

THE ROLE OF ATTENTION IN FALL AVOIDANCE: EVALUATION OF DUAL
TASK INTERFERENCE WITH POSTURAL AND VISUAL WORKING
MEMORY TASKS IN YOUNG VERSUS OLDER ADULTS,
DOES CAPACITY LIMITATION INFLUENCE
POSTURAL RESPONSES?

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DISSERTATION ABSTRACT

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Title: The Role of Attention in Fall Avoidance: Evaluation of Dual Task Interference with Postural and Visual Working Memory Tasks in Young Versus Older Adults, Does Capacity Limitation Influence Postural Responses?

The primary goal of this research was to explore attentional factors contributing to normal balance control and to determine how age-related changes in these factors constrain balance in the aging adult. Though previous research has demonstrated attentional interference between postural control and performance of cognitive tasks in young (YA) and older adults (OA), the mechanisms contributing to interference have not been identified. This study utilized as a cognitive task, a visual working memory task (the change detection task), which identified the short term working memory (or attentional) capacity limits of participants. Participants were asked to perform the cognitive task (determining a change in the color of squares in a first vs. second memory array) either in isolation or with postural tasks of increasing complexity, including quiet sitting (control), quiet stance in isolation, quiet stance (but intermixed with support surface perturbations), and support surface perturbations. YA showed a significant decline in working memory capacity between the control and perturbation condition ($p < 0.01$) but no change in postural performance between single and dual task conditions, as determined by increased steps in response to perturbations ($p < 0.33$).

In a second set of experiments, the performance of OA was compared to YA. Results showed that OA had reduced working memory capacity on the change detection task compared to YA even in the control condition (YA: 2.8 ± 0.6 items; OA: 1.8 ± 0.7 ; $p < 0.001$). OA showed an even greater decline than YA in memory capacity in the dual task condition ($p < 0.001$), along with difficulty regaining balance following perturbations, evidenced by significant increases in up on toes ($p < 0.05$) and stepping strategies ($p < 0.05$).

These results suggest that visual working memory (for simple features) and postural control share a common attentional resource that is limited and that postural control is favored over the cognitive task in YA. In OA, attentional capacity was significantly reduced and both postural and cognitive tasks were impaired in the dual task condition, suggesting that with aging even simple cognitive tasks can negatively affect balance under challenging postural conditions.

This dissertation includes previously unpublished co-authored material.

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CHAPTER I

INTRODUCTION

The broad goal of this research is to provide information that can be used to create rehabilitation programs to reduce falls among older adults. Falls are a major health risk in the older adult and often result in injuries that require medical attention. About 30% of older adults over the age of 65 fall each year and the risk of falls increases significantly with age, with 32-42% of older adults over the age of 75 falling at least once per year (Tinetti, Speechley, & Ginter, 1988; Downton & Andrews, 1991; Alexander, Rivara, Wolf, 1992; Berg et al., 1997)

As a large proportion of our society ages it is critical to increase our understanding of neural mechanisms associated with the control of posture, and particularly how these mechanisms are affected by aging. The incidence of falling associated with aging is particularly evident under dual task conditions (performance of two tasks at once, for example, when a cognitive task such as reading a map or a grocery list is combined with a task that requires the control of posture such as walking) (Beauchet et al., 2008; Faulkner et al, 2007). There is no clear understanding, however, of how postural and cognitive processes are linked. The current work probed neural mechanisms of postural control among young and older adults using a dual task paradigm to address fundamental issues related to changes seen along the functional continuum across age groups.

The Effects of Aging on the Control of Posture

Research in the area of postural control has identified that aging affects multiple systems that contribute to the control of posture, including vestibular, visual,

somatosensory, motor and musculoskeletal systems (Nashner, 1976; Macpherson and Inglis, 1993; Horak, Nashner, & Nutt, 1988; Stapely et al., 2002; Macpherson and Fung, 1999; Horak and Nashner, 1986; Vandervoort, 1992; Whipple, Wolfson, Amerman, 1987; Horak and Macpherson, 1996; Pitts, 1982). The deleterious effects of aging on the central nervous system are extensive. They include structural changes within systems that result in reduced accuracy of incoming sensory information used to provide feedback for balance control, and a decline in the level of redundancy of sensory information used in the integration of sensory resources, leading to a decline in adaptability to changing task contexts. They also include motor and musculoskeletal impairments, such as reduced muscle strength and reduced range of motion (see Shumway-Cook and Woollacott, 2011, for a review of these changes).

One of the biggest challenges associated with determining underlying postural mechanism changes associated with aging is the level of heterogeneity within the aging process. Specific examples of deficits within the multiple systems involved in controlling balance include changes in the temporal and spatial sequencing of muscles when responding to loss of balance, reduction in amplitude of responses of postural muscles used for balance recovery, increased dependence on visual cues for postural control, and a decreased ability to organize and select sensory information for postural control (Shumway-Cook & Woollacott, 2011). Deterioration of systems is progressive but occurs at different rates and patterns of decline across all sensory and motor subsystems and varies across individuals.

Establishing the Link Between the Control of Posture and Cognitive Processing

Traditionally neural processing for balance control was thought to occur automatically, within spinal and brainstem reflex circuits; however, recent research suggests that the cerebral cortex and cognitive processing also influence aspects of balance. Research, using a dual task postural paradigm, suggests the process of controlling stability requires attentional resources, defined as available information-processing resources, which are assumed to be limited. Competition for processing resources may occur during the performance of two attentionally demanding tasks and lead to task interference (Woollacott & Shumway-Cook, 2002).

It is postulated that falls result from balance system deficits in combination with the inability to effectively allocate attention to balance in multi-task conditions or the reduction of attentional resources available for allocation. The postural task is considered the primary task and the cognitive task the secondary task. A decline in performance of either or both tasks has been thought to reflect interference or sharing of limited attentional resources between the two tasks (Woollacott & Shumway-Cook, 2002).

Dual Task - Young Adults

Initial studies pairing postural with concurrent cognitive tasks in young adults, showed no change in postural performance; however a decline was seen in secondary task performance in most instances (Kerr, Condon, & McDonald, 1985; Lajoie et al., 1993; Norrie, Maki, & Staines, 2002). In a study by Kerr and colleagues (1985) two types of cognitive tasks, the Brooks spatial and a non-spatial verbal memory task were paired with a difficult standing balance task (Tandem Romberg – heel/toe stance). The spatial

task required mentally placing numbers in an imagined 4 X 4 matrix and remembering the placement of those numbers as number-word pairs, and the non-spatial memory task required remembering number-word pairs without a spatial component. The authors found increased errors in the spatial but not the non-spatial verbal memory task. Thus, the authors concluded postural control to be attentionally demanding in young adults and suggested that spatial memory tasks and postural tasks share resources while non-spatial cognitive tasks access resource stores separate from the postural system.

The aim of work by Lajoie et al. (1993) was to determine whether attentional demands varied as a function of the type of postural task. Four conditions of increasing postural demand were studied; 1) sitting (control), 2) stance with narrow base of support (feet together), 3) stance with broad base of support (feet hip width), and 4) walking – single versus double support. The cognitive task consisted of a verbal response to an unpredicted auditory stimulus and reaction time (RT) was measured between auditory stimulus and the onset of the verbal response. Young adults showed no change in balance performance across balance or walking conditions in the dual task paradigm. They noted that since there was no change in postural task performance, they could infer the attentional requirements of postural control through the extent of performance reduction in the cognitive task. They noted that the RT of the cognitive task was slower with increasing postural demand, with sitting reaction time faster than standing, which was in turn faster than walking. It was concluded that attentional demands for postural control increased with the complexity of the postural task.

Norrie, Maki & Staines (2002) attempted to determine temporal characteristics of shifts in resource allocation associated with compensatory balance control; unexpected

support surface perturbations were used to assess cognitive influence on postural control in young adults. In this study the secondary task was a visuomotor tracking task with the dominant hand used to rotate a potentiometer held by the non-dominant hand; no attempt was made to keep motor demands of the upper extremity constant in both single and dual task conditions.

Results showed that there was no significant change in the early component of the automatic postural response phase (0-200ms) between dual and single task conditions. However, the postural measures showed, a complete absence in tracking approximately 345 ms after the onset of perturbation, during a later, possibly more cognitively controlled or voluntary aspect of the postural response. The allocation of cognitive resources toward the control of posture was interpreted as a bias toward maintaining upright stability during this time period, following an early more automatic phase.

In an alternative study, authors examined factors they felt might contribute to the variability of findings in previous studies on young adults. They hypothesized that broader changes would be seen in the control of posture among young adults by increasing the difficulty level of the working memory (WM) tasks and that more errors would be present in working memory performance under conditions of greater postural demand (Dault, Frank, & Allard, 2001). Postural tasks of increasing difficulty included stance with feet hip width apart and feet in tandem position (heel/toe). Two of the working memory tasks were verbal and visuo-spatial tasks with the third being a verbal task, each with easy and difficult versions. No degradation in performance was seen with the postural or cognitive tasks independent of level of difficulty of either task. In this

instance the authors proposed that the postural and cognitive tasks were not sufficiently difficult to produce a re-weighting of attention allocation in young adults.

Dual Task - Older Adults

The following studies explore the effects of a secondary task on postural control in healthy young and older adults as well as balance impaired older adults under varying postural conditions. Shumway-Cook et al. (1997) investigated the effect of two cognitive tasks on stability in young versus older adults with and without a history of falls. The postural conditions included a normal and altered (foam) support surface and the secondary task included language processing (sentence completion) and visual spatial processing (judge line orientation).

There was no significant difference between young and older adults on the normal surface but the postural sway pattern in the balance-impaired individuals was significantly increased. When task complexity increased, either through the addition of a secondary cognitive task or more challenging postural condition, differences between young and healthy older adults began to emerge but were not significant. Postural stability differences between groups were much more substantial on the compliant surface; balance-impaired adults demonstrated the greatest center of pressure displacement and younger adults the least. There was no significant effect of surface condition on number of responses completed for either cognitive task; however, young adults were significantly faster (number of responses completed within 30 seconds) at both tasks than either older group. No differences were found between the two groups of older adults on speed of performance on either cognitive task. Both healthy and balanced-impaired older adults showed interference between postural and cognitive tasks (sentence

completion) whereas young adults did not. In general, the theories associated with attentional capacity suggest there is a finite amount of processing space available in the central nervous system to perform tasks and these findings support a reduction in total capacity, which limits the amount of attention that both healthy and balance-impaired older individuals can direct to postural recovery when performing a postural and cognitive task simultaneously (Kahneman, 1973, Baddeley & Hitch, 1974; Norman & Bobrow, 1975, Wickens, 1983, Luck & Vogel, 1997, Cowan, 2000).

Huxhold et. al. (2006) proposed that performing a concurrent secondary task low in cognitive demand would benefit postural control for both young and older adults by directing individuals' overt attention away from postural control processes which are usually carried out automatically, and thus allow postural control to be more efficient without adding additional, and often less efficient and slower, voluntary processing. The authors hypothesized that graded increments in difficulty of the secondary task would eventually result in attentional resource competition, hampering the regulation of postural sway. Subjects were tested under two conditions (sitting and standing) with four cognitive tasks (1. watched a random series of digits ranging from 1-9 presented on the computer screen, 2. choice (digit) reaction time, 3. n-back (2) digit working memory, 4. 2-back spatial working memory). The postural results were presented relative to standing, with a low to high continuum of difficulty of the cognitive task (1-4). A U-shaped relationship between cognitive demands of the secondary and postural task was observed, with better postural control than under single task conditions when an easy cognitive task was added, changing to decrements in the control of posture as the task was made more difficult. The rising part of the U-shaped function occurred at a lower level of cognitive

task difficulty in older compared to young adults. The authors assert that these results suggest a two-part account of the relationship between postural sway and cognition, the first being the beneficial range of the secondary task (the decreasing part of the U-shaped interaction) and the second showing that cognitive tasks of greater difficulty hinder postural control through cross-domain resource competition (rising part of the U-shaped curve). They maintained that the benefits of the secondary task in older adults are eclipsed by the negative effect of resource competition as the cognitive demand of the secondary task increased.

