as the secondary task. Recovering postural stability following a perturbation resulted in significant decline in secondary task performance for both age groups, thus supporting the hypothesis that there was a drain on attentional resources in both groups. However, the decrement in secondary task performance was significantly greater in the older group than the younger group.

These results indicated that even highly practiced postural tasks such as standing and walking require attentional resources. Furthermore, they suggest that the ability to recover a stable posture following an external perturbation was more attentionally demanding for older adults than for younger adults, as was evidenced by a decline in accuracy and speed of counting backwards. Furthermore, with the older adults, but not the younger adults, there appeared to be a hierarchy or continuum of attentional resources required by the various types of postural recovery strategies.

Collectively then, these studies all suggest that postural balance is in fact attentionally demanding (Bard et al., 1992; Teasdale et al.,1993; Brown et al., 1999). Furthermore, there is evidence that the demands increase both with task difficulty (Bard et al., 1992; Teasdale et al., 1993; Brown et al., 1999), and with age (Teasdale et al., 1993; Brown et al., 1999).

Spatial Memory and Attentional Resources

Although it was once believed that spatial location was remembered at no cognitive cost (Hasher & Zacks, 1979), there is now evidence to support the notion that spatial memory also requires attentional resources (Kausler, 1994). Hasher and Zacks (1979) set out several criteria for determining whether or not a task requires attentional resources or can be carried out automatically with no corresponding drain on attentional resources. Two of the most compelling of these criteria are the effect of intentionality and the effect of concurrent tasks on spatial memory task performance.

If spatial memory requires no attentional resources, this implies that it occurs automatically. Performance on tasks that occur automatically should not theoretically be influenced by the intention to remember. However, if the task requires attentional resources, then intention to remember should theoretically result in improved memory performance.

Park and others (1982) conducted a study with 30 college students and 30 older adults (mean age 65.9 years) in order to determine whether or not explicit instructions to remember spatial location improved spatial memory. Subjects were presented drawings that were placed either on the right or left half of a photographic slide. Half of the subjects were told to remember the picture (incidental group), whereas the other half of the subjects were told to remember both the picture and its location (intentional group). For both age groups, memory for spatial location was above chance in the incidental group; however, spatial memory performance was significantly higher in the intentional than in the incidental group.

A study conducted by Waddell & Rogoff (1987) also examined whether intentionality to remember improved spatial memory performance. A group of middle aged and a group of older women were exposed to an array of objects under one of two conditions. In the intentional condition, the women were exposed to an array of objects in a contextually organized panorama and informed that they would be asked to reconstruct the array. In the incidental condition, the women were exposed to the array without knowledge that a subsequent reconstruction would be required. Similar to

Park,et al. (1982) it was found in both age groups that, although some learning did occur in the incidental group, the spatial memory performance of the intentional group was significantly superior.

The results of both of these studies support the hypothesis that spatial memory tasks require attentional resources. This was the case when the spatial task was egocentric (Park et al., 1982) and when it was allocentric (Waddell & Rogoff, 1987).

In order to determine if spatial memory is negatively affected by a concurrent task, Andrade and Meudell (1993) conducted a study with 60 university students who were randomly assigned to four groups. The target stimuli were 32 nouns presented on a colour monitor in one of four corners of the screen, in a random order. Groups 1 and 3 were asked to count forward by 1s from 454 (easy task) during the presentation of the first 16 words, and to count forward by 7s aloud from 305 (difficult task) during the presentation of the next 16 words. Groups 2 and 4 were given the difficult task first and then the easy one. Groups 1 and 2 were asked to concentrate mainly on trying to remember the target words and their positions, and groups 3 and 4 were asked to concentrate mainly on the counting task. Each of the target words was later displayed with four other nontarget words. Subjects were asked to identify which was the target word and where it had been located. Spatial memory scores were unaffected by intentionality or difficulty of distracter tasks, which would suggest that perhaps spatial memory is automatic and thus requires no attentional resources. One criticism of this study is the small sample size (15 subjects per group), which may have rendered the study insufficiently powerful to detect a difference. A second criticism is the simplicity of the egocentric spatial memory task (i.e., only one of four potential spatial positions). If the spatial memory task was not sufficiently difficult, perhaps the attentional resources of the participants were not exceeded even when performing two tasks concurrently. A third criticism is that the effect of the cognitive tasks on the counting task performance could not be determined because there was no measurement taken of the counting task alone. If attentional resources were exceeded by the demands of concurrent task performance, it is possible that the decrement in performance was in the speed or accuracy of the counting task, rather than the spatial task.

In summary, there is some evidence that spatial memory tasks require attentional resources in that intention to remember spatial location results in improved memory (Park et al., 1982; Waddell & Rogoff, 1987). Conversely, the study by Andrade and Meudell (1993) using a dual task paradigm did not support the hypothesis that spatial memory is in fact attentionally demanding. This latter study, however, may have used too simple a memory task and too small a sample size. Further dual task studies involving both spatial memory and postural balance were examined in order to determine whether spatial memory tasks require attentional resources.

Dual Task Paradigms with Spatial Memory and Postural Balance

Several studies have used a dual task paradigm to determine whether or not spatial memory is affected by postural demands as secondary task. This is a particularly interesting question given its pragmatic implications, as both spatial memory and balance are critical for independent living in the elderly. If spatial memory and postural balance tasks both require attentional resources, and attentional resources are finite in nature, then they are in competition for limited attentional resources. This competition may help to explain both the decline in spatial memory and the increase in falls associated with aging.

Kerr, Condon, and McDonald (1985) believed that because visual information is critical to both postural control and visuospatial memory, then maintaining a difficult posture should interfere with visuospatial memory but not verbal memory. They conducted a study in which student participants were asked to complete the Brooks (1967) spatial and nonspatial memory tasks while sitting, and then while standing in the Tandem Romberg position (heel of the front foot in direct contact with toe of back foot). Brooks' tasks require listening to a series of sentences through headsets and then attempting to repeat the sentences word-for-word in order. For the spatial task a 4 × 4 matrix was described which always started with the instruction "in the starting square place a 1." Subsequent sentences required the next subject to place another number in the square to the right, left, up, or down. The nonspatial task was intended to be the verbal memory equivalent of the spatial task. Similar to the spatial task, the first sentence was "in the first square put a 1." The following instructions were identical to that of the spatial task except that the words *right*, *left*, *up*, and *down* were replaced with *quick*, *slow*, *good*, and *bad*. For example the researcher would state "In the square next to the quick place a 2. In the square next to the good place a 4."

This study found that the more difficult postural task did affect performance detrimentally on spatial but not nonspatial tasks. Kerr et al. (1985) believed that this result could be explained by the fact that postural control and visuospatial memory compete for the same visual pathways. As an aside, they also noted that participants were more stable when doing memory tasks while standing than when they were standing without a concurrent task. Unfortunately, they did not provide information as to whether this differed with the spatial task and the verbal task.

There are several questions that remain unanswered by Kerr's study. The study was conducted with 24 healthy young adults and thus results cannot be generalized to other populations such as older people or people with balance difficulties. Standing even in a difficult position may not require a large amount of attentional resources for a young healthy population. Thus the relationship between balance and cognitive task performance may appear smaller than in more difficult postural conditions. Also, this was a between-groups design. Thus, differences in performance between those conducting the spatial task and those conducting the verbal task could be explained by individual differences. Unfortunately, the authors acknowledged that a within-groups design cannot be used with Brooks' verbal and spatial memory tasks as a pilot study revealed that participants are unable to use different memory strategies with the two different tasks. Once participants developed a successful strategy they continued to use it.

Andersson, Yardley & Luxon (1998) conducted a study with 24 patients with vertigo and 24 normal control individuals with a mean age of 44.9 years. The purpose of the study was to determine whether postural balance affects performance on a visuospatial memory task. The postural tasks were standing on a moving platform with eyes open or with eyes closed. The mental task was adapted from the Brooks Spatial Memory task. It was found that performance on the spatial task deteriorated for both groups when performing the demanding balance task. Also, a further analysis dividing participants into good and poor balance groups found that the *good balance* group swayed more during the dual task condition, whereas the *poor balance* group actually swayed less in the dual task condition. This difference was even more pronounced in the eyes-open condition than the eyes-closed condition. The results of this study support the idea that both postural balance and spatial memory require attentional resources, and that there is decrement in the performance of one or both tasks when they are performed simultaneously. However, it also indicates that when this relationship is examined separately in good and poor balance groups the two variables are related "...in complex and varied ways that merit further investigation (Andersson et al., 1998, p. 632)." Unfortunately, no explanation of this complex relationship was offered.

Shumway-Cook, Woollacott, Kerns, and Baldwin (1997) conducted a study with 20 young healthy adults, 20 healthy older adults and 20 older adults with a history of falls and balance difficulties. The study investigated the effects of two types of cognitive tasks on balance. One task was a spatial task (judgment of line orientation) and the other was verbal (sentence completion). The two balance conditions were: standing on a firm surface versus standing on a compliant surface. For the younger group and the older healthy group, balance was unaffected by the spatial task, but was negatively affected by the spatial task. In the older group with poor balance, both the spatial task and the verbal task led to a decline in balance in the dual task condition, however this decline was significantly greater in the verbal task condition. It was hypothesized at the outset of the study that a posture-first hierarchy exists in the allocation of attentional resources during the performance of dual tasks. In other words, where the postural task is difficult and the threat of injury is great, posture takes precedence. However, this hypothesis was only supported in some conditions.

In this study, the spatial task chosen, the judgment of line orientation task, is a visual perceptual matching task that does not require memory. It would be interesting to examine whether spatial memory task performance is affected by varying postural tasks.

Maylor & Wing (1996) conducted a study with two groups of 19 subjects each (mean ages 57 and 77, respectively). Their dual task paradigm involved sitting versus standing and five cognitive tasks (random digit generation, Brooks' spatial memory task, backward digit recall, silently counting from 1 to 100, and counting backward by threes aloud). It was found that varying postural stance from sitting to standing had a detrimental impact only on the performance of random digit generation only. Balance, as measured by anterior-posterior weight distribution, was affected in the Brooks spatial memory task condition and the digit backward recall conditions differentially in the two groups of participants. Specifically, the older group had greater postural instability in these two conditions than did the younger group. A limitation of this study, as acknowledged by the author, is that the postural task of standing with feet apart and arms at side is likely not a sufficiently difficult postural task to affect cognitive performance in a healthy sample.

Maylor, Allison, and Wing (2001) conducted another study with 70 participants aged 20 to 79 years. All participants performed the Brooks spatial memory task and Brooks nonspatial memory task while standing and sitting. It was found that both spatial and nonspatial memory declined with age, but were not affected by postural stance. Postural stability, as measured by sway velocity and sway variability, also declined with age and was negatively influenced by a concurrent cognitive task. Furthermore, there was an interesting relationship between the postural sway and the cognitive tasks. During encoding phase of the cognitive tasks, sway was reduced in comparison with the no-task condition, particularly during the spatial task. During the maintenance stage of the cognitive memory tasks, sway was increased, but more so in the verbal memory task.

Again, this study suggests that postural balance as well as spatial and nonspatial memory are attentionally demanding. Furthermore, it suggests that attention is diverted from the balance task rather than the cognitive task (or both tasks). Thus, the results of this study are in contrast to the *posture first* hypothesis proposed by Shumway-Cook, et al. (1997).

The fact that all participants completed both the Brooks spatial and nonspatial tasks in this study raises a concern. Participants may have used similar memory strategies for both the tasks, thus leading to contamination of the two conditions, as was discovered by Kerr et al. (1985). This leaves ambiguity as to how to interpret the results, given that it is not possible to know which memory strategies were used in which condition. Another limitation is the simplicity of the postural stance condition, which involved standing on a firm surface with feet apart and arms at sides. The participants were healthy adults who were likely to have had good balance, although this was not explicitly stated. It may be that participants were able to divert attention from the simple balance task to a cognitive task without risk of losing balance. It would be interesting to determine if the results would be different if a more difficult postural task were used, or subjects with poorer balance were included in the study. In a more ecologically valid setting, where loss of balance poses a real risk, results may be quite different. For instance, an elderly person navigating a slippery sidewalk in the winter may have a difficult time with the spatial memory task of remembering his or her way through the neighborhood. However, in the safety of a laboratory, with grab bars on either side of the participant, attention may be more safely diverted from the postural task to the cognitive tasks.

Dault, Frank, & Allard (2001) conducted a study with 20 university students. Participants were required to either stand on a force plate with feet apart, stand on a force plate in the tandem Romberg position, or sit on a chair while performing one of three working memory tasks, a visuospatial task, a verbal task, and a central executive task. In the visuospatial task (the Manikin test) participants had to name the hand in which a manikin in front of them was holding a black or white circle. In the verbal task words appeared on a monitor and had to be categorized as *winter* or *summer*, *meat* or *not meat*, and *hard* or *soft*. The third task consisted of random number generating, which was considered to tax the central executive. In addition, there were simpler and more difficult versions of each of the spatial, verbal, and random numbers conditions.

There was no effect on performance of any of the cognitive tasks in the dual task versus single task conditions. With all tasks, there was a decrease in postural sway in the dual task versus single task conditions. However, there was no difference in balance between the type of tasks, or as a function of the difficulty of tasks. What makes these results interesting is that postural balance actually became more stable rather than less stable in the dual task conditions. There was no explanation of this provided within an attentional framework.

This study was conducted with young healthy university students. It would be interesting to replicate this study with older adults and with individuals with good and poor balance.

Swan, Otani, Loubert, Sheffert, & Dunbar (2004) conducted a study with 20 young adults (mean age 21 years), and 20 older adults (mean age 64 years). Each participant was asked to stand with feet shoulder width apart on a force platform while performing the Brooks spatial memory task, the Brooks nonspatial memory task, or while simply standing. The order of these three conditions was randomly determined for each participant. The difficulty of the balance task was manipulated by varying the availability of visual input and the motion of the platform. The results indicated that cognitive performance was unaffected by the balance task. However, balance became more stable rather than less stable for older adults while concurrently performing both the spatial and the nonspatial task, and this was even more evident in the most difficult balance conditions.

Overall, several findings emerge in the literature. First, there is evidence to support an age-related decline in both balance (Bard et al., 1992; Teasdale et al., 1993; Brown et al., 1999) and spatial memory (Simon, et al., 1992; Arbuckle, et al., 1994; Charness, 1981; Evans et al., 1984; Light & Zelinski,1983; Moore et al., 1984; Park, et al., 1982; Pezdek, 1983; Salthouse, 1991; Salthouse, et al., 1990; Wahlin, et al., 1993). Furthermore, there is evidence to support the fact that both spatial memory tasks (Park et al., 1982; Waddell & Rogoff., 1987) and postural balance tasks (Bard et al, 1992; Teasdale et al., 1993; Brown et al., 1999) are attentionally demanding, and that more difficult tasks require more attentional resources. The relationship between spatial memory and postural balance in dual task paradigms is less clear. There is a relationship between performance on balance and spatial memory tasks. Some studies show that balance tasks affect spatial memory task performance (Kerr et al., 1985; Andersson et al, 1998), others show that spatial memory task performance affects balance task performance (Kerr et al., 1985; Andersson et al., 1998; Shumway-Cook, et al., 1997; Maylor & Wing, 2001; Dault et al., 2001; Swan et al., 2004). However, the nature of the effect on the balance task varies across studies. Some studies have indicated that concurrent spatial and postural tasks cause greater postural instability in some groups

(Andersson et al., 1998; Shumway-Cook et al., 1997), and others have found the reverse, that postural stability was enhanced under dual task conditions (Kerr et al., 1985; Andersson et al., 1998; Maylor et al., 2001; Dault et al., 2001; Swan et al., 2004). In the majority of these studies there is little exploration of the theoretical reasons, from an attentional perspective, as to why these results may be mixed. This may be, in part, because many of the researchers publishing in this area have backgrounds in such areas as physical therapy, kinesiology, and rehabilitation sciences. As a result, the interest and focus lies more with whether or not there are interference effects between balance and other tasks, and how balance is affected. There is less of a focus on explaining why the interference is occurring from an attentional perspective. In short, the nature of the relationship between spatial memory and balance, and whether this can be attributed to competition for a unitary and finite source of attentional resources, remains unclear.

Several limitations exist in previous studies. First, the most commonly used measures in studies involving dual task paradigms were Brook's spatial and nonspatial memory tests (Kerr et al., 1985; Anderson et al., 1998; Maylor & Wing, 1996; Maylor et al., 2001; Swan et al., 2004). The benefit of the frequent use of this test is that comparison of results can be more easily made across studies. However, no information could be found regarding the reliability and validity of these tests. Furthermore, in many instances both of these measures were given to all participants in the study (i.e., a within-groups design). Kerr et al. (1985) noted that using a within-groups design with these two tests could result in participants using the same memory strategy for both tests, thus leaving the results of the tests somewhat difficult to interpret. In addition, some studies used relatively simple postural stances in health populations, which may or may not have required sufficient amounts of attention to tax the available attentional resources (Maylor & Wing, 1996; Maylor, et al., 2001; Swan et al., 2004). As well, most of the studies asked the participants to remain as still as possible (Maylor & Wing, 1996; Maylor, et al., 2001; Swan et al., 2004, Kerr et al., 1985), two asked that the participants to complete the cognitive task as quickly as possible (Anderson et al., 1998; Dault et al., 2001), and one study requested that participants stand as still as possible and complete the cognitive task as quickly as possible (Shumway-Cook et al., 1997). However, none of the studies allowed the participants to divide their attention as they saw fit. As a result, dual task interference effects under more ecologically valid conditions remain unknown.

A final limitation of the previous literature lies in the theoretical underpinnings of the studies. Although several studies found interference between balance performance and spatial memory performance, the mechanism underlying this interference still remains unclear. It could be due to the fact that both tasks compete for the same finite quantity of attentional resources. However, there could easily be another explanation. For instance, both tasks involve visual components and could be competing for the same visual pathways. It would be useful to determine if another attentionally demanding non-visual task had similar interference effects. One such task is finger tapping.