Evaluation of Dual Task Postural Results

Much of the research described above used cognitive tasks that accessed a set of broad attentional resources. For example, those studies that used the Brooks spatial memory task required both maintenance and updating of a mental matrix that accessed alternative resource stores; specifically, the attentional capacity limit in the above task is shared between chunk storage and the storage of intermediate results of processing as the mental matrix is updated (Kerr, Condon, & McDonald, 1985; Quinn, 1994; Quinn & Ralston, 1986; Cowan, 2000). The secondary task in the Norrie, Maki, & Staines (2002) paper had an additional motor component and no attempt was made to keep motor demands of the upper extremity constant in the single and dual task conditions. It also appears that the working memory tasks described in the Dault, Frank & Allard (2001) study accessed additional resources other than those associated with working memory; for example the visuo-spatial task required visual identification of a manikin as well as mental rotation in multiple planes to determine target location. Evidence from imaging research shows that the supplementary motor area (SMA) and the premotor cortex are

involved in computing rotations of Shepard-Metzler figures; thus it can be argued that these same areas would be involved in the mental rotation of a manikin (Logie et al., 2011).

Furthermore, studies using functional magnetic resonance imaging (fMRI) have identified regions in the posterior parietal and occipital cortex associated with cognitive processing during the execution of a visual working memory task (Todd & Marois, 2004, 2005; Xu & Chun, 2006). Thus the working memory tasks selected in the Dault, Frank, Allard (2001) study was complex and required access of extensive attentional resources during processing. Given the complexity of the integration of sensory inputs that control upright stance, it is critical to use a cognitive task that probes a unique attentional resource store in the dual task postural paradigm to provide greater insight into underlying mechanisms of interference patterns identified in many of the studies described above.

Research Overview

The primary objectives of this project were to further illuminate and understand neural factors contributing to normal balance control and determine how age-related changes in these factors constrain balance in the aging adult. Though previous research has demonstrated interference between postural control and performance of secondary tasks in young and older adults, mechanisms contributing to this interference remain unclear, in part due to ambiguity among results of previous studies, due to the variety of cognitive tasks paired with postural tasks.

We speculated that experimental results related to interference between the control of posture and central neural processes would be clearer if cognitive tasks selected probed a

unique attentional resource. Thus a visual working memory task (change detection of features) was selected for the current research protocol, as it maintains information in storage with no associated manipulation demands. Since no previous studies have used a visual working memory task that specifically identifies capacity limits to study the interference pattern between cognitive processes and the control of posture, the research presented in Chapter II established the extent of interference between the two modalities in young adults during a variety of postural tasks. The co-authors for the research presented in Chapter II are Dr. Marjorie Woollacott and Dr. Edward Vogel.

Once the relationship between visual working memory and the control of posture among young adults was established, these results formed the basis of comparison of dual task interference for older versus young adults. Dual task demands were evaluated and compared under conditions of increasing postural challenge in Chapter III and Dr. Marjorie Woollacott was the co-author. In addition, the general limits of visual working memory capacity were contrasted for young and older adults. We hypothesized that visual working memory capacity for older adults would be significantly lower than for young adults. We also hypothesized that the attentional resources required to perform postural tasks would be significantly greater for older adults than young adults, and thus we expected increased decrements in the performance of the cognitive task for older compared to young adults in the dual task context. Finally we hypothesized that any postural performance decrements in the dual task compared to single task context would be greater in older than young adults.

CHAPTER II
DOES WORKING MEMORY CAPACITY DECLINE WHEN PAIRED
WITH STANDING BALANCE CONTROL

This chapter includes co-authored work; the experimental paradigm was designed in collaboration with Dr. Marjorie Woollacott with valuable input from Dr. Edward Vogel. I collected all the data and paper 1 was written entirely by me, with my coauthors providing feedback and editorial assistance. This chapter introduces a unique dual task postural paradigm that addresses technical issues related to the targeting of a specific set of central attentional resources in young adults. The paper establishes an inverse relationship between visual working memory capacity and the control of posture under conditions of increased motor challenge in young adults; specifically it shows the reduction of working memory capacity when postural task difficulty is increased from quiet sitting through balance recovery in response to support surface perturbations.

Introduction

The ability to perform more than one task concurrently has long been a tool used in the study of neural processing associated with attention and memory. The dual task paradigm (performing two tasks at once) has been used extensively to probe patterns of interference between two cognitive tasks (Baddeley & Hitch, 1974; Baddeley, 1986; Logie, Zucco, & Baddeley, 1990). One area of dual task studies has paired cognitive tasks with upper extremity perceptual motor tasks, e.g. finger tapping or manual tracking (Cocchini et al., 2002; Della Sala et. al., 1999; Della Sala et. al., 2010). At the root of these investigations is the nature of the neural resource store. Specifically, the studies

investigated whether online processing and temporary storage of information occurs by means of a number of specialized cognitive functions or whether a central resource is shared among these functions. In the early 70's Baddeley & Hitch (1974) proposed a multi-component model of working memory, in which separate capacity limited subsystems for visual and verbal information storage were controlled by a central executive. Alternatively, Cowan (2000) proposed that working memory is a general purpose attentional resource employed in all tasks regardless of modality. This model suggests it is the focus of attention itself that is capacity limited, averaging 4 items represented in memory, with a central resource store that is not modality specific, but limited by time and susceptible to interference (Cowan, 2000).

Dual Task – Cognitive Psychology

A number of studies, in the area of cognitive psychology, have demonstrated that with some combination of cognitive tasks, healthy adults can perform under demanding dual-task conditions with little performance degradation in either task. For example when the following tasks, a memory span for visual matrix patterns or a visually presented letter sequence, were paired with a concurrent arithmetic or a concurrent task which involved manipulation of visuo-spatial material, no significant decline in performance was observed across tasks (Logie, Zucco, Baddeley, 1990). Other studies have combined a cognitive task with that requiring motor control. The pairing of a digit recall task with a tracking task demonstrated minimal reductions in performance in either the digit recall or tracking tasks (Della Salla et al., 2010). Non-significant decrements (10%-12%) were observed when a verbal memory task was paired with a tracking task (voluntary motor control of the upper extremity), despite both tasks having very high demands (Baddeley,

1986). When a visuo-spatial working memory task was performed concurrently with a voluntary hand movement task cognitive performance was unaffected by the arm movement (Logie & Marchetti, 1991). In addition, visual immediate memory tasks have been shown to be largely unaffected (drop of approximately 11%) by concurrent physical movement of the upper extremity (Cocchini et al., 2002; Della Salla et al., 1999).

In two studies, which paired a spatial memory task, a series of sentences were presented instructing placement of digits into a mental matrix, with a manual task (tracing out the sequence of the matrix) an interference pattern was present; however, interference only occurred in those conditions of incompatible movement patterns (opposite direction to the set sequence) (Quinn, 1994; Quinn & Ralston, 1986). These results indicate that level of difficulty of either task may be a factor influencing performance under dual task conditions.

One group of researchers probed location memory versus appearance memory (the font of the letter); when paired with a keypad tapping task, longer mean latencies were observed for location memory but not appearance memory (Darling, Della Sala, & Logie, 2007). These results were interpreted to suggest that each task employs different specialized cognitive functions that operate in parallel. The authors suggested that it is the type of tasks that are combined, and not the overall cognitive demand of the dual task requirements, that determine whether or not performance will be substantially impaired under dual task conditions (Logie, Zucco, & Baddeley, 1990; Cocchini et al., 2002).

Dual Task – Motor Control of Posture and Gait

The dual task paradigm has been applied within the domain of the control of posture and gait as well. Until recently postural control had traditionally been thought to occur at an automatic level; however select evidence from dual task postural paradigms, pairing a postural task with a cognitive task, suggests the cerebral cortex and high-level cognitive processing contribute to aspects of balance control.

Research in the area of postural control, supports a systems model of balance control; specifically, multiple perceptual systems contribute to the control of posture, including vestibular, visual and somatosensory (Macpherson & Inglis, 1993; Horak, Nashner, & Nutt, 1988; Stapley et al., 2002; Macpherson & Fung, 1999; Horak & Nashner, 1986). The influence of different sensory modalities on posture changes according to the task requirements. When standing, an individual rapidly selects the most functionally appropriate combination of sensory feedback within a given sensory context; for example, when standing on the deck of a boat, the body increases weighting on incoming visual information to establish vertical orientation rather than use signals from foot and ankle somatosensory receptors that are less helpful in vertical orientation. Alternatively, when balance is disturbed, such as the forward or backward movement of the support surface as experienced when standing on a train or bus during stops and starts, the nervous system responds automatically to avert a fall. The automatic (involuntary) postural response increases weighting on foot and ankle somatosensory receptors that provide rapid input with onset latencies that range from 80-120ms. The onset latency of visual input is too long (>200ms) to contribute during the recovery response following a disturbance to stance (Nashner & Berthoz, 1978; Lestienne, Soechting & Berthoz, 1977).

The ability to re-weight sensory inputs under conditions of incoming sensory conflict may be described as adaptability within the central nervous system or a form of redundancy that enhances the efficiency of postural control (Nashner, 1982).

Postural research using a dual task paradigm, suggests that the process of controlling stability requires attentional resources, defined as available information-processing resources that are assumed to be limited. Competition for processing resources may occur during the performance of two attentionally demanding tasks and lead to task interference. It has been postulated that altered performance in one of the tasks suggests a re-allocation of resources from either the postural or cognitive task, whereas a change in both tasks reflects a sharing of attentional resources between the two tasks. Many studies have shown interference patterns under postural dual task conditions, pairing a postural task with a cognitive task, demonstrating a reduction in performance of the cognitive task, the postural task or both tasks. (Kerr, Condon, & McDonald, 1985; Lajoie et al., 1993; Maylor, Allison, & Wing, 2001; Woollacott & VanderVelde, 2008). Paralleling results from the cognitive psychology literature, not all of the postural dual task research shows interference in the performance of postural and/or cognitive tasks.

Questions arose as to whether altered performance under postural dual task conditions was influenced by the degree of difficulty of either the postural or cognitive task. In some studies that increased the level of postural demands (stance with feet hip width apart, heel/toe stance, walking) paired with different types of cognitive tasks (e.g. verbal response to auditory stimuli, the Brooks spatial task, and the non-spatial verbal memory task), no change in postural performance was seen across postural conditions, though degradation was seen in the performance of the cognitive tasks (Lajoie et al., 1993; Kerr,

Condon, & McDonald, 1985). In these studies the researchers concluded that increasing levels of postural demand cause an increased demand for attentional resources, thus lowering the performance level on the cognitive task. In other studies, examining either stance postural control and/or sudden unexpected perturbations of the standing support surface paired with a cognitive task, results showed deterioration in both the postural and the cognitive task (Brown et al., 1999; Shumway-Cook et al., 1997; Rankin et al., 2000; Brauer et al., 2001; Doumas et al., 2008). As seen in the cognitive psychology literature, researchers in the area of postural control began to suspect that the type of cognitive task chosen influenced whether or not performance would be substantially impaired under dual task conditions.

The type of cognitive task chosen to pair with either a postural or a second cognitive task relates directly to the type and amount of resources utilized or targeted. One research group (Woollacott and Vander Velde, 2008) examined factors they felt might contribute to the variability of findings in previous studies. They examined the extent to which modality (visual vs. auditory) and code (non-spatial vs. spatial) specific cognitive resources contributed to postural interference in young adults in a dual-task setting. The findings from this study showed that postural performance on the Tandem Romberg task was significantly influenced by the type of cognitive task. At comparable levels of cognitive task difficulty (n-back demands and accuracy judgments) the performance of challenging auditory-spatial tasks produced significantly greater levels of postural sway than either the auditory-object or visual-object based tasks. These results suggest that it is a limitation in non-visual spatially based coding resources that may underlie previously observed visual dual-task interference effects with stance postural control.

Though the above studies have added valuable information to our understanding of dual task interference with postural control, there is still considerable debate regarding the exact nature of the interference between postural control and a variety of different cognitive tasks. We hypothesize that previous researchers may not have considered access to more complex networks during task selection under dual task conditions. For example, cognitive tasks such as the n-back task, verbal response to auditory stimuli, the Brooks spatial task, the non-spatial verbal memory task, and sentence structure tasks include processing involving the manipulation of information (Kerr, Condon, & McDonald, 1985; Quinn, 1994; Quinn & Ralston, 1986; Woollacott and Vander Velde, 2008). We propose that experimental results related to interference between control of posture and central neural processes would be clearer if cognitive tasks selected required simple maintenance of information as opposed to tasks using additional attentional resources associated with manipulation of information. The visual change detection task (Luck and Vogel, 1997; Pashler, 1988) is such a task, with minimal processing demands.

The change detection task thus is a robust measure that can be tested in the absence of additional processing using a change detection paradigm for simple features; performance does not appear to be influenced by perceptual processes (Sperling, 1960). In experiments by Luck & Vogel (1997), subjects were presented with a sample array consisting of 1-12 colored squares for 100ms (encoding) followed by a 900 ms blank interval (maintenance/retention) and then a test array was presented for 2000 ms that was either identical to the sample array or differed in the color of one of the squares (retrieval). Subjects retained the colors of roughly 4 items in visual working memory. In an alternative experiment decision requirements were reduced by provision of a cue that

indicated which square might have changed, with similar results, retention of roughly 4 items. The average limit of 4 items persisted with the evaluation of integrated objects; bars differed in 4 dimensions (size, orientation, color, and presence or absence of a central gap). Performance remained the same with an average of 4 items identified regardless of the 4 stimulus attributes attended. The capacity limit reflected the number of integrated objects, not the number of object features. In addition, individual differences in visual working memory capacity were identified using a neural correlate of visual working memory; the lateralized amplitude of event-related potentials (ERP's) reflected the encoding and maintenance of items in visual working memory (Vogel & Machizawa, 2004). The authors showed ERP "difference waves" (the ipsilateral activity was subtracted from the contralateral activity for each array size) in which amplitude asymptotes at individual storage capacity limits, low-capacity individuals reached this plateau sooner than high-capacity individuals. Thus, a change detection task that predicts visual working memory capacity was selected as the cognitive task in the present study.

Based on outcomes of this evolving research, it is our fundamental tenet that the use of a cognitive task that targets attentional capacity and lacks additional processing requirements will improve upon the technical aspect of the dual task paradigm. Working memory capacity has been well defined; it is a type of limited-capacity memory system for short-term retention and manipulation of information that has a fixed capacity limit (defined as the number of unique items held in working memory, 3-4) (Luck & Vogel, 1997; Vogel & Machizawa, 2004; Halford, Wilson, & Phillips, 1998; Vogel, Woodman, & Luck, 2001; Pashler, 1988). However, no previous studies have associated capacity limit of a visual working memory task (change detection of simple features) with the

motor demands of postural control in a dual task paradigm; this work will facilitate the prediction of attentional capacity under single task conditions and identify any changes in capacity under dual task conditions. The experimental protocol will provide pivotal insight into the nature of the interaction between central resource stores associated with each modality.

Overview of the Present Study

The goal of the present study was to determine the interaction between visual working memory (using a task that simply maintains information) and the control of posture among young adults. Specifically, aims included: 1) determining whether the concurrent presentation of a visual working memory task, change detection of simple features (colored squares), and postural tasks of increasing challenge demonstrate an interference pattern and 2) determining whether there is a threshold point, along a continuum of increasing challenge (increase in set size associated with the visual working memory task versus varied postural demands), at which a decline in performance of one or both tasks occurs. We hypothesized that performing a visual working memory task in conjunction with postural tasks of increasing challenge would result in the modulation of visual working memory capacity. We posited that a sharing of resources between the two subsystems would result in a decrease in working memory capacity and/or an alteration in the postural response to maintain upright stance. We also hypothesized that there is a threshold point of increased postural demand at which interference between the two subsystems occurs.

Experiment 1A: Testing Interference Between Visual

Working Memory and Postural Control

Experiment 1A used a change detection task of simple features (colored squares) to demonstrate the presence of an interference pattern between visual working memory capacity and the control of posture within a postural dual task paradigm. The diagram in Figure 2.1 represents the design of the study and includes an example of the stimuli.

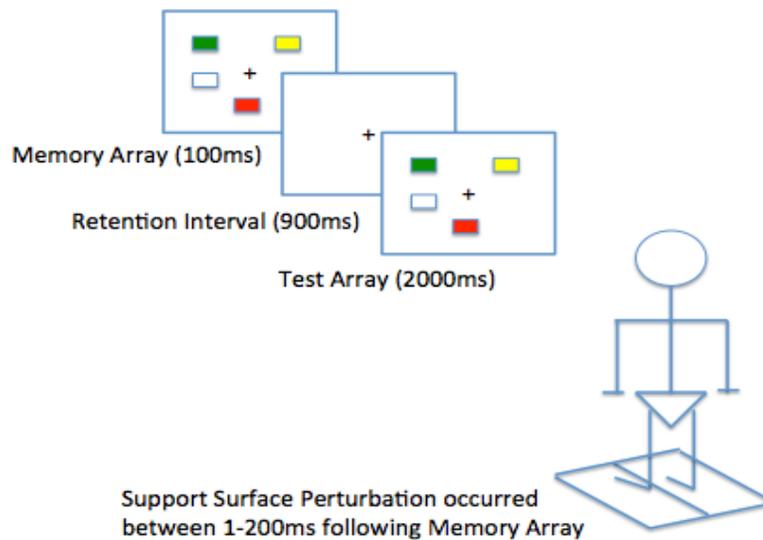


Figure 2.1: Diagram representation of the paradigm for experiment 1, subjects used a button press to indicate the status of the stimuli, memory array versus test array, with left for no change and right for change.

Method

Participants. Thirty-two neurologically normal University of Oregon students, 11 males and 21 females, ranging in age from 21 to 35 years (mean 24.3 ± 3.7) participated in the study. Each was informed of experimental conditions and gave written consent prior to initiating the testing session. All procedures were approved by the office for protection of human subjects at the University of Oregon.

Cognitive Task. Visual working memory incorporates three component processes: consolidation, maintenance, and retrieval. A change-detection protocol measured visual working memory capacity. During consolidation, memory arrays of set sizes 4, 6, or 8 squares were viewed for 100ms, followed by a blank grey screen with a central cross (distance of 70 cm), during which subjects retained in memory the number, position, and color of the array for 900ms. In the 2000ms retrieval phase, which followed, subjects indicated whether memory and test arrays were identical or different using bilateral button presses (Left - no change, Right - change). Each set of squares was presented thirty times for a total of 90 trials, with a short practice session preceding experimental conditions to eliminate a learning effect. An algorithm was developed to randomly select from a set of seven highly discernable colors (red, blue, violet, green, yellow, black and white); individual colors appeared no more than twice within an array. Stimulus positions were randomized on each trial, with the constraint that the distance between squares was at least 2° (center to center). The color of one square was different in half of the test arrays. An adjustable tripod with a platform was used to raise and lower the screen between postural conditions.

Postural Tasks. Postural conditions included the control (sitting), isolated stance, and perturbation of the support surface. Of note, to eliminate habituation during perturbations a randomized number of quiet stance trials occurred between displacements of the support surface; thus isolated stance trials were intermixed with perturbation of the support surface trials. During these isolated stance trials subjects knew that a perturbation would occur but due to the randomization of the time between perturbations they did not know exactly when it would occur; thus this condition will be referred to as the “expectation” condition.

Perturbations consisted of backward movement of a force platform support surface system built by the Institute of Neuroscience Technology Group at the University of Oregon, with a displacement of 10 cm at a velocity of 20 cm/s. Baseline memory capacity was measured while subjects were seated. Foot position, in the stance conditions, was held constant by tracing the feet on the support surface. Visual observation was used in this preliminary study to identify change in postural strategy, no step versus step. Participants performed the visual memory task and maintained neutral posture in all conditions; they were instructed to keep their feet within the initial traced position and to focus equal attention on maintaining upright posture and accuracy on the change detection task. Platform movement occurred randomly between 1-200ms following presentation of the 100ms memory array. The experimental design was balanced to ensure condition order did not confound working memory task performance: e.g. sit-stand-perturbation, perturbation-sit-stand, and stand-perturbation-sit. Note that the “expectation” condition (isolated stance intermixed with perturbations) was associated with the perturbation condition. The subjects wore a safety harness attached to an overhead trolley, to ensure safety during the perturbations in case a loss of balance occurred.

Data Analysis. A simple equation was used to estimate visual working memory capacity, the number of items (K) stored in working memory (Pashler, 1988; Cowan, 2000). The value for K was determined using the following formula, $K = SS (HR + CR - 1)$, where SS = set size (4, 6, or 8), HR = hit rate (number of times the change in squares was correctly identified), and CR = correct rejection (number of times no change in squares was correctly identified). Working memory capacity was calculated for the 30 trials of each set size and used to calculate the average K-score for the 90 trials by summing the set size K-scores and dividing the total by the number of set sizes included in the visual working memory task, in this case 3. Working memory capacity (K-score) was estimated based on presentation of the 90 visual working memory trials during the control (sitting), isolated stance and perturbation conditions. However, a mean of 1061 ± 39 visual working memory trials was presented during the “expectation” (isolated stance intermixed with perturbations) condition, as the working memory task was repeated during the randomized time periods between perturbations. The study is a repeated measures design. Since working memory capacity demonstrated high variability it was used as the sample size determinant (Norman & Streiner, 2000) and repeated-measures one-way ANOVA was used to analyze the data. Post-Hoc paired samples t-tests were performed between conditions. Visual working memory capacity, K-scores, from the control (sitting) condition were rank ordered from low to high and the median split determined. Individuals with K-scores less than the median split value, were assigned to the low capacity group and those greater than the median split value were assigned to the high capacity group. Regression analyses were used to determine whether processes associated with performance changes in low versus high capacity individuals were similar or different. In addition, regression analyses were

used to help identify whether the drop in K-score for each set size was the result of similar or differing underlying neural processes. Changes in postural strategy in the presence of a concurrent working memory task were noted (no step versus step).

Results and Discussion

Reductions in overall visual working memory capacity were anticipated during the more challenging condition of perturbation of the support surface however modulations were observed in two of the postural conditions, during the perturbation condition and also during the “expectation” (isolated stance intermixed with perturbations) condition. The inverse relationship between postural conditions and visual working memory capacity is presented in Figure 2.2 A.

In addition, Figure 2.2 A shows that little change in visual working memory capacity was seen between the control (sitting) and isolated stance conditions. Results from a repeated measures one-way ANOVA supported these observations with a significant main effect of condition, $F(3,29) = 4.95$, $p < 0.02$ with an effect size of 0.66. Post-Hoc paired samples t-tests identified no significant difference in working memory capacity between the control (sitting) condition and stance in isolation. A significant difference in working memory capacity, however, was identified between the control (sitting) and the “expectation” (isolated stance intermixed with perturbations) condition ($p < 0.05$), the control (sitting) and perturbation condition ($p < 0.01$), isolated stance and the “expectation” (isolated stance intermixed with perturbations) condition ($p < 0.05$), and the isolated stance and perturbation conditions ($p < 0.01$).