Rapid finger tapping is a task requiring attention but not requiring vision. Although it was not used in any of the aforementioned studies, a number of studies have used rapid finger tapping as a secondary task. These studies have found interference between finger tapping performance and performance on word reading tasks (Van Hoof & Van Strien, 1997); reading, speaking, and maze tasks (Crossley & Hiscock, 1992); and verbal tasks (Fearing, Browning, Corey & Foundas, 2001). Rapid finger tapping has also been used as a secondary task in a study of balance (Ebersbach, Dimitrijevic, & Poewe, 1995). It was found that when subjects performed a rapid finger tapping task while walking they had to modulate their gait strategy in order to maintain balance. If in addition to interference between balance and cognitive tasks there was interference between finger tapping and balance, or finger tapping and cognitive task performance, then one could more confidently conclude that it was due to the competition for attentional resources.

A better understanding of the relationship between postural balance and spatial memory in older adults, and older adults with poor balance, is important for several reasons. Both are critical for independent living in older populations. For all elderly people, it may be increasingly difficult to simultaneously maintain their balance and perform spatial memory tasks. An elderly person with poor postural balance might be particularly at risk for spatial memory deficits. Understanding the nature of the relationship is the preliminary step to intervention and thus is important to study.

Research Questions

Several questions still need to be addressed. In an older population, does concurrent performance of a balance and spatial memory task cause interference and thus a decrement in performance on either task? Is this unique to spatial memory tasks, or is it also true for verbal memory task performances? How can one be sure that interference between a spatial memory task and a balance task is due to competition for attentional resources? Is there similar interference in task performance between balance and another type of attentionally demanding task, such as finger tapping? Similarly, is there interference between spatial memory and another type of attentionally demanding task such as finger tapping? Are these decrements in performance exaggerated in seniors with poor balance as compared to those with good balance? The purpose of the current study is to answer these questions.

Kahneman's theory would predict the following hypotheses based on the questions above. In all dual task conditions there should be a decrement in performance in one or both tasks, regardless of whether the cognitive task were spatial or verbal if the tasks were sufficiently attentionally demanding. Secondly, a similar pattern of interference effects should exist, with both the balance task and the finger tapping task. In addition, one would expect that seniors with poor balance would need to divert more attentional resources towards maintaining their balance than seniors with good balance. Thus, one would expect exaggerated interference effects in the poor balance group.

In order to test these hypotheses, two groups of older adults were recruited, one with good balance and one with poor balance. These participants performed both a spatial memory task and a verbal memory task while sitting (single task condition), while finger tapping (dual task nonbalance condition), and while standing on a compliant foam surface (dual task balance condition). In addition, balance measures were taken during quiet stance (single task condition) and during the performance of the verbal task, spatial task, and finger tapping tasks (dual task conditions). The interference effects were determined by comparing dual task performance to single task performance.

Method

Participants

In order to determine the number of subjects required, a review of similar studies was conducted. Specifically, the aforementioned dual task studies that concurrently examined balance and cognitive tasks were reviewed. Unfortunately, effect sizes were not reported. The sample sizes used in similar studies to date have ranged from 6 to 24 per group, with a mean of 14.1 participants per group. These sample sizes have been sufficiently large to detect significant differences in balance when a reaction time task was concurrently performed (Bard et al., 1992; Teasdale et al., 1993) and when a cognitive task was concurrently performed (Brown et al., 1999; Maylor & Wing, 1996), including a spatial memory task (Maylor et al., 2001; Dault et al., 2001; Swan et al., 2004). Furthermore, significant decrements in spatial memory performance (Kerr et al., 1985; Andersson et al., 1998) and other cognitive task performance (Maylor & Wing, 1996) have been demonstrated when a concurrent balance task was performed. Such sample sizes have been sufficiently large to detect differences in secondary task performance, which are exaggerated in older adults (Teasdale et al., 1993; Brown et al., 1999) and in adults with poorer balance (Andersson et al., 1998; Brown et al., 1999; Shumway-Cook et al., 1997). Given the fact that the two groups in the current study consist of older adults with good balance and older adults with poor balance, it would seem that a sample size similar to these aforementioned studies would have sufficient power to detect a significant difference between groups. A sample of 60 participants (approximately 30 per group) was deemed large enough to answer the research questions.

Inclusion criteria included English-speaking individuals over the age of 65 who stated that they would be capable of standing unassisted for 15 minutes, and repeatedly tapping their thumb on a button without discomfort. Individuals who had broken a bone in a lower extremity in the last 6 months, as well as those who had a history of stroke or any other neurological disorder were excluded from the study. Seventy-three potential participants were recruited who met these criteria, 31 from the community and 42 from seniors' residences. Of these, 12 were unable to complete the study because they could not safely perform the balance task. Of the 61 who remained, 29 were assigned to the poor balance group and 32 to the good balance group. The mean age in the good balance group was 72.93, and the mean age in the poor balance group was 80.78. Two-sample t tests for independent means were conducted to check for group differences. There was a significant age difference between groups, $t(1, 60) = 4.35, p = .00$. The mean number of years of education was 13.4 years in the poor balance group and 14.43 in the good balance group. These differences were not significant $t(1, 60) = 1.31, p = .20$. There were no group differences in cognitive impairment as measured by the Modified Mini Mental State Examination $t(1, 60) = -1.37, p = .18$

Materials

The screening of potential participants was done using a telephone questionnaire and the Modified Mini Mental State Examination (see Appendix A). The Berg Balance Scale (see Appendix B) was used to assign people to the good balance and poor balance groups. Spatial memory was measured using the Spatial Span (SS) subtest of the Wechsler Memory Scale III (WMS-III) and verbal memory was measured using the Letter Number Sequencing (LNS) subtest of the WMS-III (see Appendix C). Balance was measured using a Kistler force plate that was placed on the floor under a medium-density foam block. Finger tapping was measured by a hand-held counter, which recorded the number of taps electronically. Each measure and its reliability and validity will be discussed below.

Modified Mini Mental State Examination (3MS)

The 3MS is a 15-item brief cognitive screening instrument originally designed to detect dementia (Bassuk & Murphy, 2003). It was conducted in person with a trained interviewer as per the 3MS administration manual (Teng & Kristjansson, 2001). A cutoff score of $\leq$77 was used to ensure that potential participants who suffered from dementia would not be included in the study. Reliability and validity of this tool have been well established, as has the cutoff point of 77 to screen for dementia. A study of 1092 elderly community residents was conducted to determine appropriate cutoff points for identifying dementia (Bland & Newman, 2001). It was found that using a cutoff of $\leq$77, only 0.64% of individuals with dementia were missed. Of those identified using this screening tool, one case in three was later determined through neuropsychological testing to have dementia, and the remaining 2 cases were found to involve cognitive impairment without dementia (Bland & Newman, 2001).

Similarly, the Canadian Study on Health and Aging used a score of 77 on the 3MS as a cutoff point for detecting dementia and found that in a sample of 8,900 community dwelling seniors across Canada this cutoff was associated with 87% sensitivity and 89% specificity (McDowell, Kristjansson, Hill, & Hebert, 1997). In the same study, alpha internal consistency for the English version of the 3MS was found to be 0.87, and the split half reliability was 0.82.

Another study of 885 community dwelling Canadian adults over the age of 65 also examined the reliability of the 3MS (Bassuk & Murphy, 2003). They found interrater reliability to be high (interclass correlation of .98) as was internal consistency (coefficient alpha = .91). Furthermore, test–retest reliability was .78 over a 3-year period.

Berg Balance Scale

The Berg Balance Scale was used to divide subjects into good and poor balance groups. This is an ordinal level scale which consists of 14 common everyday tasks to determine the participants' ability to maintain positions or movements of increasing difficulty, from sitting, to standing, to standing on one leg (Berg, Wood-Dauphine, Williams, & Gayton, 1989). Each item is scored from 0 to 4 for a maximum of 56 points.

Two studies were conducted with 14 clients aged 65 and over to examine reliability of the Berg Balance Scale (Berg, Williams, Wood-Dauphine, & Maki, 1992; Berg, Maki, Williams, Holiday, & Wood-Dauphine, 1992). Cronbach's alpha for the total score was 0.96, ranging from 0.72 to 0.90 for the individual items. Intrarater reliability was conducted with four clinicians who rated videotapes of the same 14 clients, 1 week later. The ICC was 0.99, ranging from 0.71 to 0.99 for the individual items. Five clinicians rated the evaluation of these same 14 clients to determine interrater reliability. The ICC for the total score was 0.99, and for the individual items it ranged from 0.71 to 0.99.

Construct validity testing was conducted with 70 acute-stroke patients using two other well known balance measures, the Barthel and the Fugl-Meyer, at 4, 6, and 12 weeks poststroke (Berg, Williams, et al., 1992; Berg, Maki, et al., 1992). Correlations between the Berg Balance Scale and the Barthel were 0.80 – 0.94. Correlations between the Berg Balance Scale and Fugl-Meyer Scale were 0.62 – 0.94.

Predictive validity (Berg, Williams, et al., 1992; Berg, Maki, et al., 1992) was tested in a sample of 113 seniors who were followed for a 12-month period. A Berg Balance Scale score of < 45 was found to be predictive of multiple falls during that period.

Wechsler Memory Scale-III

The Working Memory Index of the WMS III is a measure of tasks requiring a high degree of attention. These tasks stress the ability of an individual to attend to information, to hold and process that information in memory, and to retrieve the information from memory. This index is comprised of two subtests, Spatial Span (SS) and Letter-Number Sequencing (LNS).

SS is a spatial memory task in which a configuration of 10 blue blocks is presented. These blocks are fixed to a white board. From the researcher's perspective, the blue blocks are numbered from 1 to 10. From the participant's perspective, the blue blocks are unmarked and identical. The researcher reads the explanation of the test to the participant as specified in the WMS III manual and then proceeds in accordance with these instructions.

The researcher points to three blocks consecutively at a rate of one block per second. The participant is required to immediately repeat the sequence in the same order by pointing to the blocks with a finger. If the participant is able to do so correctly, a different sequence is presented and the length of the sequence is increased by one block. If the participant makes an error, a second trial of the same length but different sequence is performed. If the participant succeeds, the number of blocks in the sequence is increased by one, and a different sequence is presented. If the participant fails the second consecutive trial, the test is discontinued. The second part of the SS test is identical except that the participant is asked to point to the blocks in the reverse order of the researcher. The scores of spatial span forward (SSF) and backwards (SSB) are recorded separately, but can also be combined to give a total SS score. SSF and SSB, differ in that SSB is expected to make more demands on working memory, and as such it is implied that it is more difficult (The Psychological Corporation, 1997).

The LNS task is a verbal memory task. It involves listening to and immediately repeating a sequence of letters and numbers. First, the researcher reads the instructions as per the WMS-III manual (Wechsler, 1997). These instructions include four opportunities to practice. Afterwards, the researcher reads a sequence of three numbers and letters, and the participant is asked to immediately repeat them back with the numbers first, in order from lowest to highest and then the letters in alphabetical order. If the participant is successful, the sequence is changed and its length increased by one. If the participant is not successful, another sequence of the same length is presented. After three unsuccessful attempts at sequences of a given length, the trial is discontinued. In order to have different sequences for each condition, a random numbers table was used to generate these sequences.

Standardization and normative information of the WMS-III is based on a representative sample of the U.S. population of adults aged 26–89 years of age (The Psychological Corporation, 1997). The sample for the WMS-III included 1,250 adults in 13 age bands. One hundred participants were included in each group except the two oldest, which consisted of 75 participants each. In addition to the sample, 437 individuals were tested so that at least 20 participants would be included in each of five education levels (≤ 8 years, 9–11 years, 12 years, 13–15 years, and greater than 15 years). Equal numbers of men and women were included in each group, except for older groups where gender representation was consistent with that of the 1995 census. Race/ethnicity and geographic location of participants in each age group were also representative of 1995 census data.

The reliability coefficients for LNS and SS were calculated by rank-ordering the items in order of difficulty, and then dividing them in half by an odd–even split. The correlations were calculated between the total scores of the two half-tests corrected by the Spearman–Brown formula for the full subtest of the Subtests of interest and age group of interest. The reliability coefficients ranged from .71 - .88 for seniors over the age of sixty-five, grouped in five year intervals.

Test–retest reliability was conducted with intervals ranging from 2 weeks to 12 weeks with a mean of 35.6 days. Data for 55–89 year olds were collapsed. The stability coefficient for SS was .70 and for LNS was .77.

Content Validity is made up of two components: content coverage and content relevance. Content coverage is based on the extent to which the tests adequately represent all aspects of the construct that they are intended to represent. Content relevance means that all items included in a subtest measure some element of the construct of interest.

Several steps were taken to ensure content validity. A comprehensive literature review was conducted to determine appropriate content of the WMS III. Numerous neuropsychologists, school psychologists, and clinical psychologists reviewed the test during its development (The Psychological Corporation, 1997).

Correlations between the WMS-III and Measures of Spatial Processing were conducted to determine construct validity (Powell, Kaplan, Whitla, Weintraub, Catlin, & Funkenstein, 1993). When compared to the spatial processing Index of the Microcog, the Working Memory Index correlated highly (.67). Correlation with the Judgment of Line Orientation (JOLO) was .26 for the Working Memory Index. The direct copy condition of the Rey-O (Rey, 1941, 1959) had a correlation of .28 with the Working Memory Index. The relatively low correlations of these latter two tests are to be expected given that the JOLO and direct copy condition of the Rey-O have spatial components, but not memory components.

Finger Tapping Measures

A cylindrical counter approximately 8 cm in length and 2.5 cm in diameter was used to count the number of finger taps. The counter was attached via cable to the amplifier that was in turn attached to the computer where the number of taps per second could be recorded using in-house data acquisition software. The end of the counter had a green button that could easily and rapidly be depressed.

The Kistler Force Plate

Balance was measured using a Kistler force plate. This is a 50 cm × 90 cm metal plate, which stands approximately 5 cm off the ground. It was placed on a 2.5 cm thick piece of plywood (60 cm × 120 cm) in order to minimize the differences in the compliance of the floors if the plate were moved. On top of the force plate, was a 50 cm × 50 cm compliant foam surface. Maintaining one's balance on this surface is more difficult than maintaining one's balance on a firm surface.

The Kistler force plate is embedded with eight piezoelectric crystals. When an individual stands on the force plate, these crystals are compressed, and they detect ground reaction forces, and send a signal via eight channels to an amplifier. The amplifier in turn amplifies the signal and can then be recorded on a lap-top computer using in-house data acquisition software.

Four measures of balance were obtained for current study using the Kistler force plate: mean center of pressure range in the anterioposterior direction (A-P range), mean center of pressure range in the mediolateral direction (M-L range), and mean root mean square in the anterioposterior (A-P RMS) and mediolateral (M-L RMS) directions. During quiet stance, individuals sway slightly, which causes the center of pressure beneath their feet to shift. The more exaggerated the sway in the forward–backward direction, the more extreme the value for A-P range. The more exaggerated the sway side-to-side, the more extreme the value for M-L range. The root mean square measure is the average of the COP movement squared in the anteriorposterior and mediolateral directions.

Design

A dual task paradigm was used in what was conceptualized as two separate studies. The primary question was whether or not spatial memory and verbal memory task performance were negatively influenced by a secondary attentional task (balance or finger tapping), and conversely, whether balance or finger tapping rate were affected by a secondary cognitive task.

The first study examined whether three different attentional conditions (sitting, standing on a compliant surface, and finger tapping) influenced performance on cognitive test scores (SSF, SSB, SS total and LNS). This was a 2 × 3 mixed two-factor design with group (good balance and poor balance) as the between factor and attentional conditions (sitting, standing on a compliant surface, and finger tapping while sitting) as the within factors. Spatial span forward, spatial span backward, and spatial span total scores as well as letter number sequencing scores were the dependent measures.

The second study examined whether five different attentional conditions (standing, SSF, SSB, LNS, and finger tapping) influenced quiet stance balance measures (A-P range, M-L range, A-P RMS, and M-L RMS) or finger tapping rate. This was a 2 × 5 mixed two-factor design with group (good balance and poor balance) as the between factor and attentional condition (standing, SSF, SSB, LNS, and FT) as the within factors. Four balance measures (A-P range, M-L range, A-P RMS, and M-L RMS), and finger tapping rate were the dependent measures.

All participants took part in both studies. There were six conditions in the first study and four in the second. However, two of these conditions were part of both studies and did not need to be repeated. Thus, each participant took part in a total of nine different conditions: Sitting and finger tapping (single task), sitting and SS (single task), sitting and LNS (single task), sitting and finger tapping and SS (dual task), sitting and finger tapping and LNS (dual task), standing on a compliant surface (single task), standing on a compliant surface and SS (dual task), standing on a compliant surface and LNS (dual task), and standing on a compliant surface and finger tapping (dual task).

The conditions varied with respect to the amount of attention that they demanded. The sitting condition required the subjects to sit on a chair. The assumption was that sitting is not attentionally demanding. Standing on a compliant surface (standing), finger tapping (FT), conducting the SS, and conducting the LNS are all attentionally demanding. Thus, the SS, LNS, and FT in the sitting position are single task conditions. Standing on a compliant surface alone is also a single task condition. The SS, LNS, and FT carried out while standing on a compliant surface are dual task conditions. Performing the SS tasks, and the LNS task while FT are also dual task conditions.

Procedure

The 31 community participants were recruited from various sources in the following ways. Nine were participants from a previous unrelated study, who had expressed interest in participating in future studies and had provided their phone numbers. Two were recruited from a local bridge club by a research assistant who attended a bridge meeting and briefly explained the study. Names and telephone numbers of potentially interested participants were recorded on a sheet of paper that was circulated at the meeting. Twenty participants were friends of individuals who had already participated in the study. The previous participants first contacted these latter recruits. The names and telephone numbers of interested friends were then given to the researcher.

The remaining 42 participants were recruited from six seniors' residences in the Ottawa Carleton Region. The Directors of Care of these seniors' residences were contacted and the study explained. They were asked to identify appropriate residents and approach them to ask if they might be interested in the study. Those who expressed an interest were contacted by telephone or in person and had the study explained by the researcher. Those who were still interested in participating were screened for eligibility.

Determining eligibility for participation was a two-step process. The first step was done prior to meeting with the participants. Each of these potential participants was contacted by telephone, and had the study explained. Those who were interested were screened to determine if they met the first stage of inclusion/exclusion criteria. Inclusion criteria included English-speaking individuals over the age of 65 who stated that they would be capable of standing unassisted for 15 minutes, and repeatedly tapping one thumb on a button without discomfort. Individuals who had broken a bone in a lower extremity in the last 6 months, as well as those who had a history of stroke or any other neurological disorder, were excluded from the study.