The results in Figure 2.2 A suggest that reductions in visual working memory capacity were graded and we posit that the decline observed was related to a threshold within the

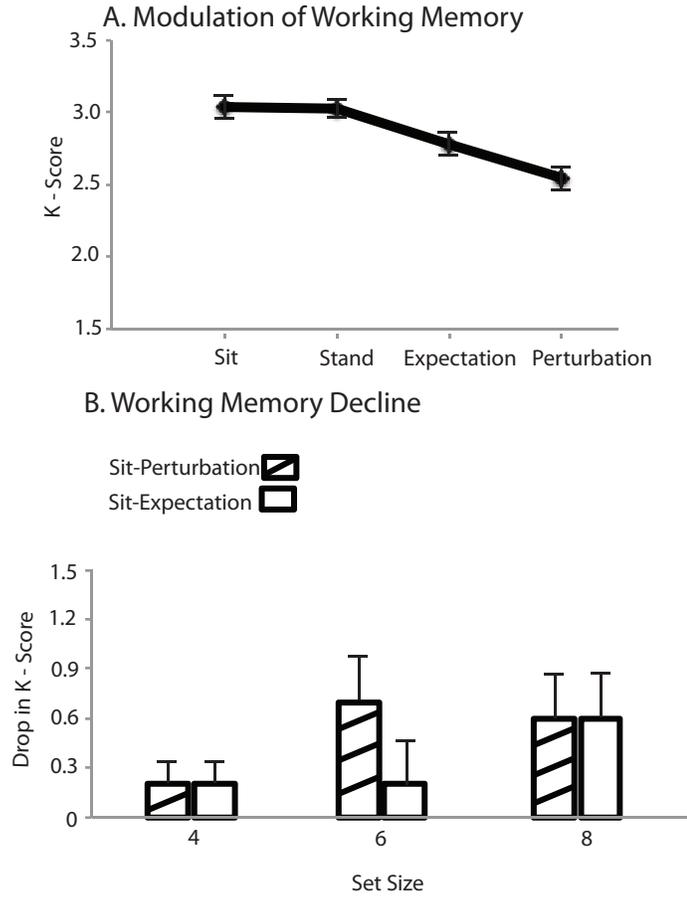


Figure 2.2: A. Visual working memory capacity (averaged K-Score) decline across postural conditions for young adults. B. Drop in working memory capacity (K-Score) between the control (sitting) and perturbation conditions versus control (sitting) and “expectation” (isolated stance intermixed with perturbations) conditions for each set size 4, 6 and 8. Error bars represent standard error of the mean (SE).

nervous system at which performance of one or both tasks is altered when paired concurrently. The presence of an interference pattern between visual working memory and the two postural conditions suggests the sharing of attentional resources.

Subjects were subdivided into high and low capacity groups to determine whether one group had a greater influence on the main condition effect. Since there was no significant difference in K-scores between the control (sitting) and isolated stance conditions, K-scores for these two conditions were combined and averaged. The difference between the combined K-scores and the “expectation” (isolated stance intermixed with perturbations) and perturbation conditions for both the high and low capacity group was calculated. The p-value level associated with the regression analysis was set at 0.01 and as such no correlation was found between high and low capacity individuals for the perturbation ($r = 0.56$; $p < 0.03$) and/or “expectation” ($r = 0.36$; $p < 0.20$) conditions. Thus the modulation in K-scores seen with increased postural challenge suggests that the visual working memory task and the postural conditions of increased challenge were tapping into a common resource but not the same resource that separated groups by capacity.

The difference (drop in K-scores) between the control (sitting) condition and both the “expectation” (isolated stance intermixed with perturbations) and perturbation conditions was contrasted in Figure 2.2 B for set sizes 4, 6, and 8. The drop in K-scores for perturbations seen in Figure 2.2 B between 4 and 6 squares suggests that both increased set size and level of postural challenge impacted performance. A similar drop in K-scores was seen in the perturbation condition with set size 6 and 8, which reflects the asymptote effect typically seen with set size levels above 4 items (Vogel & Machizawa, 2004). Alternatively, the “expectation” (isolated stance trials that were intermixed with perturbations) condition showed a similar drop in K-scores for set size 4 and 6. Of note is the difference in drop in K-scores for set sizes 4 and 6 for the two postural conditions; a larger drop is seen during the perturbation condition than when subjects were “expecting” a

perturbation during the isolated stance intermixed with perturbations condition during set size 6. Using the same criteria as above, no correlation was seen for drop in K-scores between perturbations and “expectation” (isolated stance intermixed with perturbations) conditions for set size 4 ($r = 0.13$; $p < 0.47$). However, there was a correlation for set sizes 6 ($r = 0.51$; $p < 0.01$) and 8 ($r = 0.49$; $p < 0.01$). In general the presence of a correlation between the 2 conditions suggests that the interference pattern for the two postural conditions used similar neural mechanisms, whereas the absence of a correlation suggests that separate neural mechanisms were utilized in each condition. It is unclear whether the “expectation” of perturbation effect was simply a weak perturbation effect.

During the dual task condition of perturbations paired with the visual working memory task, however 22 percent of subjects took a step, indicating greater instability than for perturbations alone (no participants stepped). Perturbation parameters used in this study do not typically necessitate taking a step when applied in the absence of an additional task. This points to a change in control of postural performance under the current dual task conditions. In addition, the “expectation” (isolated stance intermixed with perturbations) condition resulted in modulation of visual working memory capacity, specifically a reduction in the number of object representations consolidated in working memory; this was an unexpected result.

Experiment 1B: Arousal Control

Experiment 1B was designed to evaluate variability in K-scores and rule out an arousal effect. Postural condition was further manipulated after the identification of an increase in K-scores between the control (sitting) and isolated stance in 40% of subjects (13 individuals); the relationship is demonstrated in Figure 2.3 A.

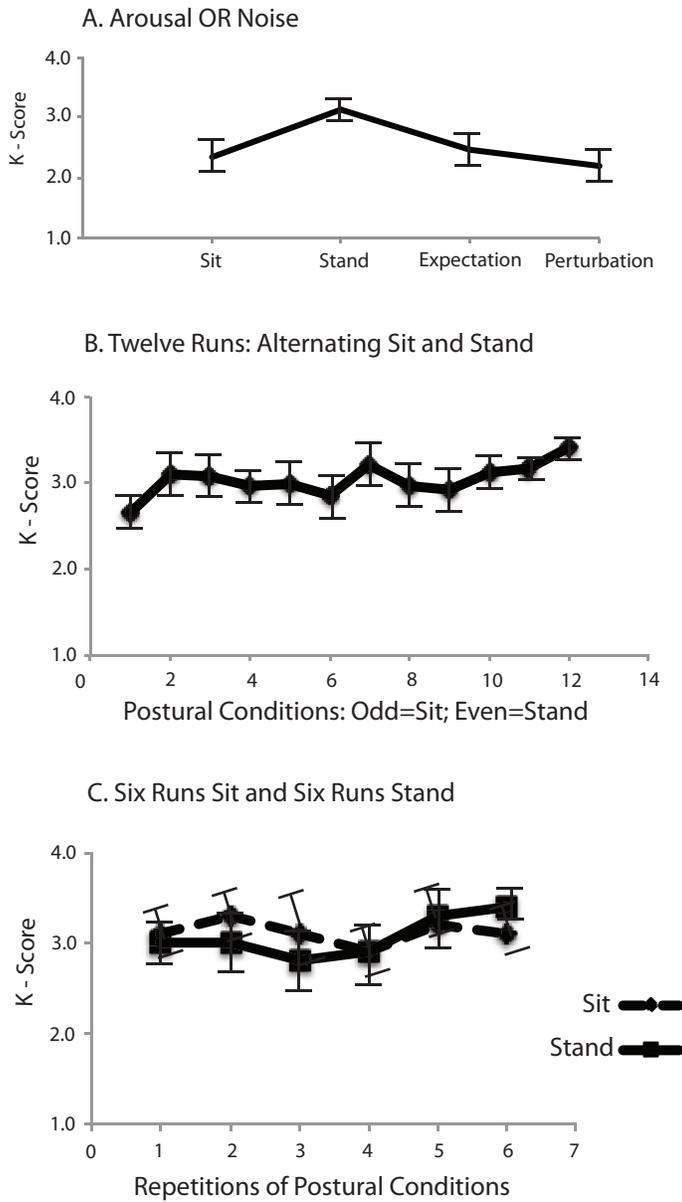


Figure 2.3: A. Condition means for 13 individuals, visual working memory capacity (K-Score) increased between the sit and stand position. B. Working memory capacity (means) for subjects alternating between the sit and stand position; the first data point represents sitting. C. Six consecutive trials in sitting followed by 6 in standing. Error bars represent standard error of the mean (SE).

To determine whether the increase in K-scores represented an arousal effect (higher arousal in stance versus sitting) further data were collected from a subset of 6 individuals from the study population. We speculated that if the spike in K-scores from sitting to isolated stance resulted from an increase in arousal associated with the difference in these two positions we should see a coincident increase in K-scores with standing and decrease with sitting.

Method

The cognitive task was identical to that used in Experiment 1A. The postural conditions were reduced to include the control (sitting) and isolated stance. Subjects participated in two additional testing sessions that included: 1) 12 repetitions of a set of 90 trials of the change detection task during alternating postural conditions between the control (sitting) and isolated stance conditions and 2) 12 repetitions of a set of 90 trials of the change detection task during 6 consecutive control (sitting) conditions followed by 6 consecutive isolated stance conditions.

Results and Discussion

Figure 2.3 B shows the response pattern from averaged K-scores when experimental conditions were alternated between the control (sitting) and isolated stance conditions. Figure 2.3 C shows further manipulation of the experimental conditions by repeating the control (sitting) condition 6 times consecutively followed by the isolated stance condition 6 times consecutively. The response patterns in Figures 2.3 B and Figure 2.3 C did not show consistent changes with shifts from the control (sitting) to isolated stance conditions; rather the responses appeared to reflect within subject variability across runs.

Thus, the initial spike in K-scores observed in 40% of subjects was more likely a reflection of the within subject variability across subjects than an arousal effect.

The interference pattern seen in Experiment 1A provides the unique finding of the sharing of resources between a visual working memory task (specifically a simple storage task that maintains information as opposed to a task that requires increased processing for the manipulation of information) that provides an estimate for attentional capacity, and the control of stance posture. A distinctive feature of this work was the prediction of attentional capacity under single task conditions that facilitated the identification of any changes in capacity under dual task conditions. These findings support earlier research that shows an interaction between cognitive and postural task performance. In addition, the findings from experiment 1 concur with research that has presented differences in interaction between postural and cognitive tasks based on level of both postural and cognitive task complexity (Kerr, Condon, & McDonald, 1985; Lajoie et al., 1993; VanderVelde, Woollacott, & Shumway-Cook, 2005; Vogel & Awh, 2008; Vogel & Machizawa, 2004). The findings from Experiment 1 gave rise to a number of questions about the nature and robustness of the interference pattern that will be addressed in Experiment 2.

Experiment 2

Experiment 2 was designed to shed light on the robustness of the interference pattern between visual working memory and postural control seen in experiment 1. Research shows that encoding/consolidation of information into working memory places large demands on processing resources. Thus, alterations were made to the paradigm in experiment 2 to provide evidence that the decline in visual working memory performance was associated with a competition for attentional resources as opposed to the disruption of

encoding information into working memory (refer to Figure 2.4 for changes to the experimental paradigm). In addition, set sizes were adjusted to broaden the continuum of the level of difficulty within the cognitive task to include a non-challenging level. Motor demands of the upper extremity were kept constant in both the single and dual task conditions and to ensure visual demands remained constant between the two conditions, a cross was projected on the monitor during single task conditions and subjects were asked to focus on the cross.

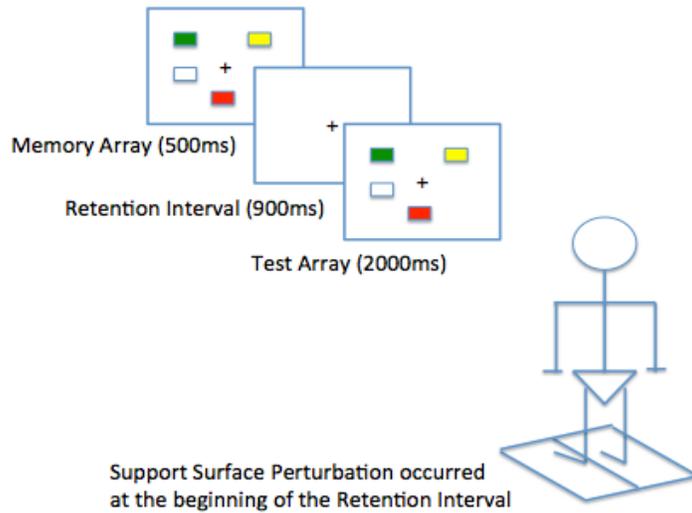


Figure 2.4: Documents experimental paradigm changes relative to study 1. Specifically, memory array presentation increased to 500ms and all support surface perturbations occurred at the beginning of the retention interval.

Method

Participants. Thirty-four neurologically normal University of Oregon students, 11 males and 23 females, ranging in age from 19 to 24 years (mean 20.6 ± 1.5) participated in the study. Each was informed of experimental conditions and gave written consent prior to initiating the testing session. All procedures were approved by the office for protection of human subjects at the University of Oregon.

Protocol Changes. The stimuli were similar to those in Experiment 1, except memory array set sizes were changed to 2, 4, or 6 squares and displayed on a monitor in front of the subjects for 500ms. Displacement of the support surface occurred immediately following removal of the memory array, coinciding with the beginning of the retention interval. The change in set sizes was made to broaden the continuum of difficulty of the cognitive task from very easy to more difficult, more closely paralleling the different challenge levels of the postural tasks. To eliminate the possibility of interrupting encoding, which has been shown to take approximately 250-300ms (Vogel, Woodman, & Luck, 2006), the memory array was increased to 500ms. Since the cognitive task required button presses, we included button presses during the single task postural condition because the main focus of the experiment was to determine the interference between attentional demands of the cognitive task and postural task. Therefore additional motor requirements had to be equal across both tasks. Thus, subjects were instructed to randomly depress right and left buttons during the single task postural condition. Likewise, to ensure visual demands remained constant between the two conditions, a cross was projected onto the monitor during single task conditions and subjects were asked to focus on the cross.

Consistent with Experiment 1, visual observation was used to identify change in postural strategy. Forward perturbations of the support surface were interspersed among backward perturbations, adding a further level of randomization uncertainty to the postural tasks. In addition, force platform displacement was kept the same at 10 cm; however, velocity was increased to 30 cm/s. The subjects wore a safety harness attached to an overhead trolley to ensure safety during the perturbations in case a loss of balance occurred.

Results and Discussion

The results of Experiment 1 were replicated in Experiment 2. Modulation of visual working memory was seen when paired with various levels of postural challenge. Figure 2.5 A shows the inverse relationship between visual working memory and postural conditions.

As seen in Experiment 1, reductions in working memory capacity were observed at a threshold point of increasing postural challenge, during perturbations and again during the “expectation” (isolated stance intermixed with perturbation) conditions. Little change in visual working memory capacity was seen between the control (sitting) and isolated stance conditions. These observations were supported statistically (repeated measures one-way ANOVA) by the significant main effect of condition, $F(3,31) = 4.27, p < 0.05$ with an effect size of 0.71. Post-Hoc paired samples t-tests identified no significant difference in working memory capacity between the control (sitting) and isolated stance conditions or between the isolated stance and “expectation” (isolated stance intermixed with perturbations) conditions. A significant difference in working memory capacity, however, was identified

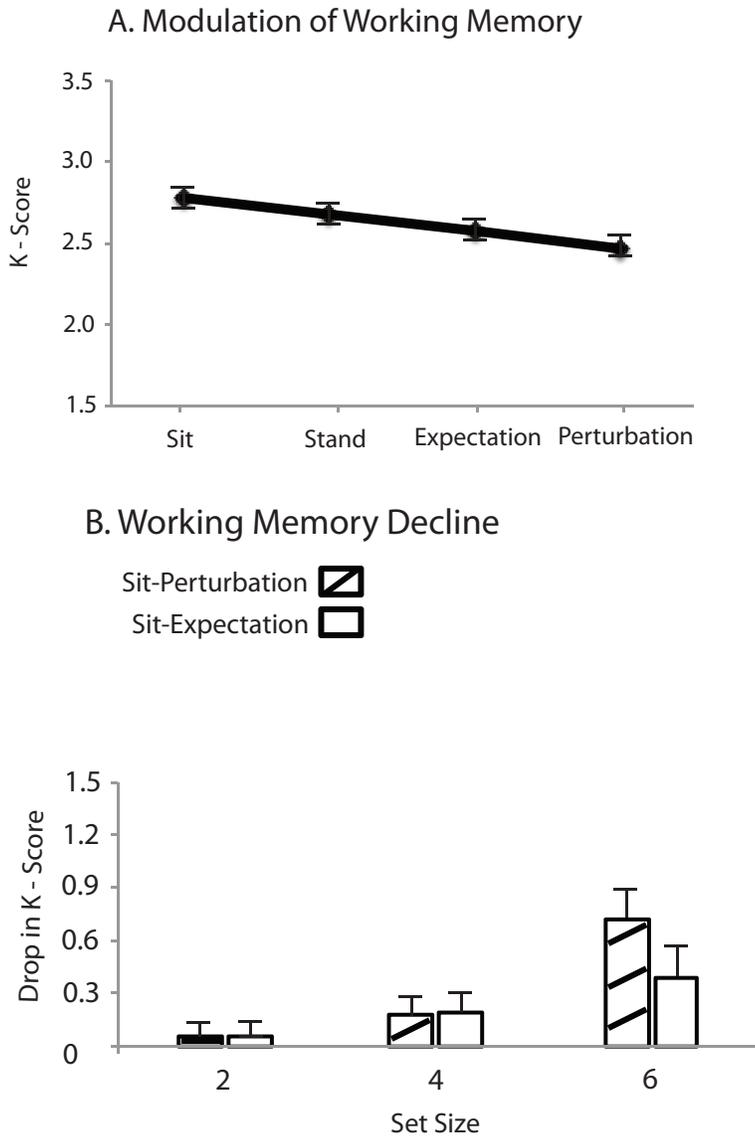


Figure 2.5: A. Visual working memory capacity (averaged K-Score) decline across postural conditions for young adults. B. Drop in working memory capacity (K-Score) between the control (sitting) and perturbation conditions versus control (sitting) and “expectation” (isolated stance intermixed with perturbations) for each set size 2, 4 and 6. Error bars represent standard error of the mean (SE).

between the control (sitting) and “expectation” (isolated stance intermixed with perturbations) conditions ($p < 0.05$), the control (sitting) and perturbation conditions ($p < 0.01$), and isolated stance and the perturbation conditions ($p < 0.05$). These results provided further evidence supporting the interference pattern between visual working memory and postural recovery from an unexpected perturbation, observed in experiment 1.

These results raised further questions about the nature of the “expectation” (isolated stance intermixed with perturbation) effect that was seen in Experiment 1. The absence of a condition effect between the isolated stance and “expectation” (isolated stance intermixed with perturbations) conditions in Experiment 2 lead to the evaluation of within subject variability among this study population. Since 40% of the population in Experiment 1 showed an increase in K-score between the control (sitting) and isolated stance conditions we decided to explore the percentage of subjects in Experiment 2 who showed a similar pattern of response. Twenty-nine percent of the population in experiment 2 (10 individuals) demonstrated an increase in K-score between the control (sitting) and isolated stance conditions. When means and standard deviations for individuals showing this pattern of within subject variability were compared across the two study groups (Experiment 1, control (sitting): 2.3 ± 0.9 , isolated stance 3.1 ± 0.7 ; Experiment 2, control (sitting): 2.2 ± 0.5 , isolated stance: 2.7 ± 0.7), no statistical difference was found between the control (sitting) condition ($p < 0.8$) or the isolated stance ($p < 0.3$) conditions between Experiment 1A or 2.

Alternatively, it may be that there is a threshold point at which the level of difficulty of the cognitive task negatively influences cognitive performance during the “expectation” (isolated stance intermixed with perturbations) condition as set sizes in experiment 1 were more difficult (4, 6, and 8). Since a condition effect was present between the control

(sitting) and “expectation” (isolated stance intermixed with perturbations) conditions in both Experiment 1 and 2, it may be that at a specific level of difficulty, processes involved in the expectation of postural disturbances compete for attentional resources used to complete the visual working memory task.

When subjects were divided into high and low capacity groups, as in experiment 1, the decline in capacity was similar in both high and low groups across conditions. No correlation was found between low and high capacity individuals in either the perturbation ($r = 0.04$; $p < 0.88$) or the “expectation” (isolated stance intermixed with perturbations) conditions ($r = 0.16$; $p < 0.55$). This is further evidence that the visual working memory task and postural conditions were tapping into a common resource but not the same resource that separated groups by capacity.

Figure 2.5 B contrasts the difference (drop) in K-scores between the control (sitting) condition and both the perturbation condition and “expectation” (isolated stance intermixed with perturbations) conditions for set sizes 2, 4, and 6. A minimal drop in K-scores was seen for set size 2 in both postural conditions reflecting the low level of difficulty. The pattern for drop in K-scores was similar in both experiment 1 and 2 for set sizes 4 and 6, with a greater drop in K-scores seen for perturbations; this showed the impact of set size on performance. As in Experiment 1, there was little difference in the drop in K-scores for the “expectation” (isolated stance intermixed with perturbations) condition for set sizes 4 and 6. Correlations were found for drop in K-scores between the perturbation and “expectation” (isolated stance intermixed with perturbations) conditions across all three set sizes, 2 ($r = 0.64$; $p < 0.01$), 4 ($r = 0.84$; $p < 0.01$), and 6 ($r = 0.73$; $p < 0.01$). In isolation, these results suggest that similar neural processes were involved in both postural conditions.

No significant difference was seen in the number of steps when single and dual task conditions were compared ($p < 0.33$). During the dual task condition of perturbations paired with the visual working memory task, however 29 percent of subjects took a step; indicating greater instability for dual task conditions than for perturbations alone. Of this group, only 9% stepped during the single task conditions and those individuals who took a step during one of the single trials, stepped during multiple trials of the dual task condition. Perturbation parameters used in this study do not typically necessitate taking a step when applied in the absence of an additional task. Further analysis of postural measures would provide insight as to whether young adults show a coincident reduction in postural performance. Increased postural challenge associated with regaining stability resulted in the modulation of working memory capacity, specifically a reduction of the number of object representations consolidated in working memory.

The results of Experiment 2 showed an interference pattern between visual working memory and the maintenance of postural control under challenging conditions, particularly during perturbation of the support surface; this is a replication of the findings in Experiment 1. Since memory array presentation was increased to 500ms in Experiment 2, consolidation was complete before the perturbations occurred. Thus the interference pattern seen in Experiment 2 could not be due to the disruption in the consolidation of information. In addition, increased stepping during the dual task condition seen among a number of subjects may reflect an altered postural strategy during the dual task condition. Taken together the results of Experiments 1 and 2 provide strong evidence that the attentional resource associated with visual working memory is shared with postural responses recruited to recover from an unexpected disturbance of balance.

General Discussion

The primary aim of this study was to determine whether the concurrent pairing of a visual working memory task that targeted specific isolated attentional stores and tasks of increasing postural challenge demonstrated an interference pattern. We posited that a sharing of resources between the two tasks would result in a decrease in working memory capacity and/or an alteration in the postural response to maintain upright stance. Experiment 1 suggested a decline in working memory capacity with increased challenge for both the cognitive and postural tasks. Since no one had previously examined the relationship between working memory and posture using a simple storage task that was limited to the maintenance of information, this was a unique finding. As such, efforts were made to replicate the findings seen in Experiment 1 to demonstrate the robustness of the effect.

Since the memory array for the visual working memory task was presented for 100ms and perturbations occurred between 1-200ms following the completion of the memory array in Experiment 1, one possible cause of the interference pattern was the interruption of the consolidation process of getting information into working memory. This was tested in Experiment 2 by increasing the memory array presentation to 500ms, thus ensuring that the squares were consolidated into visual working memory before application of the postural perturbations. The results from both Experiment 1 and 2 demonstrated an interference pattern, regardless of whether the postural conditions were applied during the consolidation or maintenance phases of the visual working memory task. One interpretation of these results is that a similar resource was accessed for both consolidation and maintenance phases of working memory.