Those who were interested in participating and met the first stage criteria step were scheduled for an appointment in person at a local senior's residence, where they were screened for cognitive impairment using the 3MS. Individuals with a score of 77 or greater were asked to participate in the study. Those with a score of 76 or less were informed that the 3MS was a rough screening tool, and in no way diagnostic of memory impairment; however, there might be some difficulty with memory that should be discussed with their physicians. Twelve people did not meet the inclusion/exclusion criteria, 1 from the community (history of neurological disorder) and 11 from seniors' residences (5 due to the 3MS scores, 6 due to inability to stand unassisted on the force plate).

Participants were contacted by telephone the night before their scheduled participation to remind them of the appointment. Each participant was seen individually for approximately 60 to 90 minutes. When participants arrived, they were ushered to a screening room where they met with the research assistant. The consent form was reviewed and questions answered (see Appendix D). Following signed consent the 3MS was conducted as per manual instructions (Wechsler, 1997).

The Berg Balance Scale was conducted as per instructions (Berg et al., 1989). Originally, a cut off score of 47 was intended to be used to assign people to the good balance and poor balance groups. Unfortunately, it was found that most people who had a score below 47 were unable to perform the balance task safely. As a result, part way through the study a decision was made to change the cut off score to that which most closely divided the sample into 2 groups. After data had been collected on 61 participants, the median was used to divide the sample into two groups. A score of 52 most closely divided the sample in half. Those who obtained a score of 52 or greater were placed in the good balance group. Those with a score of less than 52 were placed in the poor balance group. The Berg Balance Scale score was recorded on a sheet kept by the research assistant. The researcher was blind to this score.

Following group assignment, the researcher and a second research assistant directed the participant to a different room where the balance and memory measures were to be conducted. Participants were randomly assigned to start with either the sitting conditions or the standing conditions. Each participant underwent all sitting conditions consecutively and all standing conditions consecutively so that they would not be asked to alternate their position frequently. The five sitting conditions and the four standing conditions were randomly assigned for each participant using a random numbers table. A description of each of these nine conditions will be discussed below.

The Five Sitting Conditions

During the sitting conditions, each participant was seated in an armchair with a small card table 75 cm in height placed in front of him or her. The researcher sat opposite the participant at the table.

Sitting and Finger Tapping (single task condition). Participants were asked to hold the counter vertically in the palm of the hand with the button facing upwards. They were asked to choose the thumb that would best be able to depress the button repeatedly without discomfort. The same thumb was used for all FT trials that followed. The participants were asked to depress the button several times to get the feel of it prior to beginning the trial. The researcher then asked the participants to begin pressing the button as quickly as possible for 3 minutes.

*Sitting and Spatial Span (single task condition).*The SS was conducted as per WMS -III manual instructions while seated in a chair.

Sitting and Spatial Span and Finger tapping (dual task condition). First the participant was seated and instructions for the SS were given as per WMS-III manual instructions. The participant was also told that if he or she stopped depressing the counter at any time during the task, the second researcher would gently touch the finger tapping hand as a reminder. The researcher then asked the participant to begin pressing the button as quickly as possible and began the SS task. When the SS task was completed, the participant was told to stop pressing the button.

Sitting and Letter Number Sequencing (single task condition). LNS was conducted according to the instructions of the WMS-III administration manual with the participant seated in a chair.

Sitting and Letter Number Sequencing and Finger Tapping (dual task condition). First the participant was seated in a chair and instructions for the LNS were given as per WMS-III manual instructions. Afterwards finger tapping was explained in the same manner as with LNS and FT above.

The Four Standing Conditions

In the standing conditions, each participant was first fitted with a safety belt that was fastened around the waste. This belt had two handles at the back, which allowed the second research assistant a means to grip and steady the participant should he or she begin to lose balance. There were three sizes of belts (small, medium, and large) to accommodate all sizes of participants. Participants were then asked to stand on the compliant foam surface that was placed over the top of the Kistler force plate. They were told to stand with their feet sufficiently widely spread that they felt well balanced. Measurements were taken between the heels and between the first metatarsals so that if the participant needed to take a rest before completing the standing conditions, it would be possible to replace his or her feet to their original position on the compliant foam. The second research assistant stood directly behind the participants with hands positioned close to the handles of the safety belt in order to steady the participant should he or she lose balance.

A-P and M-L range and A-P and M-L RMS measures were obtained simultaneously by the force plate while the participant completed the standing condition tasks. A 35 × 54 cm table approximately 98 cm in height was placed in front of the participant. This was used for the SS and LNS administration manual and also for placing the SS board.

During the standing conditions participants were frequently asked if they were fatigued and needed a break. Eleven participants stopped for a rest.

Standing (single task condition). The participants were positioned on the force plate as described above, and asked to stand without moving their arms or speaking for 3 minutes.

Standing and Finger Tapping (dual task condition). After participants were positioned on the force plate as described above they were given the counter and the finger tapping task was described as above. Participants were asked to finger tap for 3 minutes while standing on the force plate.

Standing and Spatial Span (dual task condition). After participants were positioned on the force plate as described above, the SS task was conducted according to the instructions of the WMS-III administration manual.

Standing and Letter Number Sequencing (dual task condition). After participants were positioned on the force plate as described above, the LNS was conducted according to the instructions of the WMS-III administration manual.

Results

Data cleaning was conducted according to Tabachnick and Fidell's (1996) recommendations for screening of grouped data in analysis of variance. SPSS version 11.5 was used to analyze the data. Good balance and poor balance group data were analyzed separately, as recommended by Tabachnick and Fidell. A check on accuracy of data entry, missing data, skewness, and kurtosis for the data set was done through SPSS frequencies. The minimum and maximum values, means, and standard deviations of each variable were inspected for plausibility. There were no unusual values found. The participants who were not able to complete all of the conditions were not included in the study. For the 61 participants that completed all tasks, there were no missing data for any of the dependent variables. However, in four cases, the number of years of education was not recorded, and the group mean was substituted for the purposes of descriptive analyses.

Univariate outliers were defined as those data points with standard scores in excess of 3.29 or greater. Outliers were identified through SPSS explore. The number of standard deviations above the mean was calculated for all extreme scores. Any data points greater than 3.29 standard deviations above the mean were considered outliers. These values were then transformed to maintain their ordinal position in the data, but to make them just one unit larger or smaller than the closest data point. This technique is recommended by Tabachnick and Fidell (1996, p. 69) as a means to prevent outliers from overly influencing the results, while still contributing to the results. In the study where memory was the dependent variable, there were no outliers. In the study where balance was the dependent variable, there were 1,220 balance data collected, and of these 33 were outliers and were transformed as described above. In the study where finger tapping rate was the dependent measure, there were no outliers.

The standard score of skewness was determined by dividing the skewness by standard error of skewness. Similarly, the standard score of kurtosis was determined by dividing the kurtosis by the standard error of kurtosis. There were only minor deviations from normality. The central limit theorem indicates that with large sample sizes, sampling distributions of the mean are normally distributed regardless of the shape of the distribution of the variables. Tabachnick and Fidell (1996) indicated that if there are at least 20 degrees of freedom for error in a univariate ANOVA, the *F* test is robust to violations of normality of variables. The degrees of freedom for the error term are 59 in this study. Therefore it was considered that the *F* test would be robust to these minor deviations from normality.

Age is negatively correlated with both spatial memory performance (Simon et al., 1992; Arbuckle et al., 1994; Charness, 1981; Evans et al., 1984; Light & Zelinski,1983; Moore et al., 1984; Parket al., 1982; Pezdek, 1983; Salthouse, 1991; Salthouse et al., 1990; Wahlin et al., 1993) and balance (Bard et al., 1992; Teasdale et al., 1993; Brown et al., 1999). The poor balance group was significantly older than the good balance group. Therefore, the possibility of using age as a covariate was considered. However, there is a risk to using a covariate in the analysis if it is also related to the independent variable. Doing so may "...result in removal of some portion of the effect of the IV on the DV—the portion of the effect that is associated with the covariate "(Tabachnick & Fidell, 1996, p. 326). For this reason, a decision was made not to use age as a covariate in current study.

Study 1

Study 1 examined how different attentional tasks (sitting, standing, and finger tapping) influenced scores on a spatial memory task (SSF, SSB, and SS total) and a verbal memory task (LNS). A 2 × 3 ANOVA (Group × Attentional Task) was conducted for each of the four dependent variables (SS forward, SS backward, SS total, LNS). An alpha level of .05 was used to determine statistical significance when LNS was used as the dependent variable. A significance level of .02 was used when SSF, SSB, and SS total were used as the dependent variables, as they were all measuring aspects of the same construct. The Hundt-Feldt correction was used to adjust for violations of the sphericity assumption. The Bonferonni adjustment for multiple comparisons was used for all post hoc tests. Means and standard deviations by group in single task and dual task conditions are presented by group (see Appendix F).

For LNS there was an interaction between task and group, $F(1, 116) = 3.26$, $p = .04$ (see Figure 2). An analysis of the simple effects of task revealed that in the good balance group there was no effect of task, $F(2, 56) = .45$, $p = .64$. However in the poor balance group there was an effect of task, $F(2, 60) = 5.40$, $p = .007$. A pairwise comparison of tasks in the poor balance group revealed that LNS scores were higher when sitting than when standing, $p = .027$, and they were also higher when sitting than when finger tapping, $p = .037$. However LNS scores were equal while standing and while finger tapping, $p = .93$.

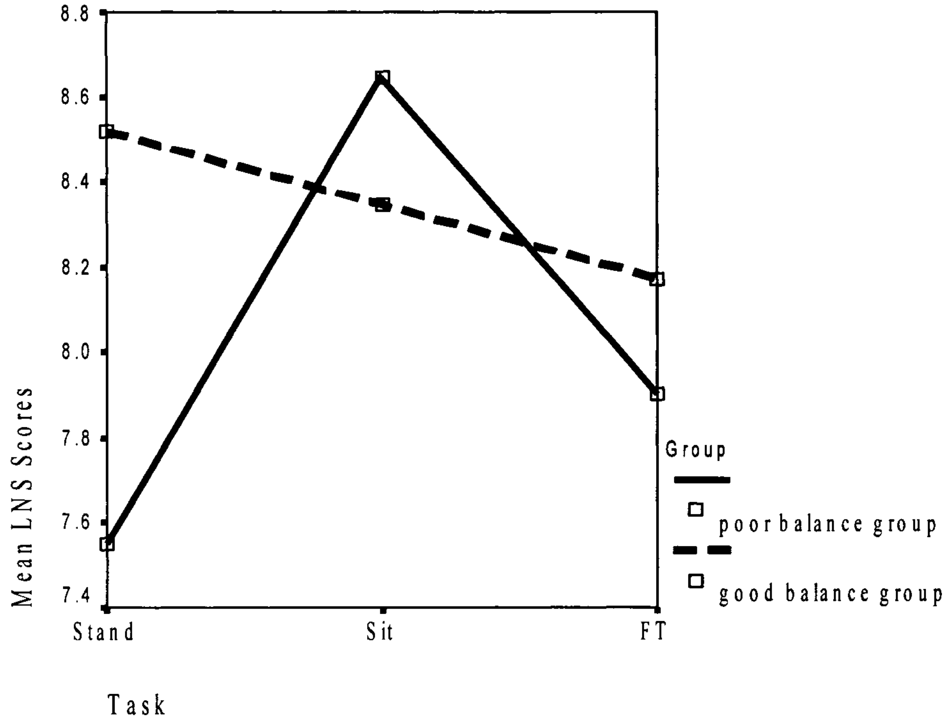

Figure 2. Mean Letter Number Sequencing (LNS) score when standing, sitting, and finger tapping (FT).

For SS forward there was a significant interaction between task and group, *F*(1.99,117.93) = 4.51, *p* = .01 (see Figure 3). In the poor balance group there was a significant effect of task, *F*(2, 62) = 10.96, *p* = .00. SS forward scores were similar (*p* = .339) in the sitting and standing conditions. However, scores in the finger tapping condition were lower than in both the sitting (*p* = .00) and standing conditions (*p* = .00). In the good balance group, there no effect of task, *F*(1.89, 52.89) = 3.37, *p* = .04. In this group, the scores were equivalent while sitting and while standing. The scores were also equivalent in the sitting and finger tapping conditions (*p* = .04) as well as in the standing and finger tapping conditions (*p* = .69).

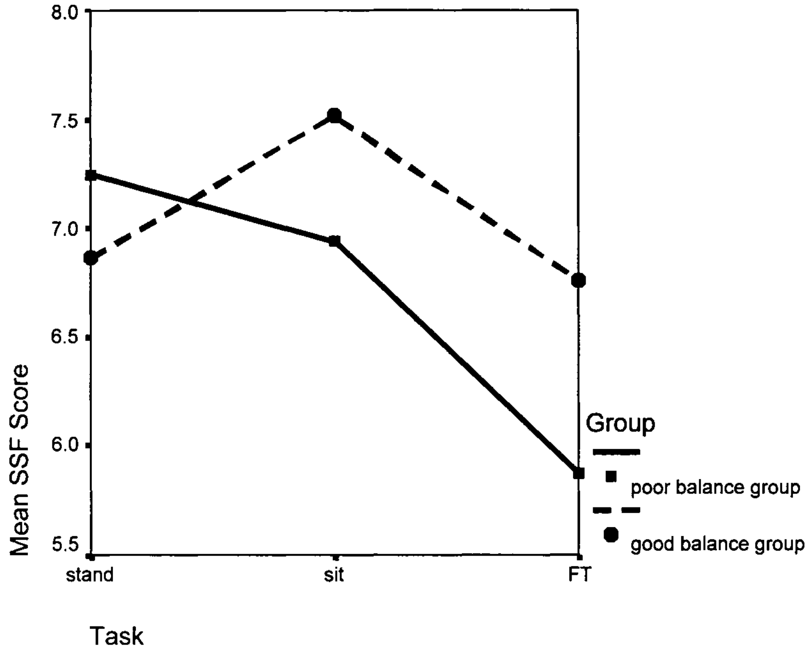

Figure 3. Mean Spatial Span Forward (SSF) score while standing, sitting, and finger tapping (FT).

For spatial span backwards, there was no interaction between task and group, *F*(2, 118) = .49, *p* = .61 (see Figure 4). However, there was a main effect of task, *F*(2, 118) = 20.00, *p* = .00, and a main effect of group, *F*(1, 59) = 5.81, *p* = .019. With respect to task, this main effect stemmed from the fact that SSB scores were significantly higher in the sitting condition than in the standing condition (*p* = .00) or the finger tapping condition (*p* = .00). Furthermore, the SSB scores were equal while standing and while finger tapping (*p* = 1.00). The main effect of group was due to the good balance participants scoring higher on SSB than poor balance participants (*p* = .00).

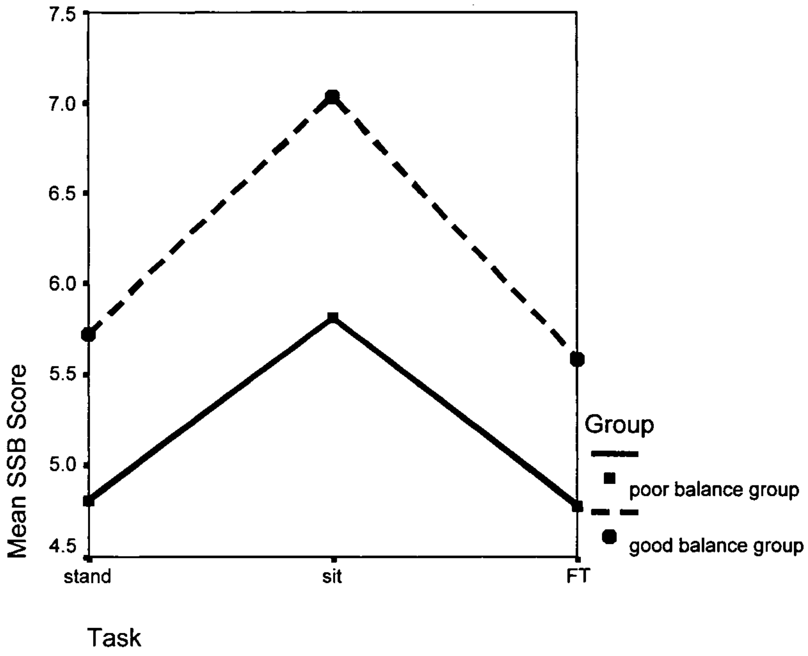

Figure 4. Mean Spatial Span Backward (SSB) while standing, sitting, and finger tapping (FT).

For SS total, there was no interaction between group and task *F*(2, 118) = 2.15, *p* = .12 (see Figure 5). There was no main effect of group, *F*(1, 59) = 4.08, *p* = .05. There was a main effect of task, *F*(2, 118) = 23.72, *p* = .00, which was due to the fact that the SS total scores differed from one another in all conditions. Scores were highest while sitting. They were significantly lower while standing(*p* = .00) and lower still while finger tapping (*p* = .02).

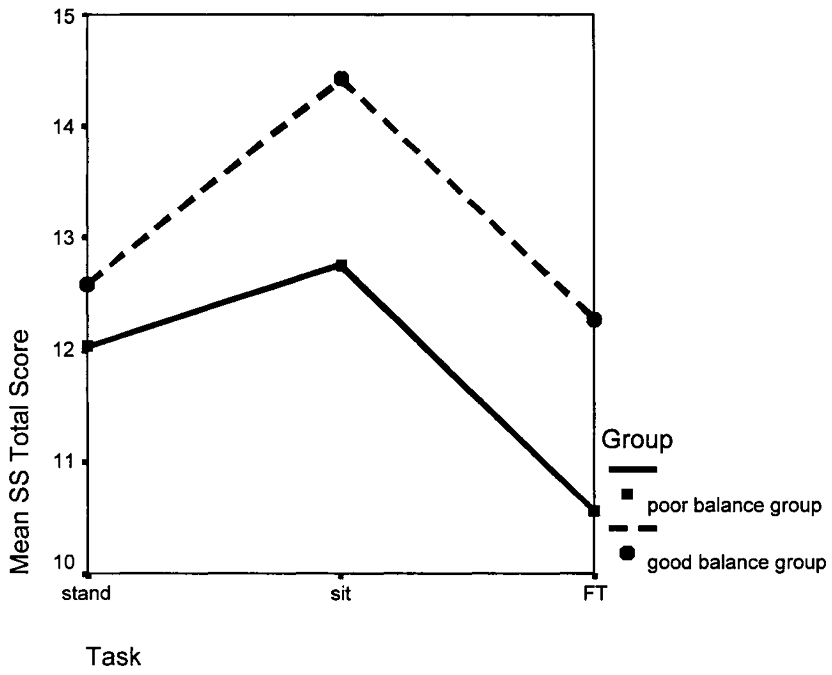

Figure 5. Mean Spatial Span Total (SS Total) score while standing, sitting, and finger tapping (FT).

In summary, the results of study 1 indicate that there was an interaction between group and task when LNS was used as the dependent variable. This interaction resulted from similar LNS scores in the sitting, standing and finger tapping conditions in the good balance group, but significantly lower LNS scores in both the standing and finger tapping conditions as compared to the sitting condition in the poor balance group.

With respect to spatial memory, there was no interaction between group and task when SS total was used as the dependent variable. However, there was a main effect of task, with the standing condition having lower SS total scores than the sitting condition, and the finger tapping condition having the lowest scores. SSB and SSF are the two scores which are combined to yield the SS total score. When these scores were examined individually, it was apparent that both standing and finger tapping conditions producing lower SSB scores than the sitting condition. However, with SSF there was an interaction between task and group. This interaction was due to significantly lower SSF scores in the finger tapping condition as compared to the standing and sitting conditions in the poor balance group. However, in the good balance group SSF scores were equivalent in all three conditions. With the SS total score, the standing condition produced lower SS total scores than the sitting condition, and the finger tapping condition produces SS total scores significantly lower than the standing condition.

Study 2

In the second study the purpose was to determine whether or not a change in attentional task (SSF, SSB, LNS, or finger tapping) influenced four different measures of balance (A-P range, A-P RMS, M-L range, and M-L RMS) or whether a change in attentional task (SSF, SSB, LNS, or standing) influenced finger tapping rate. Because there are four dependent variables which all measure an aspect of balance, a significance level of .01 was used for the balance measures. A significance level of .05 was used for finger tapping rate. Once again, the Hundt-Feldt correction was used to adjust for violations of the sphericity assumption and the Bonferonni adjustment for multiple comparisons was used for all post hoc tests. Means and standard deviations by group in single task and duals task conditions are presented by group (see Appendix G)

For mean A-P range, there was no interaction between group and task, $F(3.61, 212.73) = 1.22, p = .31$ (see Figure 6). There was a main effect of group that approached significance, $F(1, 59) = 4.90, p = .03$, as a result of the poor balance group having a greater range in the anterior-posterior direction. There was a main effect of task, $F(3.61, 212.73) = 6.66, p = .00$. The main effect of task was due to the fact that A-P range while standing and conducting LNS was higher than when only standing ($p = .01$), A-P range was higher when standing and finger tapping than when standing and conducting SSB ($p = .01$), and A-P range was higher when standing and conducting LNS than when standing and conducting SSB. As well, A-P range while only standing was equivalent to A-P range while standing and conducting SSF ($p = 1.00$), while standing and conducting SSB ($p = 1.00$), and while standing and finger tapping ($p = .76$).

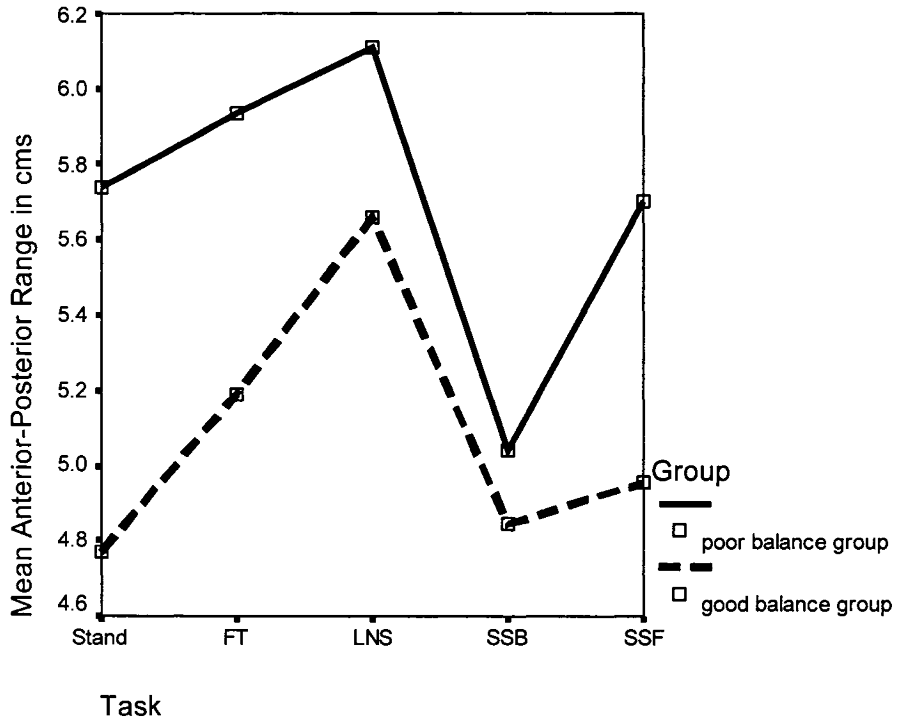

Figure 6. Mean Anterior-Posterior Range measures while standing, finger tapping (FT), and performing Letter Number Sequencing (LNS), Spatial Span Backward (SSB), and Spatial Span Forward (SSF) tasks.

For mean M-L range there was no interaction between group and task, $F(3.41, 201.49) = 3.16, p = .02$ (see Figure 7). There was a main effect of group, $F(1,59) = 12.59, p = .00$, which resulted from the poor balance group having a larger M-L range than the good balance group. There was also a main effect of task, $F(3.41, 201.49) =$

4.35, *p* = .00. This main effect was due to a higher M-L range while standing and conducting LNS than while standing and finger tapping (*p* = .00) or while standing and conducting SSB (*p* = .00).

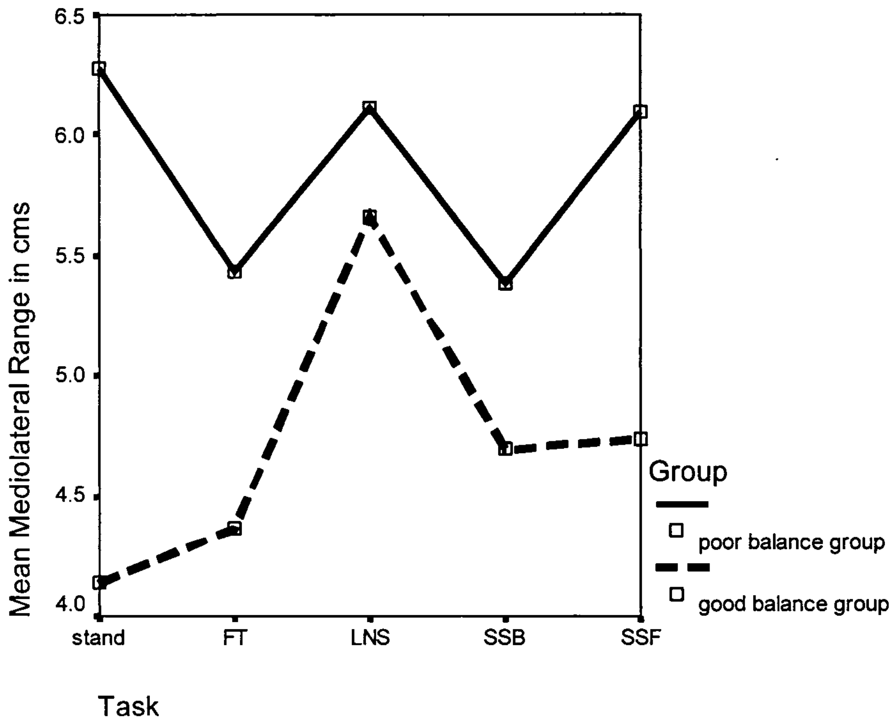

Figure 7. Mean M-L Range measure while standing, finger tapping (FT), and performing Letter Number Sequencing (LNS), Spatial Span Backwards (SSB), and Spatial Span Forward (SSF) tasks.

For mean A-P RMS there was no interaction between the group and task, *F*(3.42, 201.81) = .63, *p* = .62 (see Figure 8). There was no main effect of task, *F*(3.42, 201.81) = 1.29, *p* = .28, or group *F*(1, 59) = .91, *p* = .35.

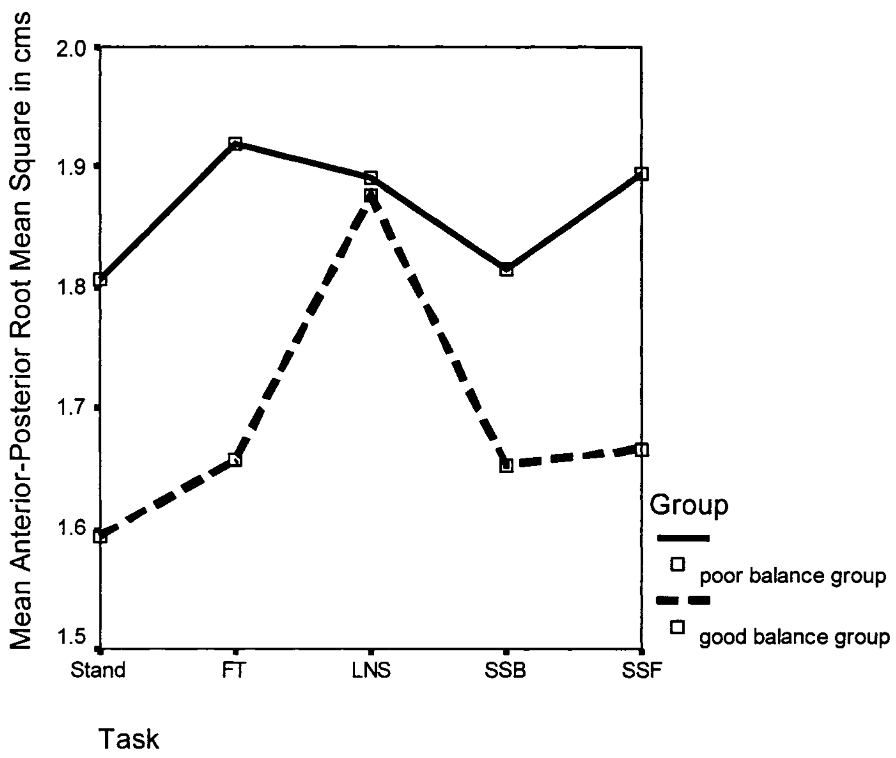

Figure 8. Mean Anterior-Posterior Root Mean Square (A-P RMS) measure while standing, finger tapping (FT), and performing Letter Number Sequencing (LNS), Spatial Span Backwards (SSB), and Spatial Span Forward (SSF) tasks.

For mean M-L RMS there was no interaction between task and group, *F*(3.60, 212.47) = .72, *p* = .28 (see Figure 9). There was no main effect of task, *F*(3.60, 212.47) = .42, *p* = .77. There was a main effect of group *F*(1, 59) = 7.06, *p* = .01 which was due to the fact that the poor balance group had a larger M-L RMS than the good balance group.

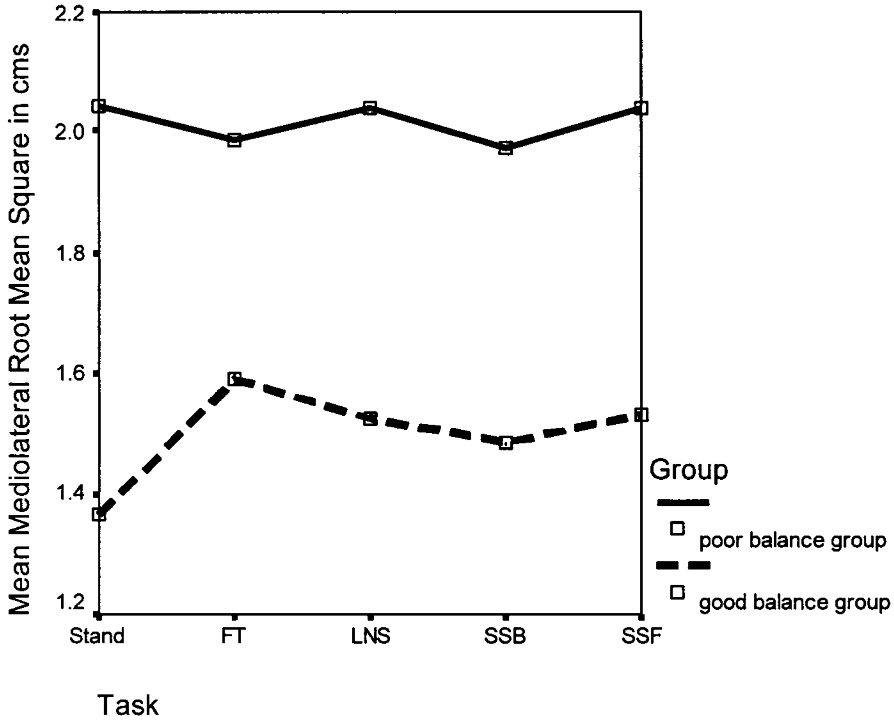

Figure 9. Mean Medio-Lateral Root Mean Square measure while standing, finger tapping (FT),and performing Letter Number Sequencing (LNS), Spatial Span Backwards (SSB), and Spatial Span Forward (SSF) tasks.

There was no interaction between task and group for finger tapping, *F*(3.85, 226.94) = 1.67, *p* = .16 (see Figure 10). There was no main effect of group, *F*(1, 59) = 3.15, *p* = .08. There was a main effect of task, *F*(3.85, 226.94) = 68.44, *p* = .000. This main effect was due to the fact that finger tapping rate was equal when conducted as a single task, as compared to when finger tapping was conducted while standing (*p* = 1.00). However, finger tapping rate was significantly higher when finger tapping was conducted alone as compared to when it was conducted with SSB (*p* = .000), SSF (*p* = .000), and LNS (*p* = .000).

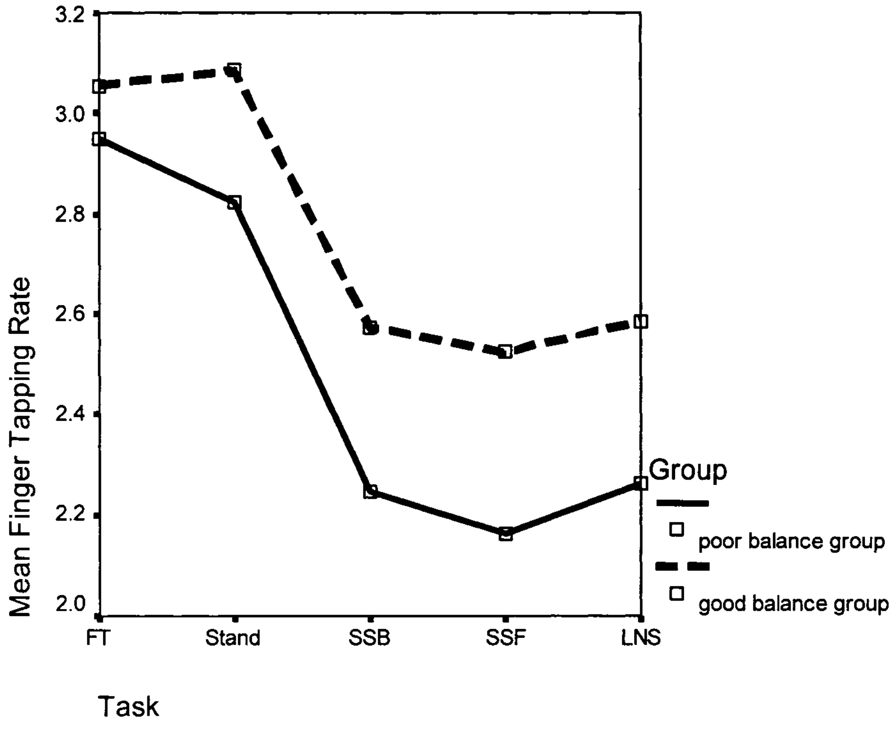

Figure 10. Mean rate of finger tapping (in seconds) while sitting, standing, SSB, SSF, and LNS.

In summary, the results of study 2 indicated that there were no interactions between task and group for any of the four measures of balance. There was a main effect of group in two balance measures (M-L RMS, M-L range), with the poor balance group having higher means than the good balance group. There was also a main effect of task on two measures (A-P range, M-L range) with the LNS condition producing a higher mean range and SSB producing a lower mean range.

Finger tapping rate was equal when finger tapping as a single task and when finger tapping and standing. It was significantly lower when conducting SSB, SSF and LNS.

Discussion

In order for Kahneman's (1973) theory of attentional resources to be unequivocally supported by this study, the following three hypotheses should have been supported.

1. In all dual task conditions there should have been a decrement in the performance of one or both tasks which was proportional to the combined attentional requirements of the two tasks.
2. There should have been exaggerated interference effects in the poor balance as compared to the good balance group because the poor balance participants theoretically require more attentional resources for balance tasks.
3. If interference effects are to be explained by a competition for a single, finite source of attentional resources, then a similar pattern of interference should have existed for finger tapping as for balance.

Each of these hypotheses will be discussed with respect to the results.

Hypothesis 1

With respect to hypothesis 1, first it is important to examine whether or not the various tasks appeared to be attentionally demanding. There were interference effects in dual task situations that included spatial memory measures, verbal memory measures, balance measures and finger tapping measures. This finding suggests, as was expected, that each of these tasks requires attentional resources. The next question is, in the dual task situations, was the decrement in the performance of one or both tasks proportional to the combined attentional requirements of the two tasks?