The results showed that reductions in visual working memory capacity were graded and that modulation was related to a threshold point at which performance of one or both tasks was altered when paired concurrently with a specific level of postural challenge, consistently during the perturbation condition in both Experiment 1 and 2. The term “threshold” in the current study relates to the level of postural demands associated with various positions. Our results show that the increased postural demands between isolated stance as compared to the recovery from a perturbation of the support surface was consistent in both Experiment 1 and 2, regardless of the characteristics of the perturbation (velocity of the support surface perturbations varied between Experiment 1 (20 cm/s) and Experiment 2 (30 cm/s) with a constant displacement of 10 cm). The results suggest that the “threshold” relates to the level of attentional demand required during the automatic recovery response as compared to the control (sitting) or isolated stance conditions.

The results supported our supposition that a sharing of resources between two subsystems would result in a decrease in working memory capacity. The behavioral measures used to evaluate postural response were insufficiently sensitive to clearly determine exact changes in postural performance. Evaluation of alternative postural measures typically used in postural control research will be performed in future work to identify the nature of the postural responses and whether they were affected under the present experimental conditions.

We postulate that competing resources from the postural system relate to formation of the “central set”. The “central set” relates to the influence of the central drive on automatic postural responses to external perturbations (Brooks, 1984). Setting aspects of the response in advance were shown to be beneficial to decrease the time for the central nervous system

(CNS) to transform an incoming postural stimulus into an appropriate response. Errors in postural responses were seen however when the stimulus or external conditions unexpectedly changed, e.g. subjects consistently produced responses greater than warranted when a number of large velocity displacements of the support surface were followed by a slow velocity trial (Horak, Diener, & Nashner, 1989). The modulation in visual working memory capacity seen in the perturbation condition may reflect a similar disturbance to the postural central set as seen when characteristics of the perturbation stimulus are changed.

The significant cognitive-postural task interference pattern differences seen in Experiment 1 between the isolated stance and “expectation” (isolated stance intermixed with perturbations) conditions was an unexpected effect and raised questions as to the nature of the attentional resources and how they are shared. Expectation has been shown to be part of a category of the “central set”, however, we have insufficient evidence at present to firmly conclude that the significant effect between isolated stance and expectation of perturbation is related to processes associated with postural “central set”. The fact that a significant effect was seen between the control (sitting) and “expectation” (isolated stance intermixed with perturbations) conditions in Experiment 2 does show a level of interference as a result of a change in postural challenge, unfortunately the underlying nature of the interference pattern remains unclear.

Several authors have proposed capacity-sharing models in which interference between two tasks originates in a reduction of the efficiency with which each task simultaneously operates, induced by a graded sharing of resources between tasks (Kahneman, 1973; Norman & Bobrow, 1975; Wickens, 1983). The simplest version of this theory suggests that only a single general resource is allocated to all cognitive processes. The findings of

the present study suggest neural processing related to visual working memory (a simple storage task that maintains information), and the control of posture under challenging conditions compete for a common resource; it thus supports a capacity-sharing model of visual working memory.

Interference patterns under dual task conditions using complex visual working memory tasks have been presented previously (Kerr, Condon, & McDonald, 1985; Maylor, Allison, & Wing, 1993; Shumway-Cook & Woollacott, 2000; Woollacott & VanderVelde, 2008); however, the interaction between visual working memory using a simple storage task and postural control is unique. The fact that there is a reduction of visual memory capacity when simply expecting that a postural perturbation might occur, in addition to conditions of actually recovering balance, gives further evidence that maintaining balance is less automatic than originally believed. These results provide further support that cognitive processes may be taxed under specific postural conditions.

CHAPTER III

THE ROLE OF ATTENTION IN FALL AVOIDANCE

EVALUATION OF DUAL TASK INTERFERENCE WITH POSTURAL AND VISUAL WORKING MEMORY TASKS IN YOUNG AND OLDER ADULTS: DOES CAPACITY LIMITATION INFLUENCE POSTURAL RESPONSES?

This chapter includes co-authored work; I collected all the data and performed the analyses and this chapter was written entirely by me in collaboration with Dr. Marjorie Woollacott who provided feedback and editorial assistance. This chapter compares and contrasts cognitive and postural performance of young and older adults using the research paradigm described in Chapter II.

Introduction

The incidence of falling increases with aging and the adverse effects of falls are broad, ranging from extended hospitalization to death (Tinetti et al. 1988; Downton and Andrews 1991; Alexander et al. 1992; Berg et al. 1997). As a large proportion of our society ages it is critical to increase our understanding of neural mechanisms associated with the control of posture; particularly how these mechanisms are affected by aging.

Increased incidence of falls has been associated with balancing and walking under dual task conditions (performing two tasks at once). For example young adults readily perform motor and cognitive tasks simultaneously (e.g. reading e-mail on a hand held device while walking) with little impact on performance of either task; however similar activities among older adults more commonly result in a fall (Beauchet et al. 2008; Faulkner et al. 2007).

Studies have shown interference patterns under postural dual task conditions, in which postural and high-level cognitive tasks are paired, suggesting a sharing of attentional resources between the two independent modalities (Kerr et al. 1985; Lajoie et al. 1993; Maylor et al. 2001; Dault et al. 2001; Woollacott and VanderVelde 2008).

The current study was designed to examine the effect of aging on the interaction between concurrent cognitive and postural demands by comparing performance in young and healthy older adults. The general capacity theory for attention suggests there is a finite amount of processing space available in the central nervous system to perform tasks. Thus a reduction in overall attentional resources with aging may negatively influence the ability to re-direct these resources to a postural task. Other effects of aging are widespread, occurring at many levels of the nervous system, including cognitive function (Schaie 1990), sensory systems, the integration of sensory information essential for balance control, as well as motor and musculoskeletal impairments, such as reduced muscle strength and reduced range of motion (Macpherson and Inglis 1993; Horak et al. 1988; Stapely et al. 2002; Macpherson and Fung 1999, Horak and Nashner 1986; Mecagni et al., 2000; Verbaken and Johnston, 1986). Therefore, aging may negatively impact the ability to allocate sufficient cognitive resources to postural tasks when an attentionally demanding cognitive task is performed simultaneously.

Not all of the postural research, however, shows interference in the performance of postural and cognitive tasks under dual conditions (Dault et al. 2001). Altered performance under postural dual task conditions is influenced by the degree of difficulty of the primary or secondary task and the nature of the attentional resource targeted during the cognitive task. For example a number of cognitive tasks have increased processing

demands such that information stored in working memory must be manipulated to complete the task; this type of processing is required for the n-back task (each digit in a continuous series is compared with the digit that occurred n items ago) (Huxhold et al. 2006) or the Brooks spatial memory task (requires maintenance and updating of a mental matrix) (Kerr et al. 1985; Quinn, 1994; Quinn and Ralston, 1986; Cowan, 2000). A cognitive task that simply stores information would permit the isolation of a specific cognitive resource, and thus provide a better understanding of the interaction between the attentional resources required for a working memory task that solely maintains information and the control of different types of postural tasks.

The visual change detection task (Luck and Vogel 1997; Pashler, 1988) used in the current study requires only that information be stored in working memory and we propose it provides a more sensitive tool to study the nature of the interaction between cognitive processing and the control of posture. It is a robust measure that provides an estimate of visual working memory capacity and its performance does not appear to be influenced by perceptual processes (Luck and Vogel 1997; Sperling 1960). The visual working memory task was paired with postural tasks of increasing levels of challenge, from sitting to standing to automatic postural responses to backward perturbation of the support surface of 10 cm at 30 cm/s. The perturbation trials were challenging for both young and older subjects in that the excursion of the center of pressure (COP) induced by the motion neared the anterior limit of stability.

Our previous study showed a decline in visual working memory capacity in young adults for stance and perturbation trials compared to sitting. In this study we demonstrate that older adults have a lower memory capacity than the young and their capacity also

declines with postural tasks compared to sitting. Furthermore, young adults show no significant change in their ability to recover from the balance perturbations whereas older adults and, even more so the frail elderly, have greater difficulty in recovering balance. In particular, older adults tend to use more stepping and up on toes rather than feet-in-place strategies. These results increase our understanding of the mechanisms underlying increased potential for falling in the elderly population.

Materials and Methods

Research Participants

Thirty-four healthy young and 39 healthy older adults (Young: 23 females and 11 males; Older: 30 females and 9 males) were recruited for the study. The young adults (YA) ranged in age from 19 to 24 years (mean 20.6 ± 1.5) and the older adults from 65 to 90 years (mean 73.0 ± 5.7); mean height and mass for young adults was 170.8 ± 9.5 cm and 70.2 ± 11.4 Kg; for older adults it was 163.7 ± 7.6 cm and 74 ± 14 Kg respectively. Each participant was informed of experimental conditions and gave written consent prior to initiating the testing session. All procedures were approved by the office for protection of human subjects at the University of Oregon.

Protocol

Cognitive Task

The visual working memory task was described fully in the preceding paper. In brief, the change-detection for simple features protocol was used to establish a value for visual working memory capacity. During consolidation, memory arrays of 2, 4, or 6 squares were viewed for 500ms, followed by a blank grey screen with a central cross (distance of 70 cm), during which subjects retained in memory the number, position, and color of the

array for 900ms. In the following 2000ms retrieval phase, a test array was presented and subjects indicated whether memory and test arrays were identical or different using bilateral button presses (Left - no change, Right - change). Memory arrays of 2, 4, or 6 objects were used following pilot testing with older adults, in which it became clear that they were not able to perform the task with arrays of 4, 6, and 8 objects (those typically used for young adults). The use of 2, 4, and 6 object arrays also broadened the continuum of difficulty of the cognitive task from very easy to more difficult, to parallel the levels of difficulty of the postural task.

Each set of squares was presented thirty times for a total of 90 trials, with a short practice session preceding experimental conditions to eliminate a learning effect. In some instances the older adults required 2-3 repetitions of the practice session before becoming proficient with the change detection task. An algorithm was developed to randomly select from a set of seven highly discernable colors (red, blue, violet, green, yellow, black and white); individual colors appeared no more than twice within an array. Stimulus positions were randomized on each trial, with the constraint that the distance between squares was at least 2° (center to center). The color of one square was different in half of the test arrays. An adjustable tripod with a platform was used to raise and lower the screen between postural conditions. Figure 3.1 is representative of the experimental protocol.

Postural Conditions

Postural conditions included the control (sitting), isolated stance, “expectation” (isolated stance intermixed with perturbations) and perturbation of the support surface; the cognitive task was performed across all conditions. Note, the term “expectation” is used

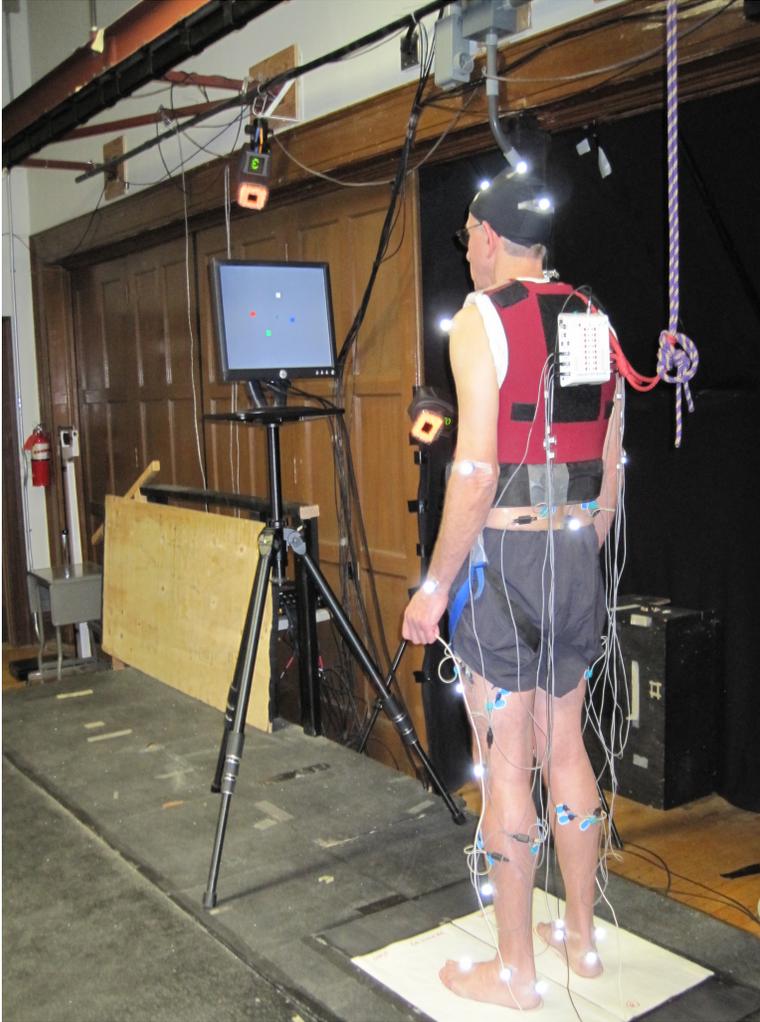


Figure 3.1: Experimental paradigm. Subjects gazed at the screen in front of them when performing the visual change detection task. They held buttons in each hand that were depressed during both single and dual task conditions. They retained the same foot location throughout all trials. Subjects were also regularly instructed to place equal attention on both the cognitive and postural tasks throughout the testing session.