This is a more difficult question to answer for reasons that were discussed by Abernethy (1988). When the performance of the primary task is held constant, the change in performance of the secondary task is believed to be indicative of the attentional requirements of the primary task. However, when neither task is primary nor secondary, as was the case in the current study, the interpretation of results is more difficult because it is left up to the individual to determine how resources should be allocated. The decision was made in this study that the interpretive challenges posed by not prioritizing tasks were balanced by the ecological validity of the results. In order to address hypothesis 1, the results were interpreted in the following way.

If one were to envision attentional resources as being a finite resource, then if the additive attentional demands of two tasks, performed simultaneously, did not exceed the available supply of resources, there would be no decrement in performance of either task. When slightly more resources are required than are available, perhaps there is a decrement in the performance of only one task. When the attentional resources required far exceed the resources available, then perhaps both tasks would be influenced. This explanation, although admittedly simplistic, is in keeping with Kahnman's theory of attentional resources. It is also supported by Hasher & Zacks (1979), who discussed the idea that there exists a continuum of attentional resources demanded by various tasks and processes. This continuum ranges from automatic to effortful.

If the interference effects observed are the results of the summed attentional demands of the paired tasks, then by examining the pattern of results in the current study, it should be possible to arrange the tasks hierarchically according to attentional demands. Two tasks with low attentional demands paired together might lead to no decrement in either task performance in the dual task condition as compared to the single task condition. Two tasks with high attentional demands paired together might lead to decrements in the performance of both tasks, and pairings in-between might lead to a decrement in performance of only one task.

Based on these assumptions tasks were arranged hierarchically. First the mutual effects of standing on a compliant surface while conducting various attentional tasks (LNS, SSB, SSF, and finger tapping) were examined. SSF and standing did not cause a decrement in performance of either task. The same was true for finger tapping and standing. Therefore, standing on a compliant surface, finger tapping, and SSF were all initially considered to require little attention. SSB and standing caused a decrement in performance of one task. Standing was already deemed to require few attentional resources. Therefore, it was assumed that SSB requires an intermediate amount of attentional resources. LNS and standing resulted in a decline in performance of both tasks for the poor balance group and one task for the good balance group. Therefore, LNS was assumed to require the greatest number of attentional resources.

The next step was to examine the mutual effects of finger tapping with various tasks (LNS, SSB, SSF, and standing). In every dual task pairing there were mutual detrimental effects on performance except with LNS in the good balance group where LNS performance was spared, and in the standing condition, where both balance and finger tapping performance were spared. Thus, given the fact that in one group LNS performance was spared, it would also appear that LNS has fewer attentional requirements than both SSB and SSF.

When these results were examined a number of curious facts emerged. When paired with standing, SSF seemed to require the fewest resources followed by SSB, with LNS requiring the most. When paired with finger tapping it seemed that LNS required the fewest number of resources with SSF and SSB requiring more. Also, given the fact that both standing on a compliant surface and finger tapping caused interference in other tasks, why, when paired with each other, was there is no interference? Clearly, a hierarchy of attentional resource requirements alone cannot fully explain the pattern of results that exists in the current study.

In summary, there was no evidence to support the first hypothesis. It would appear that the quantity of resources required for each task could not simply be added to the quantity of resources of the task with which it was paired in order to predict the interference effect.

Hypothesis 2

The next question to be answered was whether or not these interference effects could be attributed to a competition for attentional resources, or whether there was some other explanation. This question was addressed by testing the interference effects of postural balance as well as by testing the interference effects of an attentionally demanding task which differed from balance, and did not require vision—the finger tapping task.

Perhaps the most interesting finding in this study related to hypothesis 2. The balance task and the finger tapping task caused similar interference effects in the verbal memory task (LNS). This result suggests that the two tasks were equal in their attentional demands. In the good balance group, LNS scores were equivalent in the finger tapping condition as compared to the standing condition. In the poor balance group, finger tapping and standing both caused an equivalent decline in LNS performance. Furthermore, both balance and finger tapping performance declined in the dual task condition (when paired with LNS), as compared to single task performance. Interestingly, this was not the case with the spatial memory task. SS total was the highest when sitting (the single task condition), it was lower when standing (dual task condition), and lower still when finger tapping (dual task condition). In other words, standing seems to be less attentionally demanding when paired with a spatial memory task than when paired with a verbal memory task. This difference between verbal and spatial memory was even more apparent when the dual task effect on balance and finger tapping performance was examined. Finger tapping declined significantly when performing the spatial memory tasks (SSB and SSF); however balance, when paired with these same tasks, was unaffected. The fact that verbal and spatial memory would be associated with such different interference effects was not anticipated.

In summary, the second hypothesis was not fully supported. Both finger tapping and standing were associated with decrements in the performance of some of the tasks with which they were paired. This result would imply that they are both to some extent attentionally demanding. However there were differences in interference effects, depending upon the nature of the second task, which could not be easily explained by Kahneman's theory of attentional resources. Finger tapping and standing were equally attentionally demanding when paired with a verbal memory task, but standing was less attentionally demanding than finger tapping when paired with a spatial memory task

Hypothesis 3

A further prediction was that the poor balance group would find the balance task more attentionally demanding than the good balance group, and thus there would be an interaction between task and group. This hypothesis was, again, only partially supported. There was an interaction between task and group when both the LNS task performance and with the SSF task performance were used as the dependent variable. However, there was no interaction between group and task when SSB, SSF or SS total were used as the dependent variable. When the four balance measures were used as the dependent variable, there were no interactions between group and task.

One possible explanation for the lack of interaction in most of the analyses relates to the fact that the good balance group was not sufficiently different from the bad balance group. The task of standing on a compliant surface was chosen as the balance task because it was deemed to be sufficiently difficult to require attentional resources. While this proved to be true, it was so difficult a task that many of the potential candidates declined to participate because they felt it would be too difficult, and six who felt initially that they could accomplish the task were unable to do so. As a result, the poor balance and good balance groups were fairly similar to one another. In fact they did not differ significantly on two of the four measures of balance (M-L range, and M-L RMS), thus potentially watering down the interaction that might otherwise have been there.

There was an interaction between task and group when LNS was used as the dependent measure. Participants in the good balance group had equivalent LNS scores whether they were sitting, standing, or finger tapping. In the poor balance group, adding a secondary task, whether it was a balance task or finger tapping task, caused a significant decrement in verbal memory performance. In examining the effect of conducting the LNS task on postural balance, there were two measures of balance which were affected (M-L range, and A-P range). In both instances, this was because range was higher while conducting LNS than while conducting SSB, and in the case of A-P range, this was also because range was higher while standing and conducting LNS than while just standing. It is important to remember that the measure of range represented a momentary change in balance. If one group had consistently poorer balance, this would be evident in a RMS measure. A higher range meant that people were more likely to have a momentary lapse of postural stability in the LNS condition as compared to the SSB condition.

With respect to spatial memory, the picture was somewhat more complex. With SSF, there was an interaction between task and group that resulted because the good balance group had equivalent SSF scores in all three conditions (sitting, standing, and finger tapping); however the poor balance group had equivalent scores when sitting and standing, but significantly lower scores while finger tapping.

SSB presented a different picture. There was no interaction between group and task. Adding a secondary task, either standing or finger tapping, resulted in a decrement in SSB performance in both groups. As well, in two measures of balance (A-P range and M-L range), there were significant differences between the SSB condition and the LNS condition, with balance being more stable in the SSB condition. Again, because there was no interaction between group and task, it was not possible to examine group differences statistically. However, an examination of the A-P range and M-L range graphs would suggest that the poor balance group may actually become more stable in the dual task condition (SSB and standing) as compared to the single task condition (standing).

When SSF and SSB were combined to become SS total, the results were similar to SSB. There was no interaction between task and group. However, in both dual task conditions (ie. when paired with standing and finger tapping) SS total scores declined, however this effect was greater in the finger tapping condition. The effect of SS total on the four balance measures and finger tapping rate could not be examined because SS total was not a condition in itself, but rather a mathematical sum of the SSB and SSF scores. However, in both the SSB and SSF conditions there was no decrement in balance performance, and for both SSB and SSF there was a decrement in finger tapping performance.

Finally, the pattern of effects of the finger tapping task across conditions was interesting. When finger tapping was paired with LNS, SSB, SSF finger tapping rate declined in each case, and there were mutual negative effects on performance in both tasks in all cases except one. When LNS and finger tapping were paired in the good balance group, finger tapping rate declined, but LNS scores did not. In one case, when finger tapping was paired with standing, there were no effects in either task

In summary, there were differences in the interference effects between spatial memory tasks and balance, and between verbal memory tasks and balance. The verbal memory task had an interaction in the expected direction, with the poor balance group having greater interference effects. The spatial memory task did not. There were other differences between LNS and SSF and SSB. When LNS and balance were paired, balance was affected in both cases. With the spatial memory tasks, balance was not affected. Furthermore, the interference effects were different when balance was used as a secondary task as compared to when finger tapping was used as the secondary task.

The current study is based on Kahneman's theory of attentional resources because this is the theory which guides, although sometimes implicitly, most of the research regarding the relationship between spatial memory and balance. However, all three of the expected results predicted by Kahneman's theory have not been supported. Perhaps Kahneman's theory is too simplistic.

Other studies examining the relationship between balance and cognitive tasks have also been based on a theoretical perspective similar to Kahneman's (Kerr et al., 1985; Andersson et al., 1998; Brown et al., 1999; Shumway-Cook et al., 1997; Maylor & Wing, 1996; Maylor et al., 2001; Dault et al., 2001; Swan et al., 2004). However, the results of these studies have been inconsistent. Some studies show that balance tasks affect spatial memory task performance (Kerr et al., 1985; Andersson et al., 1998); others show that spatial memory task performance affects balance task performance (Kerr et al., 1985; Andersson et al., 1998; Shumway-Cook, et al.,1997; Maylor & Wing, 2001; Dault et al., 2001; Swan et al., 2004). However, the nature of the effect on the balance task varies across studies. Some studies have indicated that concurrent spatial and postural tasks cause greater postural instability in some groups (Anderson et al., 1998; Shumway-Cook et al., 1997) and others have found the reverse, that postural stability was enhanced under dual task conditions (Kerr et al., 1985; Andersson et al., 1998; Maylor & Wing, 2001; Dault et al., 2001; Swan et al., 2004). One of the reasons that it has been difficult to explain these inconsistent results may be that their theoretical underpinnings were too simplistic.

A review of the working memory literature reveals that there has been an evolution in the conceptualization of memory from that of a unitary system, to a complex multifaceted series of systems. John Brown (1958) and later Peterson and Peterson (1959) provided the first evidence that there may be more than one system involved in memory. They demonstrated that material is forgotten within seconds if rehearsal is prevented, thus suggesting that there may be two systems, a short-term and a long-term memory system. Later Atkinson and Shiffrin (1968) proposed a model of memory in which there were three separate types of memory store, a sensory memory system, a short-term memory system, and long-term memory, which fed into one another. Unfortunately, this model could not account for those individuals who had short-term memory deficits without long-term memory deficits (Baddley, 1992).

Later work by Baddeley & Hitch (1974) suggested that memory could be further subdivided. Using a dual task paradigm, they found an effect of concurrent digit span on a wide range of cognitive tasks; however, there was a small magnitude of effect and a total lack of effect on recency. These findings did not fit with the previous model. Thus, Baddeley & Hitch (1974) proposed a multicomponent working memory model in which working memory (previously referred to as short-term memory) was controlled by a limited capacity attentional system called the central executive. The working memory was supported by at least two additional systems—the phonological loop, and the visuospatial sketch pad (Baddley, 1992). The visuospatial sketchpad in this model held visual and spatial information. The phonological loop held verbal information. The central executive was responsible for the control and distribution of the limited attentional resources.

Further studies used a dual task paradigm to determine how the various systems of this model were related to one another. A study by Baddeley & Lieberman (1980) revealed that when a spatial memory task was conducted concurrently with a second spatial memory task, there was a greater decrement in performance than if a spatial memory task was paired with a verbal memory task. Similarly, when a verbal task was performed concurrently with another verbal task, the decrement in performance was greater than when the verbal memory task was paired with a secondary spatial memory task. This would suggest that once attentional resources had been deployed to the phonological loop or the visuospatial sketchpad, there could be further competition for these resources.

As in the working memory literature, there are competing hypotheses within the attentional literature that aid in the understanding of attentional resources. Two such models will be discussed, a general resource account of interference, and a multiple resource account of interference.

This general resource account of interference suggests there is a unitary source of attentional resources that are finite in nature. All tasks requiring attention compete for this finite resource. When the demands of the tasks exceed the resources available, there is a decrement in performance of one or both of the tasks (Fernandes & Moscovitch, 2003). Only the attentional requirements of the tasks, and not the nature of the tasks, should influence the interference effects, according to this model. This general resources account of interference, more specifically Kahneman's version of this, is the model upon which the current study is based. It is also the model upon which previous studies examining balance and spatial memory are based (Kerr et al., 1985; Andersson, et al., 1998; Dault, et al., 2001; Maylor & Wing, 1996; Maylor et al., 2001; Swan, et al., 2004; Shumway-Cook et al., 1997). This model will be referred to as the unitary resource model.

In contrast to the unitary resource model, the multiple resource model suggests that there is more than one pool of attentional resources that process different types of materials (Allport, Antonis, & Reynolds, 1972; Brooks, 1968; Wickens, 1980). If two tasks are performed concurrently and they draw from the same pool of resources, then there is decrement in performance of one or more tasks. If two tasks are performed concurrently and they do not share the same pool of resources then there should be no decrement in performance. Many dual task studies have demonstrated that interference effects are larger when two verbal tasks are performed concurrently compared to a verbal and a spatial task (Baddeley, Grant, Wight, & Thomson, 1973; Farmer, Berman, Fletcher, 1986). It is in this area of research that the working memory literature and the attentional literature clearly overlap (Baddeley & Lieberman, 1980).

As was discussed above, the results of the present study cannot be entirely explained by a unitary resources model of attention. The question is: Do the results of this study fit better with a multiple resource model of attention? The multiple resource model proposes that rather than a unitary source of attentional resources, there are two separate types of attentional resources: visuospatial memory resources and verbal memory resources. Further, the multiple resource model would predict that two tasks that draw from the same resource pool, when performed simultaneously, would compete for this finite quantity of resources and thus there would be a decrement in performance in one or both tasks. Similarly, tasks that draw from two separate resource pools do not compete with one another for attentional resources and would be performed simultaneously without interference.

Unfortunately, the present study was not designed to test the multiple resources model. Therefore two verbal tasks and two visuospatial tasks were not performed simultaneously. Furthermore, some tasks were neither visuospatial nor verbal tasks. LNS, a verbal task, would draw from a verbal memory resource pool. SSB and SSF are visuospatial tasks and they would draw from a visuospatial memory resource pool. Standing is somewhat more complex. It is a motor task, but it also has a visual component and thus may in some ways draw from the visuospatial resource pool. Finger tapping is a motor task. The multiple resource model does not address the topic of motor tasks and whether such tasks are conceptualized as drawing from their own separate pool of resources. For the purposes of exploring the utility of the multiple resource model with respect to the current data, a third separate resource pool is proposed—a motor resource pool. With this added resource pool, an effort will be made to determine if the results of the current study can be explained by the multiple resource model.

The tasks from the present study can now be conceptualized as drawing from three resource pools: a visuospatial resource pool, a verbal resource pool, and a motor resource pool. In the current study there were four dual task pairings in which each of the two tasks drew from separate resource pools. LNS and finger tapping drew from the verbal resource pool and the motor resource pool, respectively. SSB and finger tapping drew from the visuospatial resource pool and the motor resource pool, respectively, and SSF and finger tapping drew from the visuospatial resource pool and the motor resource pool, respectively. When LNS and standing were paired, LNS drew from the verbal resource pool and standing on a compliant surface drew from the motor resource pool as well as the visuospatial pool. In all of these cases there were interference effects in the motor task, and in some cases (LNS and standing, LNS and finger tapping in the poor balance group) there was interference in both tasks. These results would imply that if there are multiple resource systems, they are not completely independent of one another. Furthermore, the multiple resource model would predict that two tasks which draw from the same resource pools should cause maximal interference. This did not prove to be the case.

In summary, neither the unitary model of attentional resources nor the multiple resource model can fully explain the results of the current study. The unitary model is unable to explain why two tasks shown to interfere with other tasks (standing and finger tapping) can nonetheless be performed together without decrement. Nor can it explain the lack of interaction between group and task, and the differing additive effect of attentional demands across dual task situations. The multiple resource model is unable to explain why two tasks that draw from separate resource pools demonstrate interference. Nor does it predict or explain what happens when two tasks are paired together, tasks that draw from two different resource pools, but where one of the two tasks actually draws resources from both pools.

A new model of attentional resources that combines the basic principles of both the unitary resource model and the multiple resource model may better explain the data of the current study. This new model, will be applied to the previous research in the area of balance and spatial memory to see if the results of these studies can be better explained.

A New Model

The new model (See Figure 11) will be conceptualized as having a single central resource pool as is suggested by the unitary resource model. This central pool, which will be referred to as the central executive, is responsible for the allocation of attentional resources. The central executive feeds three task-specific resource pools: a motor pool, a verbal pool, and a visuospatial pool.

Tasks are seen as varying in their attentional requirements. However, it is difficult to determine precisely the hierarchical order of attentional requirements of each task in the current study. This difficulty is due to the fact that the pattern of interference was different depending upon whether the cognitive tasks were paired with the balance task, or whether they were paired with the finger tapping task. Thus, the hierarchy of attentional requirements is not indicated in the model.

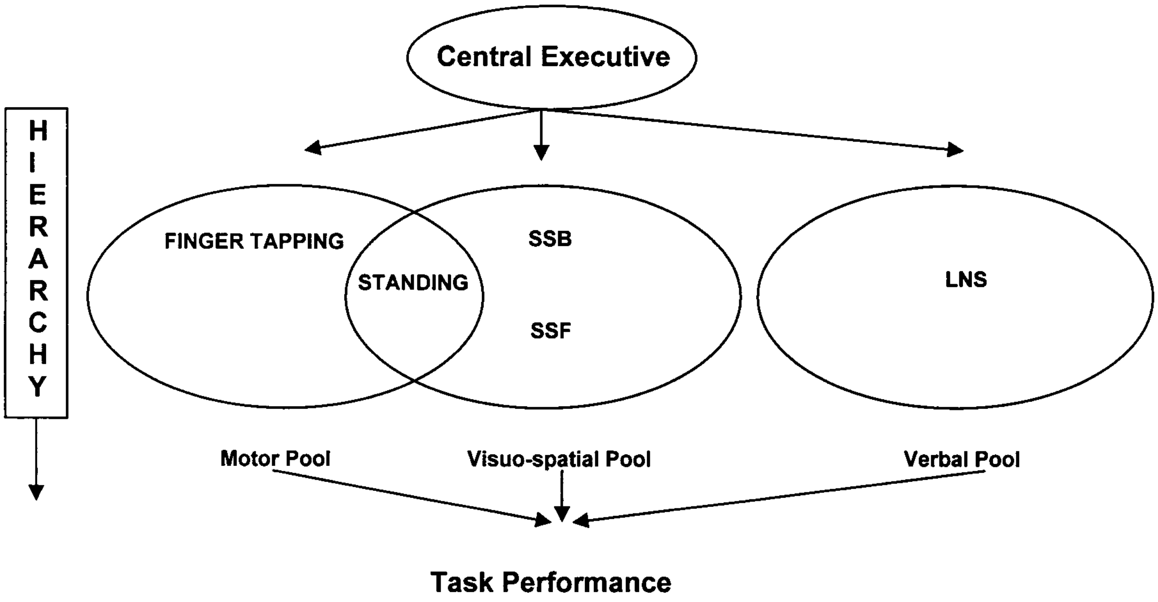

Figure 11: The New Attentional Resources Model

The balance task overlaps two resource pools. Thus, in the model, the visuospatial pool and the motor pool overlap, and the standing task is depicted in the ellipse shared by the two pools. The output of the model is task performance.

In the present study, when two tasks were paired together, sometimes the two tasks drew from separate pools and sometimes they drew, at least partially, from the same pool of resources. Using this three-pool conceptualization, we can see that the following dual task pairs draw from different pools:

SSF and FT
SSB and FT
LNS and FT
LNS and Standing

The following dual task pairs draw some of their resources from the same pool, with one of the tasks (standing) overlapping more than one pool:

Standing and SSF
Standing and SSB
Standing and FT

According to the new model, these two groups of dual task pairings are different with respect to whether or not the tasks draw from separate or common resource pools. As a result, one might expect a difference in the interference effects in these two groups. This was in fact the case. When the two tasks shared a common pool of resources (SSF and standing, SSB and standing, finger tapping and standing) the motor tasks were spared interference effects in every case. Conversely, in the four instances when there was no sharing of resource pools the motor task performance was negatively affected.

Using the new model, perhaps these results could be explained in the following way. When two tasks that draw from completely separate resource pools are performed together, the central executive makes a decision about which task takes priority and how resources should be dispersed. The size of the decrement in performance will be dependent upon the additive quantity of the attentional resources required, and the quantity of resources that are available. If one task is deemed lower priority, it will receive fewer resources and the decrement in performance of that task will be greater. The quantity of resource required to complete a task will vary from person to person. For example, a person with poor balance might require more resources than a person with good balance to carry out a balance task, thus leaving fewer resources available to carry out other tasks.

These principles are illustrated when LNS and standing are simultaneously performed. The two tasks draw from different resource pools. Both the good balance and poor balance groups must divert enough resources to the balance task to ensure safe stability. Enough resources are retained for the balance task to maintain safe postural stability, but given the attentional requirements of the secondary task, some resources must be diverted, unless, of course, the two tasks combined do not exceed the available resources. In the poor balance group, the number of resources required to maintain postural stability is greater. As a result both groups have a slight decline in postural stability whereas only the poor balance group has a decline in LNS scores.

Where there is one task overlapping two pools, the explanation is different. The central executive determines the allocation of resources as before, and the attentional resources are diverted to the appropriate resource pools. However, it is possible that this straddling of resource pools allows more flexibility in terms of where the resources for the balance task come from, or how those resources are used. The result is that the task which overlaps two pools, the balance task, is spared interference.

An anecdotal example might help to illustrate this point. In the current study, there was one woman who had particularly poor balance. The spotters were quite concerned about her safety on the force platform and were particularly vigilant in monitoring her balance, to prevent a fall if need be. Interestingly, when she performed the spatial tasks she was surprisingly more stable, so much so that the researcher and both spotters took note of this fact and discussed it afterwards. Perhaps because the balance task is complex with many facets including visuospatial and motor components, this individual was able to use a purely motor strategy (maintaining a more rigid stance) as a means of freeing up visuospatial attention for the spatial task. Furthermore, perhaps because her balance was dangerously poor, she was highly motivated to use such a strategy. This possibility fits well with the *posture first hypothesis* proposed by Shumway-Cook and colleagues (1997).

It is interesting to note that this finding is exactly opposite to what the multiple resource model would predict. The multiple resource model would predict that when two tasks draw resources from the same resource pool, they will compete for the same resources and there will be more of a decrement in performance than when the two tasks draw from separate resource pools. However, standing and finger tapping are both motor tasks and would both require motor resources. When they are performed together neither task demonstrates a decrement in performance.

Several predictions emerge from the new model.

1. If two tasks that are minimally attentionally demanding are conducted concurrently and the demands do not exceed the resources available there is no interference.
2. If two tasks are conducted concurrently and the demands exceed the resources available the nature and extent of the interference will depend upon a number of factors including the attentional requirements of the task, the attentional resources available, the task priorities as determined by individual, and the relationship of resource pools that are involved.
    - If both tasks draw from the same resource pool and no other, there is maximal interference
    - If both tasks draw from separate pools that do not overlap, a decision is made at the central executive level as to which resource pool if any has higher priority. This decision could be based on issues of safety (prevention of falling), the instructions provided by the researcher, or a number of other variables. The decrement in performance will be more evident in the task drawing from the lower priority resource pool. If both pools are deemed to have equal priority, there will be equal decrements in performance in the two tasks.

- If the two tasks draw from the same pool, but one of them also draws from another pool, the same predictions listed above apply. However, the task that overlaps the two pools is allowed more flexibility in the resources to which it has access. The result is that the overlapping task may be spared interference, or performance on that task may even be enhanced.

When these predictions are applied to verbal and spatial memory tasks, the following would be expected. If a verbal memory task and a spatial memory task require an equal number of resources the verbal memory task should be associated with greater interference effects when paired with a balance task. This would occur because the balance task overlaps two resource pools (motor and visuospatial) and thus the individual could use a more purely motor task strategy which would draw more resources from the motor pool, thus freeing up additional resources for the visuospatial pool. There are several possible outcomes when a verbal task and a spatial task are paired with a balance task. There could be a decline in stability in both the verbal and spatial task conditions, but less so in the spatial task. There could be a sparing of balance effects in the spatial task condition, but not in the verbal task condition. Lastly, there could be an increase in postural stability in spatial task condition, but not in the verbal task condition.

The question is, when a spatial and balance task are conducted concurrently, what are the factors that determine whether the balance task draws its resources from both the visuospatial pool and the motor pool as it normally would, or whether it favours one pool over another? The newly proposed model is not sufficiently complex to address this question. Perhaps some of factors proposed by Kahneman (1974) that influence how the resources are allocated also play a role here. These include:

1. *Enduring dispositions* that determine the rules of involuntary attention such as a novel signal, or a sudden movement.
2. *Momentary intentions* that allow you to make voluntary decisions about how to devote attention or divide attention.
3. *Evaluation of demands* that assesses the quantity of attentional requirement and makes decisions about how to divide attention if the demands exceed the capacity available.
4. *Effects of arousal,* which vary by the intensity of arousal. In situations of high arousal, attention is focused on the dominant aspects of the situation. High arousal impairs ability of the individual to discriminate between relevant and irrelevant aspects of the task. Thus high arousal generally leads to a decrement in performance, particularly in tasks requiring fine discrimination.

For instance, if an individual has good balance, it may be that he or she has no need to alter the typical manner in which resources are drawn from the two resource pools in order to maintain balance. A slight deterioration in postural balance may not be a problem. However, if an individual has poor balance and is asked to perform a difficult balance task, the evaluation of demands are high, furthermore arousal may be high as the task could potentially be dangerous. In such individuals an effort may be made to maximize the available attentional resources. As such, balance strategies could change. There may less of a reliance on visuospatial information, such as consciously observing the horizon for cues about postural equilibrium, because these resources are in demand for another visuospatial task. Conversely, there may be more reliance on balance strategies that draw from a motor resource pool such as tensing muscles to maintain a more rigid stance. As a result, it may be more common to see a sparing of interference effects in balance, or even increased stability, in individuals with poor balance as opposed to individuals with good balance.

Comparing the New Model with the Previous Literature

The results from previous dual task studies examining balance and spatial and verbal memory tasks have been mixed, and at times the authors have been unable to explain the findings, concluding only that the relationship between balance and cognition is complex. Perhaps this is because the theoretical underpinnings of these studies are based on models of attentional resources that are too simplistic.

When new model was applied to the previous literature that examined the relationship between spatial tasks, verbal tasks, and postural balance, the outcome was promising in that most of these studies fit with the newly proposed model. Eight such studies were examined.

The results of Andersson et al. (1998) fit well with the proposed model. This study found that a good balance group swayed more when performing the Brooks spatial memory task, but a bad balance group actually swayed less. This result could be explained by the evaluation of demands and arousal. In the good balance group, some resources could be diverted from balance without risk of falling; thus both the evaluation of demands and arousal are low. However, in the bad balance group, the evaluation of demands and arousal might both be high. Therefore, the bad balance group employed a different balance strategy. They used a more purely motor strategy to maintain safe balance, becoming more rigid in stance, thus freeing up visuospatial resources for the spatial task. There is some evidence that higher levels of arousal do moderate the effect of cognitive tasks on postural sway (Maki & McElroy, 1996).

In the study by Shumaway-Cook et al. (1997), the results again clearly fit with the proposed model. Here older healthy adults and older adults with poor balance were tested together with a group of young adults. This study found that in the younger group and the healthy older group there were no overall interference effects between a spatial task and a balance task. However, when the verbal and balance tasks were paired, balance became less stable in both groups. In the poor- balance older group the picture was somewhat different. Concurrent performance of both the spatial task and the verbal task caused greater instability, although the effect was greater with the verbal task.

In another study by Maylor et al. (2001) the results were more complex, yet still consistent with the newly proposed model. Here the study examined people between the ages of 20 and 79 while standing and performing either the Brooks spatial memory task, or the Brooks verbal memory task. In summary, the study found that during the encoding stage, stability increased during the spatial task performance, but not during verbal task performance. Conversely, during the retrieval phase, sway increased while performing the verbal task, but not while performing the spatial task. There were no effects on cognitive task performance. These results, although admittedly more complex, are still consistent with the new model. In both instances, stability was better in the spatial memory condition as compared to the verbal memory condition.

In a study by Maylor & Wing (1996) the main results that were reported seemingly conflict with the proposed model. However, a closer examination of the results indicated that in fact the fit between the results and the new model is good. Two groups of participants were included with mean ages of 57 and 77, respectively. Random digit generation, Brooks' spatial memory test, backward digit recall, silent counting, and counting backward by 3's were each performed while standing on a device designed to measure anterior-posterior weight distribution. The only two tasks which demonstrated significant interference effects were the Brooks spatial memory task and the digit span backward task. These two tasks were reported to require the use of the visuospatial sketchpad (VSSP). The interference effects reported were an interaction between group and the postural balance measure. More specifically, it was concluded that the older group had greater postural instability when performing the two visuospatial tasks than did the younger group. Thus it was reported that age differences in postural stability were increased by cognitive tasks that required the use of the VSSP. These results were interpreted to mean that tasks that required the VSSP "...reduced the ability to use external visual information in the control of postural stability (Maylor & Wing, 1996, P152)".

A closer look at the results of Maylor & Wing (1996) revealed that the interactions between group and balance resulted from a slight increase in postural stability in the younger group and a slight decline in postural stability in the older group, neither of which were significant in and of themselves. In other words, in actual fact there were only small and insignificant changes in balance in the two groups from the single task to the dual task conditions. "Thus, the interaction for Brooks' spatial memory seems to be almost as much due to a decrease in sway from single to dual task conditions for younger participants, as to an increase for older participants (Maylor & Wing, 1996, P150). This decrease in sway in the younger group was even more prominent in the backward digit recall condition. Thus, as the newly proposed model would predict, the concurrent performance of a visuospatial task and a balance task resulted in the sparing of balance performance in one group, and an improvement in balance performance in another group. What is not clear in this study is why it was the younger group rather than the older group who became less stable.

Three of the remaining four studies also found that postural balance became more stable when a spatial task was performed (Kerr et al., 1985; Dault et al., 2001; and Swan et al., 2004). However, these studies also found this to be the case when verbal memory tasks were performed. The new model would predict this result with the simultaneous performance of the spatial and balance tasks. The question is—why did balance also become more stable when performed concurrently with a verbal task?

Although the study by Kerr et al. (1985) seems to differ from the current study, in important ways it is still consistent with the model. The fact that posture was more stable during the verbal memory and spatial memory task was not one of the main findings, but rather merited a brief comment in the results section. This finding was found to be due to order effects, in that only subjects who conducted the balance-only task first were more unstable in the balance-only condition than in the dual task conditions. However, in this study, spatial memory performance declined more than verbal memory performance. The reason for this cannot be explained by the newly proposed model.

In the study by Dault et al. (2001) it was found that the interference effects of the verbal–balance pairings were similar to those of the spatial–balance pairings. However, in this instance the verbal task was presented visually, on a computer screen. Perhaps because vision was required for the verbal task, both the verbal and the spatial tasks required resources from the visuospatial resource pool. If this choice of modality meant that the verbal task also drew from the visuospatial resource pool, then the results are consistent with the new model.

Another study also used visual presentation of verbal stimuli (Riley, Baker & Schmidt, 2003). This study involved 23 healthy young adults who stood barefoot with feet together on a force plate in the single task condition. In three dual task condition they were asked to perform the balance task while doing three digit span tests of increasing difficulty. While there is some evidence to support that digit span backwards may have a spatial memory component (Li & Lewandowsky, 1995), digit span forward, which was used in this study, is generally believed to be a verbal task (WAIS – III WMS – III Technical Manual, 1997). The newly proposed model would thus predict that postural sway would increase if attentional demands exceed available resources. However, this was not the case. Postural sway actually declined, and this decline was exaggerated as the difficulty of the digit span task increased. This result would be predicted by the proposed model if the task had a visuospatial component. In fact, a closer look at the task revealed that it may well have a visuospatial component. The string of digits in the digit span test was presented visually on an LCD monitor which may have led to their being remembered using some element of visuospatial memory rather than just verbal memory. There is evidence to support this idea in that remembering items in a spatial order, whether the presentation be visual, auditory, perceptual or motor has been found to make demands on spatial attention (Smyth & Scholey, 1994).

Still another study, this one carried out by Swan et al. (2004), was again consistent with the new model. It was found that performing both the Brooks spatial and nonspatial (verbal) memory tasks while standing had similar effects on balance. That is, balance became more stable in both cases. This result is not surprising, allowing for the fact that the instructions from the researcher were to give priority to the maintenance of balance rather than the cognitive task. Thus this result can be explained by Kahneman's concept of momentary attentions which suggests that there is some voluntary control over how attentional resources are allocated. Furthermore, there were differences with respect to the effects on cognitive performance. Specifically, the performance was better on the spatial task than the verbal task. In other words, changing the balance strategy to a more rigid stance did not free up any new resources for the verbal task, but it did free up resources for the spatial task. Clearly these results are a good fit with the proposed model.

To conclude, the newly proposed model is useful in that it can be used to explain at least the majority of the results of previous studies of the relationship between balance and spatial and verbal memory. Given the fact that there has been little consensus in the past regarding how to explain the mixed results where the relationship of balance, spatial memory, and verbal memory is concerned, this in itself is promising.

Limitations and Future Research

There are a number of questions that remain unanswered. Why is it that when a spatial task is paired with a balance task sometimes the poor balance group becomes more stable than the good balance group, and at other times the reverse is true? Perhaps Kahneman's (1974) concepts of enduring dispositions, momentary intentions, evaluation of demands, and arousal offer a starting point in order to address this question. Furthermore, why is this increase in stability sometimes seen when a verbal memory task is paired with a balance task? Is it because the mode of presentation of the verbal task is such that it requires visuospatial resources, or is there another reason? Although some possible explanations for these questions were presented, these possibilities need to be formally tested in future research.

There were some limitations in the current study which also warrant consideration when planning future research. First of all, there was a significant age difference between the good and poor balance groups. Age was not used as a covariate because there was concern that removing the variance associated with age would result in the removal of a portion of the effect of the independent variable upon the dependent variable. However age is clearly a confounding variable in this study. The possibility remains that group differences may be due to age, rather than balance differences. In order to avoid this problem in the future, it would be useful to match the good balance group and the poor balance group for age.

A second limitation relates to the fact that the verbal memory tasks require articulation, whereas the spatial memory tasks do not. There is some evidence that articulation has an effect on balance due to the fact that muscular control of posture may be affected by muscular control of respiration (Yardley, Gardener, Leadbetter, & Lavie, 1999). Thus differences in postural balance during verbal and spatial task performances may be confounded by articulation.

A third limitation relates to the fact that there was little difference between the good balance group and the poor balance with respect to postural balance. This similarity was due to the fact that the balance task, standing on a compliant surface, was a very difficult task for many seniors. In order to be capable of completing the task at all, the participants required relatively good balance. The individuals with poor balance who were unable to complete the task could not be included in the study. As a result, the two groups were relatively similar to one another with respect to postural balance, a fact which may have watered down the interaction between groups and tasks.

In future research, it might be useful to simplify the balance task by having the subjects stand on the force platform alone, without a compliant foam surface. This modification to the research procedure might be sufficient to allow individuals with poorer balance to participate. Furthermore, it would be useful to design studies in which factors relating to momentary intentions, enduring dispositions, evaluation of demands, and arousal are manipulated while a balance task is paired with both a spatial and a verbal memory task. Furthermore, the modality of presentation (verbal, visual, auditory) could be manipulated to evaluate differential effects. Such studies would shed light on many of the remaining questions regarding the relationship between spatial memory and balance, and allow for the testing and refinement of the newly proposed model.