to signify the isolated stance intermixed with perturbations condition because subjects knew that perturbations would occur on some trials but could not predict on which trial they would happen. The isolated stance and perturbation conditions were evaluated under

both single and dual task conditions. Memory capacity obtained sitting was the control condition for the cognitive task. Participants were instructed to keep their feet within the initial traced position during the stance conditions and maintain a neutral posture. Under dual task conditions they were instructed to focus equal attention on postural and visual working memory tasks. To eliminate habituation during perturbation, a randomized number of quiet stance trials and forward perturbation trials occurred between displacements of the support surface in the backward direction, which caused forward sway. Adding forward perturbations also reduced the tendency of subjects to prepare for a perturbation by leaning backwards in order to reduce forward sway; it thus promoted upright positions of stance between perturbations of the support surface. These forward direction perturbations were interspersed among trials in both single and dual task conditions.

In the dual task condition platform movement immediately followed presentation of the 500ms memory array, coinciding with the beginning of the retention interval for a total of 90 perturbations. Fourteen single task perturbation trials preceded and 11 followed those trials presented with the cognitive task. The first three single task trials were removed from analysis to account for initial adaptation to the postural task. To ensure visual demands remained constant between the two conditions, a cross was projected on the monitor during single task conditions and subjects were asked to focus on the cross. Subjects were instructed to randomly depress either of the buttons they held in their hands during the single task condition, to keep any additional motor requirements constant across both tasks. The experimental design was balanced to ensure condition order did not confound working memory task performance: equal number of subjects performed the following sequences: sit-stand-perturbation, perturbation-sit-stand, and stand-perturbation-sit. All subjects wore a

safety harness attached to an overhead trolley, to ensure safety during the perturbations in case a loss of balance occurred.

Clinical Test

The Fullerton Advanced Balance (FAB) scale was used to evaluate balance control at the functional level. The Fullerton Advanced Balance scale is a predictive measure of faller status among independently functioning older adults. An older adult who scores 25 or lower on the Fullerton Advanced Balance scale has been shown to be at higher risk for falls, therefore, this tool was used to evaluate postural control and identify individuals at both extremes of the continuum in terms of functional abilities (Hernandez & Rose 2008). Behavioral data (frequency of stepping) from the 5 older adults whose scores were ≤ 25 (termed frail elderly) were contrasted with the 5 older adults who achieved close to perfect scores on the Fullerton Advanced Balance scale in order to examine the effects of postural capacity on dual task performance.

Data Collection

Recorded data included ground reaction forces (GRF), 10 channels of electromyography (EMG) and force plate position sampled at 1000 Hz using a Motion Analysis Acquisition Unit (12 bit A/D inputs with a $\pm 5V$ range and amplifier with a gain of 10 - resolution 2.441 mV/bit). Ground reaction forces and plate position were obtained using a platform system built by the Institute of Neuroscience Technology Group at the University of Oregon, consisting of two force plates that move in unison: parameters 10 cm displacement at a velocity of 30 cm/s. Raw EMG was amplified through a pre-amplifier, DC Power Supply $\pm 5V$ at 2.5 mA, with an input impedance greater than 100 M Ω using pairs of bipolar surface electrodes (disposable blue sensor, silver-silver chloride,

Medicotest, Inc.) with an inter-electrode distance of 2 cm. The following muscles were recorded bilaterally: tibialis anterior (TA), gastrocnemius (GA), rectus femoris (RF), hamstrings (HA), and erector spinae (ES) at L₄₋₅. Kinematic data were obtained using a set of 29 reflective markers secured to bony landmarks and their positions (x,y,z coordinates) tracked by a 10 camera (infra-red) system (resolution 1 mm), sampled at 100Hz. Postural behavioral data were also collected in the present study using visual observation to identify trials in which no step versus a step was taken, for both single and dual task conditions.

Data Analysis

Postural Variables

Ninety trials were included in the dual task paradigm to establish a value for visual working memory capacity in the dual task condition. The data for each subject were subdivided chronologically into 5 trial sets across the entire data collection sequence; 5 trials were included in each trial set. The single before (SB) trial set included the 5 single task trials preceding the 90 dual task trials and the single after (SA) trial set included the first 5 trials directly following the dual trials. Three dual task trial sets were identified; dual early (DE) included the 5 initial dual task trials immediately following the early single task trials, dual middle (DM) included 5 trials from the mid-point of the dual trial sequence (typically trial numbers 60-64), and dual late (DL) included the last 5 dual trials before the late single trials. If steps were taken during any of the trials typically included in the trial sets, alternative trials directly preceding or following were used in an attempt to have 5 trials per trial set. The data were subdivided in this manner to separate the dual task effect between single and dual task conditions from the attenuation of postural

responses which typically occurs following repeated application of the same stimulus (Horak and Nashner 1986; Macpherson et al. 1989).

Dual task effects were determined by comparing single before (single task) and dual early (dual task) conditions for all postural measures. In addition single before and single after conditions were compared to eliminate fatigue as a factor influencing postural responses. The number of trials in which subjects moved up on toes as part of the recovery response was assessed in each of the trial sets; 10 single task trials and 15 dual trials were combined to determine the total number of trials in which subjects used an up on toes pattern of postural recovery. Rise to toes was defined as a change in vertical heel position from the quiet stance level that exceeded 30 mm as determined from the kinematic data. This value was chosen to account for the reduction in range of motion at the ankle joint, flexibility of the feet, and general strength consistent with the effects of aging.

Vertical ground reaction forces were combined bilaterally to characterize the trajectory of the center of pressure (COP) along the anterior-posterior axis; the COP reflects the point location of the vertical ground reaction force vector that represents the weighted average of all the area in contact with the ground (Winter, 1990). The COP data were low-pass filtered at a cutoff frequency of 50 Hz and re-sampled at 100 Hz (every 10th point was selected). The area under the center of pressure trajectory along the x-axis was quantified in mm-ms for two consecutive bins of 80ms width (young adults: 190-270ms and 270-350ms following onset of platform movement; older adults 200-280ms and 280-360ms). Onset of bin1 was based on an EMG activation time of 90ms for young and 100ms for older adults (Woollacott et al., 1986) plus 100ms of estimated excitation-

contraction coupling time. The area under the anterior-posterior force trajectory, N-ms, was also quantified for the same 2 bins.

The EMG data were high-pass filtered at a cutoff frequency of 10 Hz, then full-wave rectified and low-pass filtered at a cutoff frequency of 35 Hz. Right and left side EMG traces were summed for each muscle. EMG responses were quantified by area under the EMG curve (mV-ms) for 2 bins of 80ms width (90-170ms and 170-250ms young adults; 100-180ms and 180-260ms for older adults). The 2 time bins captured events occurring during the early versus late phase of the automatic postural response (Horak et al. 1989). The onset of the initial time segment in older adults was increased to 100 ms to account for slower onset latencies seen with older adults (Woollacott et al. 1986).

Cognitive Measures

A simple equation initially developed by Pashler (1988) and later refined by Cowan (2000), was used to estimate the number of items (K) that can be maintained in working memory. The value for K was determined using the following formula, $K=SS (HR + CR - 1)$, where SS = set size (2, 4, or 6), HR = hit rate (number of times the change in squares was correctly identified), CR = correct rejection (number of times no change in squares was correctly identified). Working memory capacity was calculated for the 30 trials of each set size and used to calculate the average K-score for the 90 trials by summing the set size K-scores and dividing the total by the number of set sizes included in the visual working memory task, in this case 3. Working memory capacity (K-score) was estimated based on presentation of the 90 visual working memory trials during the control (sitting), isolated stance and perturbation conditions. However, a mean of 1061 ± 39 visual working memory trials was presented during the “expectation” (isolated stance intermixed with perturbation

condition), as the working memory task was repeated during the randomized time periods between perturbations.

Statistical Analysis

To facilitate across-subject comparisons, variables were normalized to the absolute value of the mean of bin 1 for the SB condition. Because 4 muscles exhibited low amplitude responses in bin 1 compared to bin 2, the EMG areas of TA, HA, RF, and ES were normalized to the absolute value of the mean of bin 2 in the SB condition.

The study is a repeated measures design. Since working memory capacity demonstrated high variability among all the measures, it was used as the sample size determinant (Norman & Streiner 2000). For statistical significance at a 90% power level within groups, 34 healthy young and 39 older adults were recruited. The dependent variables (behavioral) included visual working memory capacity (K-scores), hit rate ratios, correct rejection ratios, and Fullerton Advanced Balance scale scores. The dependent postural measures included normalized area under the center of pressure trajectory (nCOPx), normalized area under the anterior-posterior force trajectory (nFap), and normalized EMG amplitudes (nGA, nHA, nES, nTA, nRF) for both bin1 and bin2. Both behavioral and postural measures were analyzed using one-way repeated-measures ANOVA. Also included in the statistical analysis were the mean values of the peak COPx displacement (postural measure) as a percent of foot length (pkCOPx%). Post hoc paired sample t-tests were used to determine differences in mean K-scores, hit rate ratios, and correct rejection ratios across postural conditions and Bonferroni corrections were performed to determine differences among postural measures between conditions and groups. Regression analysis was used to determine whether there was a correlation between

the number of steps taken by the subject and the drop in K-scores. In addition regression analysis was also used to determine whether there was a correlation between the time for the COPx trajectory to recover following the perturbation and the drop in K-scores. Of note, behavioral measures data associated with the cognitive and postural tasks (K-scores and steps taken) were complete for the two age groups, young adults and older adults. However, this was not the case for the postural measures typically used to characterize postural responses, e.g. nCOPx; data from all but one of the young adults were included in the analysis of the measures reflective of postural responses and due to the increased frequency of stepping among older adults (subjects feet must remain in contact with the force plate to generate measurable data), data from seven of the older adults were excluded from the analysis of postural performance.

Results

Visual Working Memory Capacity

Modulations in overall visual working memory capacity (K-scores) were seen in both young and older adult populations, particularly under the more challenging postural condition of backward perturbations (Figure 3.2 A). The inverse relationship between visual working memory and postural conditions for both young and older adults can be seen in Figure 3.2 A. A condition effect ($F(3, 31) = 4.27, p < 0.05$ (effect size = 0.71)) was seen for the young adults. Post-Hoc paired samples t-tests identified no significant difference in working memory capacity between the control (sitting) and the isolated stance conditions or between the isolated stance and the “expectation” (isolated stance intermixed with perturbations) conditions. A significant decline in visual working memory capacity was identified between the control (sitting) and the “expectation” (isolated stance

intermixed with perturbations) conditions ($p < 0.05$), the control (sitting) and the perturbation conditions ($p < 0.01$), and the isolated stance and the perturbation conditions ($p < 0.05$).