Conclusions

Verbal memory tasks, spatial memory tasks, standing on a compliant surface, and finger tapping all require attentional resources. However, when these tasks are paired with one another, the interference effects differ depending upon which tasks are paired with which, and whether the participants have good or poor balance.

It is interesting that spatial memory and postural balance are related, given that one is a cognitive task and the other a motor task. What is even more interesting is the fact that verbal memory and spatial memory are different in their relationship to postural balance.

These differential interference effects cannot be completely explained by a unitary model of attentional resources such as that described by Kahneman (1973), in which decrements in performance are directly proportional to the additive effects of the attentional requirements of each task. Neither can they be completely explained by the multiple resource model of attentional resources (Allport et al., 1972; Brooks, 1968; Wickens, 1980), in which interference effects occur when the two tasks draw from the same resource pool, and not when they draw from different resource pools. Therefore a new model was developed which better fits the results of the current study, as well as other studies that have been conducted in this area in the past.

The newly proposed model provides a simple, alternative conceptualization of the relationship between spatial memory and balance, and why this may differ from the relationship between verbal memory and balance. This model suggests that there are at least three resource pools, a motor pool, a visuospatial pool, and a verbal pool, all of which are fed attentional resources by the central executive. If two tasks that are minimally attentionally demanding are conducted concurrently, and the attentional demands do not exceed the resources available, there is no interference. This prediction was supported when SSF and standing on a compliant surface were conducted concurrently without interference effects. The model further predicts that if the attentional demands exceed the resources available, the nature and extent of the interference will depend upon the relationship of the resource pools that are involved. Thus, if both tasks draw from the same resource pool and no other, there is maximal interference. This hypothesis was not tested in the current study but was supported in previous studies (Baddeley et al., 1975; Farmer et al., 1986). Further, if the two tasks draw from separate pools that do not overlap, a decision is made at the central executive level as to which resource pool has higher priority, based on issues of safety (prevention of falling), or the instructions provided by the researcher, or a number of other variables. The decrement in performance will be more evident in the task drawing from the lower priority resource pool. This pattern of interference was demonstrated in the current study when LNS and standing were conducted concurrently. In the good balance group only balance was negatively affected, whereas in the poor balance group both LNS scores and balance were negatively affected. A further prediction of the new model is that if two tasks draw from the same pool, but one of them also draws from another pool, the task that overlaps the two is allowed more flexibility in the resources to which it has access. The result is that the overlapping task is spared interference, or performance on that task may even be enhanced. This point can be illustrated when the visuospatial task of SSB is paired with the visuospatial and motor task of standing. In this case, if attentional requirements exceed available resources, an individual may be able to use a more purely motor strategy (drawing from the motor resource pool) to maintain balance as a means of freeing up visuospatial resources for the spatial task. As a result, the balance task is spared interference. This sparing of interference was demonstrated when SSB, SSF, and finger tapping were paired with the standing task. In each case, balance was spared interference effects. Furthermore, although it could not be tested statistically, there was some evidence to suggest (when was paired with standing) that postural balance may even have became more stable in the poor balance group.

Seniors are the fastest growing segment of the population in North America. There is no question that postural balance and spatial memory are critical for preventing falls and for maintaining independence in this group of people. Given this fact, understanding the nature of the relationship between postural balance and spatial memory is important.

One of the most promising possibilities that this research project suggests is the possibility that under some conditions, spatial memory tasks and postural balance tasks may be performed concurrently without a decrement in performance of one or either task, and perhaps even with an improvement in performance. In practical terms, this information could be used to enhance the capability of seniors to perform various tasks to their maximal capability.

Although additional research is necessary to test further the newly proposed model and to fully understand the mechanisms by which interference effects occur or do not occur, promising practical implications could evolve from this line of research. Such research may not only help to keep older adults safe, but may also be useful to help them remain active and contributing members of society.

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Appendix A

Modified Mini Mental State Examination

Some of the questions that I am going to ask you now may seem unusual, but they are routine ones we ask of everyone. Some of the questions that I ask you will be easy and may seem silly; others may be more difficult, so don't be surprised if you have trouble with some of them. I may also ask you the same question twice. Please just do the best you can.

1. ___ WHEN AND WHERE BORN? Date_______/_____/_____ Place __________/_____________
5 dd mm yy city/town province,country

Year	0 1	Province	0 1
Day	0 1		
Month	0 1	Town	0 1

2. ___ THREE WORDS (Number of presentations ______)
3

Dress 0 1 Red 0 1 Loyalty 0 1

3. ___ COUNTING FORWARDS Can __ Can't __
7

5 to 1 (write their answer ___ ___ ___ ___ ___) Score 0 1 2
5 4 3 2 1

WORLD FORWARDS Can __ Can't __

World backwards Print letter ___ ___ ___ ___ ___ Score 0 1 2 3 4 5
D L R O W

Not completed: subject can't read 67

4. ___ FIRST RECALL
9

Spontaneous recall: dress	3
Cue: Something to wear	2
Multiple: Shirt, dress, socks	1
Missed completely	0
Spontaneous recall: red	3
Cue: A colour	2
Multiple: Black, blue, red	1
Missed	0
Spontaneous recall - loyalty	3
Cue: A good personal quality	2
Multiple: Loyalty, honesty, charity	1
Missed	0

5. ___ TODAY'S DATE
15

Today's date __________	
Accurate	3
Missed by 1 or 2 days	2
Missed by 3-5 days	1
Missed by more than 5 days	0
Month ____________	
Accurate or within 5 days	2
Missed by one month	1
Missed by more than 1 month	0
Year ___________	
Accurate	8
Missed by 1 year	4
Missed by 2-5 years	2
Missed by more than 5 years	0
Day of week _________	
Accurate	1
Missed	0
Season ____________	
Accurate or within 1 month	1
Missed	0

6. ___ SPATIAL ORIENTATION
5

Province	2 0	Country	1 0
City or town	1 0	Hospital, store, home	1 0
★ MMSE: Place or address	Y N	Floor or street	Y N

7. ___ NAMING
5

Forehead	0 1	Chin	0 1	Shoulder	0 1
Elbow	0 1	Knuckle	0 1		
★ MMSE:	Pencil Y N	Watch Y N			
Not completed:	subject blind	66			

8. ___ FOUR-LEGGED ANIMALS(30 seconds)(Write animals named) ____________, ____________,
10

____________, ____________, ____________, ____________,

____________, ____________, ____________, ____________,

9. ___ SIMILARITIES(Write answer)

6

Arm-leg	
Limbs, extremities	2
Body parts, bend, move, joint	1
Very weak similarity or no similarity	0
Laughing-crying	
Feeling, emotion	2
Expressions, sounds, relieve tension	1
Very weak similarity or no similarity	0
Eating-sleeping	
Necessary bodily functions	2
Bodily functions, relaxing, good for you	1
Very weak similarity or no similarity	0

10. ___ REPETITION

5

I would like to go out.

Correct	2
1 or 2 missed/wrong words	1
More than 2 missed/wrong words	0

No ifs	1	0
ands	1	0
or buts	1	0

11. ___ READ AND OBEY "CLOSE YOUR EYES"

3

Obeys without prompting		3
Obeys after prompting		2
Reads aloud only		1
None of the above		0
Not completed:	subject blind	66
	subject illiterate	67

12. ___ WRITING(1 minute)

5

(I) would like to go out.	0	1	2	3	4	5

★ MMSE Sentence: Y N

Not completed:	subject physically unable	66
	subject illiterate	67

Note handedness L R

13. ___ COPYING TWO PENTAGONS (1 minute)

10

	Each	pentagon		Intersection
5 approx equal sides	4	4	4 corners	2
5 unequal(2:1) sides	3	3	Not 4 corner enclosure	1
Other enclosed figures	2	2	No intersection or no enclosure	0
2 or more lines	1	1	Not completed:	
less than 2 lines	0	0	subject physically unable	66

14. ___ THREE-STAGE COMMAND

3

Take this paper with your left/right hand,	1	0	Not completed:	
fold it in half, and	1	0	subject physically unable	66
hand it back to me	1	0		

15. ___ SECOND RECALL

9

Spontaneous recall: Dress	3
Cue: Something to wear	2
Multiple: Shirt, dress, socks	1
Missed completely	0
Spontaneous recall: Red	3
Cue: A Colour	2
Multiple: Black, blue, red	1
Missed completely	0
Spontaneous recall: Loyalty	3
Cue: A good quality	2
Multiple: Loyalty, honesty, charity	1
Missed completely	0

________ TOTALSCORE 3MS

Time 3MS completed ☐ :

Please use 24-hour clock

I would just like to check on your birthdate again.

When were you born? ________ / ________ / ________
dd mm yy

Where were you born? ____________________ / ____________________
Town Province (or country)

Appendix B

Berg Balance Scale

Procedure: Subject should use no support if possible

Grading: Please mark the lowest category that applies

If subject has been instructed not to do any of the following activities, make a note beside the item and proceed to the next question.

1. SITTING TO STANDING

INSTRUCTIONS: Please stand up. Try not to use your hands for support.

_____4 Able to stand, no hands and stabilize independently
_____3 Able to stand independently using hands
_____2 Able to stand after several attempts
_____1 Needs minimal assistance
_____0 Needs moderate or maximal assist to stand

2. STANDING UNSUPPORTED

INSTRUCTIONS: Stand for two minutes without holding.

_____4 Able to stand safely 2 minutes
_____3 Able to stand 2 minutes under supervision
_____2 Able to stand 30 seconds unsupported
_____1 Needs several tries to stand 30 seconds
_____0 Unable to stand 30 seconds unassisted

3. SITTING UNSUPPORTED FEET ON FLOOR

INSTRUCTIONS: Sit with arms folded for two minutes.

_____4 Able to sit safely and securely 2 minutes
_____3 Able to sit 2 minutes under supervision
_____2 Able to sit 30 seconds
_____1 Able to sit 10 seconds
_____0 Unable to sit without support

4. STANDING TO SITTING

INSTRUCTIONS: Please sit down.

_____4 Sits safely with minimal use of hands
_____3 Controls descent by using hands
_____2 Uses back of legs against chair to control descent
_____1 Sits independently but has uncontrolled descent
_____0 Needs assistance to sit

5. TRANSFERS

INSTRUCTIONS: Please move from chair to bed and back again.

PROCEDURE: One way toward a seat with armrests and one way toward a seat without armrests. (If it is not possible to go from bed to chair and back, then go from chesterfield to chair and back)

_____4 Able to transfer safely with minor use of hands
_____3 Able to transfer safely definite need of hands
_____2 Able to transfer with verbal cueing and/or supervision
_____1 Needs one person assist
_____0 Needs two people to assist or supervise to be safe

6. STANDING UNSUPPORTED EYES CLOSED

INSTRUCTIONS: Close your eyes and stand still for 10 seconds.

_____4 Able to stand 10 seconds safely
_____3 Able to stand 10 seconds with supervision
_____2 Able stand 3 seconds
_____1 Unable to keep eyes closed but stays safely
_____0 Needs help to keep from falling

7. STANDING UNSUPPORTED WITH FEET TOGETHER

INSTRUCTIONS: Place your feet together and stand without holding.

_____4 Able to place feet together independently and stand 1 minute safely
_____3 Able to place feet together independently and stand 1 min. supervised
_____2 Able to place feet together independently but not hold 30 seconds
_____1 Needs help to attain position but able to stand 15 sec feet apart
_____0 Needs help to attain position and unable to hold for 15 seconds

8. REACHING FORWARD WITH OUTSTRETCHED ARM

INSTRUCTIONS: Lift arm to 90 degrees. Stretch out your finger and reach out as far as you can. Do not lean on ruler please.

PROCEDURE: Examiner places a ruler at end of fingertips when arm is at 90 degrees. Fingers should not touch the ruler while reaching forward. The recorded measure is the distance forward that the fingers reach while the subject is in the most forward leaning position. The subject is allowed to lean forward from waist.

_____4 Can reach forward confidently more than 10 inches
_____3 Can reach forward more than 5 inches safely
_____2 Can reach forward more than 2inches safely
_____1 Reaches forward but needs supervision
_____0 Needs help to keep from falling

9. PICK UP OBJECT FROM THE FLOOR

INSTRUCTIONS: Pick up the book which is placed in front of your feet.(Do not support yourself with anything)

_____4 Able to pick up the book safely and easily
_____3 Able to pick up the book safely and but needs supervision
_____2 Unable, but reaches 1-2 inches from book and keeps balance indep
_____1 Unable to pick up and needs supervision while trying
_____0 Unable to try/ needs assist to keep from falling

10. TURNING TO LOOK BEHIND OVER LEFT ND RIGHT SHOULDERS

INSTRUCTIONS: Turn to look behind you over your left shoulder

PROCEDURE:

- It is permissible to ask them to look behind you at (name an object on the wall behind you over toward the left shoulder).
- Subject can turn from waist
- Subject should not support themselves with anything. Repeat to the right.

_____4 Looks behind from both sides and weight shifts well
_____3 Looks behind one side only; other side shows less weight shift
_____2 Turns sideways only but maintains balance
_____1 Needs supervision when turning
_____0 Needs assist to keep from falling

11. TURN 360 DEGREES

INSTRUCTIONS: Turn completely around in a full circle. Pause. Then turn a full circle in the other direction.

_____4 Able to turn 360 safely in less than 4 seconds each side
_____3 Able to turn 360 safely one side only in less than 4 seconds
_____2 Able to turn 360 safely but slowly
_____1 Needs close supervision or verbal cueing
_____0 Needs assistance while turning

12. DYNAMIC WEIGHT SHIFTING WHILE STANDING UNSUPPORTED

INSTRUCTIONS: Place each foot alternately on the stool. Continue until each foot has touched the stool four times.

PROCEDURE:

- Ask subject if they have a stool. Get stool and bring to subject if they do. If they don't, use any sturdy object 8 inches to 12 inches off the ground.
- Count number of times step touch measured stool
- Start time on 30 seconds to 1 minute.

_____4 Able to stand independently safely and complete 8 steps in 20 sec
_____3 Able to stand independently and complete 8 steps > 20 seconds
_____2 Able to complete 4 steps without aid and supervision
_____1 Able to complete > 2 steps, needs minimal assistance
_____0 Needs assistance to keep from falling/unable to try

13. STANDING UNSUPPORTED ONE FOOT IN FRONT

INSTRUCTIONS: Place one foot directly in front of the other. If you feel that you cannot place your foot directly in front, try to step far enough ahead that the heel of your forward foot is ahead of the toes of the other foot.

_____4 Able to place foot tandem independently and hold for 30 seconds
_____3 Able to place foot ahead of the other independently and hold 30 sec.
_____2 Able to take small steps independently and hold 30 seconds
_____1 Needs help but can hold 15 seconds
_____0 Loses balance while stepping or standing

14. STANDING ON ONE LEG UNSUPPORTED

INSTRUCTIONS: Stand on one leg as long s you can without holding.

_____4 Able to lift leg independently and hold more than 10 seconds
_____3 Able to lift leg independently and hold 5 - 10 seconds
_____2 Able to lift leg independently and hold 3 or fewer seconds
_____1 Tries to lift leg. Unable to hold 3 sec. but remains standing indep.
_____0 Unable to try or needs assist to prevent fall

Appendix C

The Wechsler Memory Scale III: Letter Number Sequencing and Spatial Span

8: Letter–Number Sequencing

DISCONTINUE RULE:
After scores of 0 for all three trials of an item.

RECORDING:
All responses verbatim

SCORING RULE:
0–1 pt. for each trial

Item/Trial		(Correct Response)/Response	Score 0 or 1
1.	Trial 1	**L – 2** (2 – L)	
	Trial 2	**6 – P** (6 – P)	
	Trial 3	**B – 5** (5 – B)	
2.	Trial 1	**F – 7 – L** (7 – F – L)	
	Trial 2	**R – 4 – D** (4 – D – R)	
	Trial 3	**H – 1 – 8** (1 – 8 – H)	
3.	Trial 1	**T – 9 – A – 3** (3 – 9 – A – T)	
	Trial 2	**V – 1 – J – 5** (1 –5 – J – V)	
	Trial 3	**7 – N – 4 – L** (4 – 7 – L – N)	
4.	Trial 1	**8 – D – 6 – G – 1** (1 – 6 – 8 – D – G)	
	Trial 2	**K – 2 – C – 7 – S** (2 – 7 – C – K – S)	
	Trial 3	**5 – P – 3 – Y – 9** (3 – 5 – 9 – P – Y)	
5.	Trial 1	**M – 4 – E – 7 – Q – 2** (2 – 4 – 7 – E – M – Q)	
	Trial 2	**W – 8 – H – 5 – F – 3** (3 – 5 – 8 – F – H – W)	
	Trial 3	**6 – G – 9 – A – 2 – S** (2 – 6 – 9 – A – G – S)	
6.	Trial 1	**R – 3 – B – 4 – Z – 1 – C** (1 – 3 – 4 – B – C – R – Z)	
	Trial 2	**5 – T – 9 – J – 2 – X – 7** (2 – 5 – 7 – 9 – J – T – X)	
	Trial 3	**E – 1 – H – 8 – R – 4 – D** (1 – 4 – 8 – D – E – H – R)	
7.	Trial 1	**5 – H – 9 – S – 2 – N – 6 – A** (2 – 5 – 6 – 9 – A – H – N – S)	
	Trial 2	**D – 1 – R – 9 – B – 4 – K – 3** (1 – 3 – 4 – 9 – B – D – K – R)	
	Trial 3	**7 – M – 2 – T – 6 – F – 1 – Z** (1 – 2 – 6 – 7 – F – M – T – Z)	

Total Score
Range = 0 to 21 ☐

Letter Number Sequences Test #2 – FINGER TAPPING **I.D.** ______________

	(Correct response) / response	Score
1. 1	H – 4 (4 – H)	
2	7 – N (7 – N)	
3	C – 10 (10 – C)	
2. 1	E – U – 2 (2 – E – U)	
2	Q – 6 – A (6 – A – Q)	
3	E – 2 – 6 (2 – 6 – E)	
3. 1	T – 8 – G – 1 (1 – 8 – G – T)	
2	R – 5 – B – 9 (5 – 9 – B – R)	
3	2 – K – 4 – 5 (2 – 4 – 5 – K)	
4. 1	3 – A – 7 – I – 10 (3 – 7 – 10 – A – I)	
2	N – 3 – D – 8 – L (3 – 8 – D – L – N)	
3	10 – V – 5 – Z – 2 (2 – 5 – 10 – V – Z)	
5. 1	Q – 3 – F – 5 – X – 4 (3 – 4 – 5 – F – Q – X)	
2	Y – 1 – I – V – 3 – 6 (1 – 3 – 6 – I – V – Y)	
3	3 – C – 5 – B – 9 – X (3 – 5 – 9 – B – C – X)	
6. 1	O – 1 – J – 9 – K – 1 – E (1 – 1 – 9 – E – J – K – O)	
2	3 – U – 5 – F – 7 – O – 2 (2 – 3 – 5 – 7 – F – U – O)	
3	J – 2 – F – 3 – S – 1 – C (1 – 2 – 3 – C – F – J – S)	
7. 1	2 – I – 10 – R – 7 – O – 10 – G (2 – 7 – 10 – 10 – G – I – O – R)	
2	D – 1 – O – 9 – J – 8 – U – 2 (1 – 2 – 8 – 9 – D – J – O – U)	
3	1 – L – 4 – K – 2 – I – 10 – N (1 – 2 – 4 – 10 – I – K – L – N)	
	Total Score Range	

Letter Number Sequences Test #3 – STANDING **I.D.** ______________

	(correct response) / response	Score
1. 1	H – 9 (9 – H)	
2	8 – V (8 – V)	
3	D – 9 (9 – D)	
2. 1	E – U – 3 (3 – E – U)	
2	S – 6 – D (6 – D – S)	
3	G – 6 – 7 (6 – 7 – G)	
3. 1	V – 8 – H – 3 (3 – 8 – H – V)	
2	Z – 4 – A – 6 (4 – 6 – A – Z)	
3	2 – K – 7 – 6 (2 – 6 – 7 – K)	
4. 1	6 – E – 9 – F – 4 (4 – 6 – 9 – E – F)	
2	S – 8 – H – 7 – X (7 – 8 – H – S – X)	
3	8 – T – 4 – M – 10 (4 – 8 – 10 – M – T)	
5. 1	P – 5 – A – 6 – V – 3 (3 – 5 – 6 – A – P – V)	
2	M – 5 – I – W – C – 9 (5 – 9 – C – I – M – W)	
3	1 – E – 4 – J – 3 – R (1 – 3 – 4 – E – J – R)	
6. 1	U – 9 – D – 3 – R – 9 – 5 (3 – 5 – 9 – 9 – D – R - U)	
2	2 – P – 5 – B – 10 – X – 5 (2 – 5 – 5 – 10 – B – P – X)	
3	F – 9 – G – 4 – U – 5 – D (4 – 5 – 9 – D – F – G – U)	
7. 1	6 – C – 1 – M – 10 – L – 4 – E (1 – 4 – 6 – 10 – C – E – L – M)	
2	D – 2 – V – 1 – I – 2 – L – 5 (1 – 2 – 2 – 5 – D – I – L – V)	
3	3 – V – 6 – X – 9 – D – 2 – W (2 – 3 – 6 – 9 – D – V – W – X)	
	Total Score Range	

9. Spatial Span

DISCONTINUE RULE:
After scores of 0 on both trials of any item. For both Spatial Span Forward & Spatial Span Backward, administer both trials of each item even if Trial 1 is passed.

RECORDING:
All responses verbatim

SCORING RULE:
0–1 pt. for each trial

Spatial Span Forward

Item/Trial		Response	Score 0 or 1
1.	Trial 1	3 – 10	
	Trial 2	7 – 4	
2.	Trial 1	1 – 9 – 3	
	Trial 2	8 – 2 – 7	
3.	Trial 1	4 – 9 – 1 – 6	
	Trial 2	10 – 6 – 2 – 7	
4.	Trial 1	6 – 5 – 1 – 4 – 8	
	Trial 2	5 – 7 – 9 – 8 – 2	
5.	Trial 1	4 – 1 – 9 – 3 – 8 – 10	
	Trial 2	9 – 2 – 6 – 7 – 3 – 5	
6.	Trial 1	10 – 1 – 6 – 4 – 8 – 5 – 7	
	Trial 2	2 – 6 – 3 – 8 – 2 – 10 – 1	
7.	Trial 1	7 – 3 – 10 – 5 – 7 – 8 – 4 – 9	
	Trial 2	6 – 9 – 3 – 2 – 1 – 7 – 10 – 5	
8.	Trial 1	5 – 8 – 4 – 10 – 7 – 3 – 1 – 9 – 6	
	Trial 2	8 – 2 – 6 – 1 – 10 – 3 – 7 – 4 – 9	

Forward Total Score
Range = 0 to 16

Spatial Span Backward

Item/Trial		(Correct Response)/Response	Score 0 or 1
1.	Trial 1	7 – 4 (4 – 7)	
	Trial 2	3 – 10 (10 – 3)	
2.	Trial 1	8 – 2 – 7 (7 – 2 – 8)	
	Trial 2	1 – 9 – 3 (3 – 9 – 1)	
3.	Trial 1	10 – 6 – 2 – 7 (7 – 2 – 6 – 10)	
	Trial 2	4 – 9 – 1 – 6 (6 – 1 – 9 – 4)	
4.	Trial 1	5 – 7 – 9 – 8 – 2 (2 – 8 – 9 – 7 – 5)	
	Trial 2	6 – 5 – 1 – 4 – 8 (8 – 4 – 1 – 5 – 6)	
5.	Trial 1	9 – 2 – 6 – 7 – 3 – 5 (5 – 3 – 7 – 6 – 2 – 9)	
	Trial 2	4 – 1 – 9 – 3 – 8 – 10 (10 – 8 – 3 – 9 – 1 – 4)	
6.	Trial 1	2 – 6 – 3 – 8 – 2 – 10 – 1 (1 – 10 – 2 – 8 – 3 – 6 – 2)	
	Trial 2	10 – 1 – 6 – 4 – 8 – 5 – 7 (7 – 5 – 8 – 4 – 6 – 1 – 10)	
7.	Trial 1	6 – 9 – 3 – 2 – 1 – 7 – 10 – 5 (5 – 10 – 7 – 1 – 2 – 3 – 9 – 6)	
	Trial 2	7 – 3 – 10 – 5 – 7 – 8 – 4 – 9 (9 – 4 – 8 – 7 – 5 – 10 – 3 – 7)	
8.	Trial 1	8 – 2 – 6 – 1 – 10 – 3 – 7 – 4 – 9 (9 – 4 – 7 – 3 – 10 – 1 – 6 – 2 – 8)	
	Trial 2	5 – 8 – 4 – 10 – 7 – 3 – 1 – 9 – 6 (6 – 9 – 1 – 3 – 7 – 10 – 4 – 8 – 5)	

Backward Total Score
Range = 0 to 16

Total Score
Range = 0 to 32

(Sum Forward Total Score & Backward Total Score)

Spatial Span Test #2 – FINGER TAPPING

I.D.________________

Backward		Response	Score
1. 1	9 – 10	(10 – 9)	
2	4 – 7	(7 – 4)	
2. 1	2 – 6 – 10	(10 – 6 – 2)	
2	7 – 6 – 8	(8 – 6 – 7)	
3. 1	6 – 7 – 8 – 6	(6 – 7 – 8 – 6)	
2	8 – 10 – 7 – 3	(3 – 7 – 10 – 8)	
4. 1	3 – 8 – 4 – 5 – 3	(3 – 5 – 4 – 8 – 3)	
2	9 – 8 – 5 – 2 – 10	(10 – 2 – 5 – 8 – 9)	
5. 1	7 – 6 – 5 – 10 – 1 – 2	(2 – 1 – 10 – 5 – 6 – 7)	
2	1 – 2 – 6 – 9 – 2 – 4	(4 – 2 – 9 – 6 – 2 – 1)	
6. 1	3 – 9 – 10 – 7 – 8 – 6 – 4	(4 – 6 – 8 – 7 – 10 – 9 – 3)	
2	7 – 6 – 3 – 5 – 7 – 3 – 10	(10 – 3 – 7 – 5 – 3 – 6 – 7)	
7. 1	7 – 8 – 5 – 4 – 1 – 9 – 5 – 6	(6 – 5 – 9 – 1 – 4 – 5 – 8 – 7)	
2	3 – 2 – 5 – 6 – 3 – 6 – 10 – 1	(1 – 10 – 6 – 3 – 6 – 5 – 2 – 3)	
8. 1	3 – 2 – 9 – 1 – 8 – 2 – 6 – 1 – 2	(2 – 1 – 6 – 2 – 8 – 1 – 9 – 2 - 3	
2	6 – 2 – 1 – 3 – 9 – 1 – 4 – 9 – 10	(10 – 9 – 4 – 1 – 9 – 3 – 1 – 2 -6	
		Backward Total Score	

Spatial Span Test #3 – STANDING

I.D. ________________

Backward		Response	Score
1. 1	7 – 9	(9 – 7)	
2	8 – 4	(4 – 8)	
2. 1	2 – 4 – 1	(1 – 4 – 2)	
2	7 – 6 – 10	(10 – 6 – 7)	
3. 1	3 – 4 – 10 – 3	(3 - 10 – 4 – 3)	
2	4 – 7 – 2 – 9	(9 – 2 – 7 – 4)	
4. 1	8 – 4 – 1 – 4 – 2	(2 – 4 – 1 – 4 – 8)	
2	3 – 1 – 10 – 4 – 9	(9 – 4 – 10 – 1 – 3)	
5. 1	3 – 10 – 9 – 1 – 9 – 3	(3 – 9 – 1 – 9 – 10 – 3)	
2	1 – 10 – 2 – 4 – 8 – 1	(1 – 8 – 4 – 2 – 10 – 1)	
6. 1	1 – 8 – 6 – 10 – 4 – 3 - 1	(1 – 3 – 4 – 10 – 6 – 8 – 1)	
2	6 – 7 – 5 – 6 – 2 – 1 – 6	(6 – 1 – 2 – 6 – 5 – 7 – 6)	
7. 1	3 – 10 – 5 – 2 – 3 – 5 – 4 – 6	(6 – 4 – 5 – 3 – 2 - 5 – 10 –3)	
2	2 – 8 – 3 – 9 – 6 – 3 – 4 – 10	(10 – 4 – 3 – 6 – 9 – 3 – 8 – 2)	
8. 1	5 – 8 – 10 – 2 – 4 – 8 – 3 – 4 – 1	(1 – 4 – 3 – 8 – 4 – 2 – 10 – 8 – 5	
2	3 – 5 – 7 – 5 – 9 – 3 – 9 – 6 – 10	(10 – 6 – 9 – 4 – 9 – 5 – 7 – 5 – 3	
		Backward Total Score	

Appendix D

Letter of Information and Consent

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LETTER OF INFORMATION AND CONSENT

This letter is designed to outline the research project and to explain what my involvement in the project will entail.

I ____, am interested in collaborating in the research conducted by Dr. Joan McComas from the School of Rehabilitation Sciences, Faculty of Health Sciences and her Ph.D. student Eleanor Riesen at the University of Ottawa.

THE PURPOSE of this research is to better understand how postural balance and two types of memory (verbal and spatial) affect one another. This study will provide information about how different balance tasks influence memory and how different memory tasks influence balance. The information obtained from this research will provide information about how older adults manage two tasks at once. This may increase understanding about the relationship between falls in the elderly and declining memory in the elderly.

PROCEDURE: My participation will consist essentially of attending a single one-hour research session in a location close to my home. The research session will be scheduled at my convenience.

At the start of the research session, I will answer questions about my age, years of schooling, the time and place, and simple math and memory questions. I will also be asked to do a clinical test of balance including items such as standing on one leg, standing unsupported, going from sitting to standing, and picking up an object from the floor etc. Then I will be asked to stand barefoot on a soft platform while doing one of three tasks: a verbal memory task, a spatial memory task, and a finger tapping task. I will also be asked to do the same tasks while sitting. In order to ensure that I do not fall, I will wear a safety belt with handles around my waist. Two spotters will stand close by at all times to grab these handles if I lose my balance.

I understand that the information collected from my participation will be used for research purposes only and that my confidentiality will be respected. All records from this research will be kept confidential and stored in locked cabinets for 5 years after which they will be destroyed. No names will be attached to the data anonymity will be assured by coding procedures. A number will be assigned to every participant and the master sheet containing names and numbers will be kept in a separate filing cabinet from the data. The master sheet will not be available to anyone except the researcher and her supervisor. Only researchers involved in t the project will have access to the data collected. The results may appear in publication but I will not be identified by name.

RISKS AND BENEFITS OF THESE TESTS: I understand that I may get tired, or that I may experience a loss of balance while standing on the platform. I have received assurance from the researchers that every effort will be made to minimize these occurrences. Regular rest breaks will be offered if I feel signs of fatigue. I understand that all risk of falls associated with the loss of balance will be minimized by wearing the safety belt and having two people close to me in order to give all necessary aid.

I MAY STOP THE TEST AT ANY TIME:I may stop the test at any time simply by telling the person controlling the test that I do not wish to continue. I may withdraw from the experiment at any time, without fear of reprisal, simply by informing the person controlling the test.

I will be reimbursed $10 to cover the cost of my travel to the community research site whether or not I decide to complete the study. I will receive no other direct benefit from this research

These are two copies of the consent form, one of which I may keep. Any information, requests or complaints about the ethical conduct of the project may be addressed to the University of Ottawa Health Science and Science Research Ethics Board or by calling Catherine Lesage, the Protocol Officer for Ethics in Research at 562-5800 ext. 5387, e-mail:clesage@uottawa.ca, University of Ottawa, Tabaret Hall, Room 302.

If I have any questions about the nature of the research or about my participation, I may contact the researcher Eleanor Riesen (591-6375) or her supervisor Dr. Joan McComas (562-5800 ext. 8036).

CONSENT: In signing this informed consent form, I acknowledge that I have read and understood all of the information in this document. Before signing, I have been allowed to observe the procedures that will be used in the research project.

Research Subject's Signature______________________________ Date______________

Researcher's Signature ___________________________________ Date______________

Appendix E

Participant Eligibility Interview

1. Male Female

2. What is you date of birth?________________

3. How many years of formal education have you received?

   ____

4. Can you tap your finger on a counter repeatedly without any difficulty or discomfort?__________________________

5. Do you have a history of:

   Stroke

   Neurological Problems

   A broken bon in a lower extremity in the past 6 months

6. Do you use any devices to help you maintain your balance?

   Cane

   Walker

   Other __________________________

Appendix F

Study 1 Means and Standard Deviations of Task Performance in Single Task and Dual Task Conditions by Group

Table 1.
Mean and Standard Deviation of LNS scores in single and dual task conditions by group

	Good Balance Group		Poor Balance Group	
Task	Mean	SD	Mean	SD
Sitting	8.34	1.86	8.65	2.50
Standing	8.52	2.37	7.55	2.64
FT	8.17	2.09	7.90	2.39

Table 2.
Means and Standard Deviations of SSF scores in single and dual task conditions by group

	Good Balance Group		Poor Balance Group	
Task	Mean	SD	Mean	SD
Sitting	7.52	1.75	6.94	1.43
Standing	6.86	1.43	7.25	1.52
FT	6.76	1.57	5.88	1.62

Table 3.
Means and Standard Deviations of SSB scores in single and dual task conditions by group

	Good Balance Group		Poor Balance Group	
Task	Mean	SD	Mean	SD
Sitting	7.03	2.06	5.81	1.75
Standing	5.72	1.56	4.81	1.80
FT	5.59	1.95	4.78	2.03

Table 4.
Means and Standard Deviations of SStotal scores in single and dual task conditions by group

	Good Balance Group		Poor Balance Group	
Task	Mean	SD	Mean	SD
Sitting	14.41	3.28	12.75	2.66
Standing	12.59	2.65	12.03	2.67
FT	12.28	3.16	10.56	2.96

Appendix G

Study 2 Means and Standard Deviations of Task Performance in Single Task and Dual Task Conditions by Group

Table 1.
Means and Standard Deviations of Mean Anterior-posterior Range in the Single and Dual Task Conditions by Group

	Good Balance Group		Poor Balance Group	
Task	Mean	SD	Mean	SD
Standing	4.77	1.22	5.74	1.56
FT	5.19	1.23	5.93	1.52
LNS	5.65	1.46	6.11	1.73
SSB	4.84	1.22	5.03	1.20
SSF	4.95	1.53	5.70	1.66

Table 2.
Means and Standard Deviations of Mean Medio-lateral Range in the Single and Dual Task Conditions by Group

	Good Balance Group		Poor Balance Group	
Task	Mean	SD	Mean	SD
Standing	4.14	1.36	6.28	3.03
FT	4.36	1.19	5.43	2.02
LNS	5.18	1.83	6.35	2.71
SSB	4.69	1.31	5.38	1.52
SSF	4.74	1.26	6.09	1.90

Table 3.
Means and Standard Deviations of Mean Anterior-Posterior Root Mean Square in the Single and Dual Task Conditions by Group

	Good Balance Group		Poor Balance Group	
Task	Mean	SD	Mean	SD
Standing	1.59	.77	1.81	.89
FT	1.65	.74	1.92	.85
LNS	1.87	.81	1.89	.85
SSB	1.65	.69	1.81	.96
SSF	1.67	.81	1.89	.92

Table 4.
Means and Standard Deviations of Mean Medio-lateral Root Mean Square in the Single and Dual Task Conditions by Group

	Good Balance Group		Poor Balance Group	
Task	Mean	SD	Mean	SD
Standing	1.36	.72	2.04	1.22
FT	1.59	.69	1.98	.95
LNS	1.52	.67	2.04	.94
SSB	1.49	.61	1.97	.95
SSF	1.52	.64	2.04	.96

Table 5.
Means and Standard Deviations of Fingertapping Scores in Single and Dual task Conditions by Group

	Good Balance Group		Poor Balance Group	
Task	Mean	SD	Mean	SD
Sitting	3.05	.64	2.95	.69
Standing	3.08	.62	2.82	.74
LNS	2.59	.56	2.26	.78
SSB	2.57	.51	2.25	.73
SSF	2.52	.52	2.16	.73