A condition effect ($F(3, 36) = 9.46, p < 0.001$ (effect size = 0.56)) was observed among older adults as well. Post-Hoc paired samples t-tests among older adults identified a

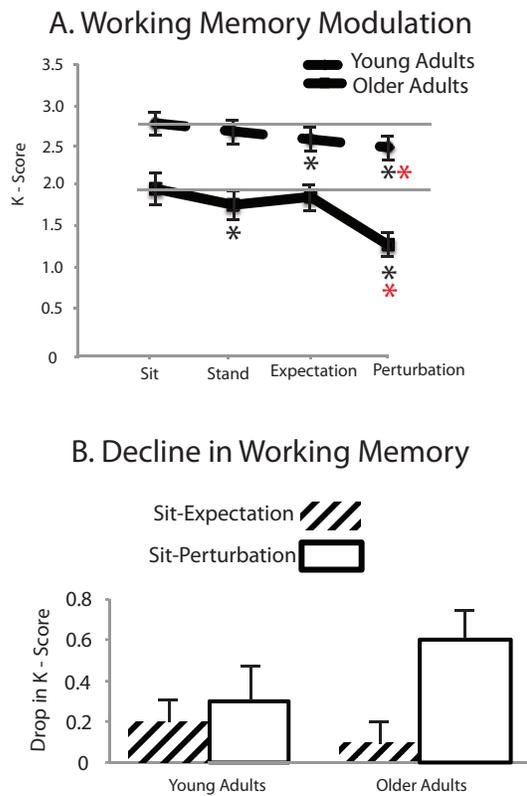


Figure 3.2: A. Young and older adults demonstrated a significant decline in working memory capacity with increased postural challenge; the greatest impact was seen during the perturbation condition. B. The drop in working memory capacity between sit and expectation and sit and perturbation was significant for older adults ($p < 0.001$) but not young adults ($p < 0.06$). The asterisk identifies differences between conditions, Legend: *=Sit and *=Isolated stance. Error bars represent standard error of the mean (SE).

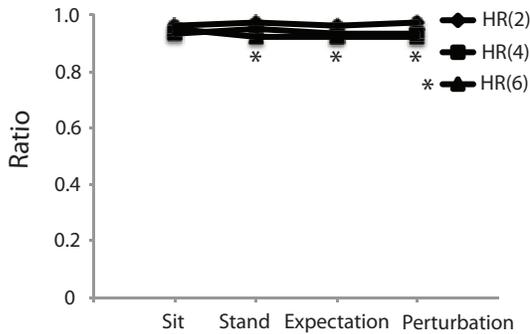
significant decline in working memory capacity between the control (sitting) and the isolated stance conditions ($p < 0.05$), the control (sitting) and the perturbation conditions ($p < 0.001$), and the isolated stance and the perturbation conditions ($p < 0.05$). The drop in visual working memory capacity (K-scores) for young and older adults between the control (sitting) and “expectation” (isolated stance intermixed with perturbations) conditions and the control (sitting) and the perturbation conditions are presented in Figure 3.2 B.

When each postural condition was compared between the two groups there were significantly lower K-scores for older adults across all 4 conditions compared to young adults, 1) the control (sitting): $p < 0.001$, 2) isolated stance: $p < 0.001$, 3) “expectation” (isolated stance intermixed with perturbation): $p < 0.001$, and 4) perturbation of the support surface: $p < 0.001$. Of particular interest was the reduced control condition (sitting) between young and older adults, that was significantly different at $p < 0.001$; young adults presented with an average visual working memory capacity of 3 (2.8 ± 0.6) as compared to 2 (1.8 ± 0.7) for older adults, an approximate decrease of 40%. This result supports our hypothesis of an overall decline in visual working memory capacity with aging.

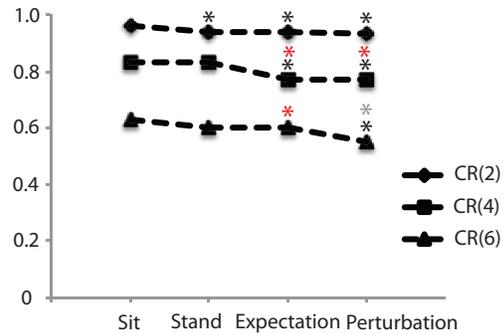
As stated earlier the estimate for visual working memory capacity was based on both the hit rate (the number of times the change in squares was correctly identified) and the correct rejection rate (the number of times no change in squares was correctly identified). As such further analysis was performed to determine whether there were differences in processing associated with hit rate ratios versus correction rejection ratios. We speculated

Young Adults

A. Hit Rate (HR) Ratios

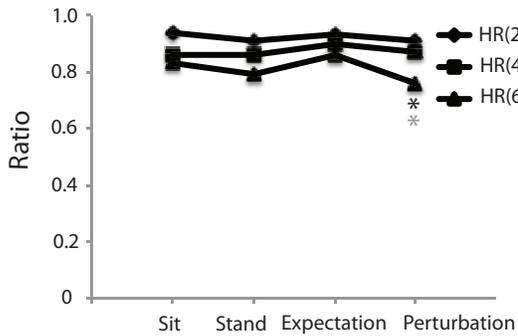


B. Correct Rejection (CR) Ratios



Older Adults

C. Hit Rate (HR) Ratios



D. Correct Rejection (CR) Ratios

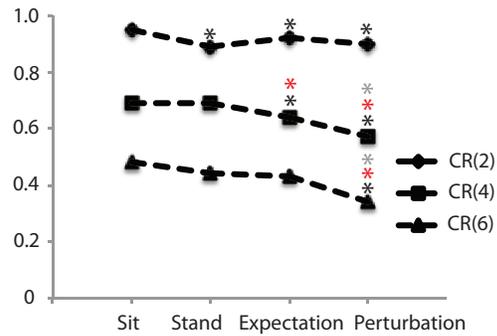


Figure 3.3: A. Hit rate = number of times the change in squares was correctly identified, for set sizes 2, 4, and 6 in young adults. B. Correct rejection = number of times no change in squares was correctly identified, for set sizes 2, 4, and 6 in young adults. C. Hit rate for set sizes 2, 4, and 6 in older adults. D. Correct rejection for set sizes 2, 4, and 6 in older adults. The asterisk above each condition identifies differences between conditions, Legend: *_{Sit}, *_{Stand}, and *_{Expectation}. Error bars represent the standard error of the mean (SE).

that if more attentional resources were required for correctly identifying change in square color, than identifying no change in color, it would be evident with the separation of the two measures.

Figure 3.3 shows a distinct separation between the identification of the lack of a change in color of one square (correct rejection) and the ability to correctly identify the presence of a change in the color of one square (hit rate) when the test array is compared to the memory array in the change detection task. Of particular note is the greater reduction in the ratio as the level of difficulty of the change detection task increases (increase in set size). These results suggest that the ability to identify the absence of a change in the color of one square (correct rejection) required increased resources during neural processing as compared to the ability to correctly identify the presence of a change in color of one of the squares (hit rate). Paired samples t-tests were used to identify a significant decrease in hit rate and correct rejection ratios for older adults compared to young adults across all conditions and set sizes. Significant differences were seen between older adults and young adults in all conditions, except for the correct rejection ratios for set size 2 in the “Expectation” condition ($p < 0.22$). The hit rate and correct rejection ratios were also evaluated across conditions among young and older adults.

There was no significant change in hit rate ratios for a set size of 2 across all 4 postural conditions among young adults (Figure 3.3 A); however there was a significant reduction in correct rejection ratios for a set size of 2 between the control (sitting) and isolated stance conditions ($p < 0.01$), the control (sitting) and the “expectation” (isolated stance intermixed with perturbations) conditions ($p < 0.01$), and the control (sitting) and the perturbation conditions ($p < 0.01$) (Figure 3.3 B). The young adults also showed no

significant change in hit rate ratios for set size 4 across all 4 postural conditions (Figure 3.3 A). The young adults did demonstrate a significant decrease in correct rejection ratios for set size of 4 between the control (sitting) and the “expectation” (isolated stance intermixed with perturbations) conditions ($p < 0.05$), the control (sitting) and the perturbation conditions ($p < 0.001$), isolated stance and the “expectation” (isolated stance intermixed with perturbations) conditions ($p < 0.01$), isolated stance and the perturbation conditions ($p < 0.001$) and between the “expectation” (isolated stance intermixed with perturbations) and perturbation conditions ($p < 0.01$) (Figure 3.3 B). The young adults did show a marginally significant decrease in the hit rate ratios for a set size of 6 between the control (sitting) and perturbation conditions ($p < 0.06$), with a significant decrease between the “expectation” (isolated stance intermixed with perturbations) and perturbation conditions ($p < 0.001$) (Figure 3.3 A). And lastly there was a significant decrease for correct rejection ratios among young adults for a set size of 6 between the control (sitting) and the perturbation conditions ($p < 0.001$), isolated stance and the perturbation conditions ($p < 0.01$), and the “expectation” (isolated stance intermixed with perturbations) and perturbation conditions ($p < 0.001$) (Figure 3.3 B).

Similar to young adults the older adults showed no significant change in hit rate ratios for set size 2 across all 4 postural conditions (Figure 3.3 C). There was a significant decrease for set size 2 with respect to the correct rejection ratios between the control (sitting) and isolated stance conditions ($p < 0.01$), the control (sitting) and the “expectation” (isolated stance intermixed with perturbations) conditions ($p < 0.01$), and the control (sitting) and the perturbation conditions ($p < 0.01$) (Figure 3.3 D). No significant difference was seen among older adults for hit rate ratios with set size 4 across all 4 postural conditions (Figure

3.3 C). The older adults did show a significant decrease in correct rejection ratios for set size 4 between the control (sitting) and “expectation” (isolated stance intermixed with perturbations) conditions ($p < 0.05$), the control (sitting) and the perturbation conditions ($p < 0.001$), the isolated stance and “expectation” (isolated stance intermixed with perturbations) conditions ($p < 0.01$), isolated stance and the perturbation conditions ($p < 0.001$), and the “expectation” (isolated stance intermixed with perturbation) and perturbation conditions ($p < 0.01$) (Figure 3.3 D). The older adults showed a marginally significant decrease in hit rate ratios for set size 6 between the control (sitting) and the perturbation conditions ($p < 0.06$) and the “expectation” (isolated stance intermixed with perturbations) and perturbation conditions ($p < 0.001$) (Figure 3.3 C). The older adults also showed a significant decrease in CR ratios for set size 6 between the control (sitting) and the perturbation conditions ($p < 0.001$), isolated stance and the perturbation conditions ($p < 0.01$) and the “expectation” (isolated stance intermixed with perturbations) and perturbation conditions ($p < 0.001$) (Figure 3.3 D). There appears to be a graded response such that the modulation in correct rejection occurs at greater levels of postural demand, specifically during recovery from an unexpected perturbation of the support surface. The hit rate appears to be influenced only at higher levels of difficulty, e.g. increased set sizes.

Balance Measures

Scores from the clinical test used to assess functional balance, the Fullerton Advanced Balance scale, were significantly reduced for older (33.4 ± 4.4) adults as compared to the young (39.1 ± 0.7) adult population ($p < 0.001$); the scores of the older adults were reduced by approximately 18% compared to the young adults.

For the behavioral measures (recovery using in place versus stepping strategies) used to assess postural control under single task (perturbation) (11 trials) versus dual (90 trials) task (perturbation plus cognitive task) conditions, no significant difference was seen in the number of steps between single (0.1 ± 0.4) and dual (0.4 ± 1.1) task conditions for young adults ($p < 0.33$), (9% versus 29% took a step in the two conditions). Figure 3.4 A presents data contrasting the average number of steps taken during single and dual task conditions across the two age groups; an age effect, $F(2, 37) = 7.40$, $p < 0.01$ was seen (effect size = 0.71). The average number of steps taken by older adults between single (3.2 ± 5.2) and dual (10.4 ± 23.4) task conditions was significant at a p-value of 0.05. Figure 3.4 B reflects the behavioral performance of five older individuals at the low end of the postural performance spectrum, as measured by the Fullerton Advanced Balance scale. The number of steps taken during single and dual task conditions for 5 frail elderly (with Fullerton Advanced Balance scale scores of ≤ 25) and 5 healthy older adults (with near perfect scores) were compared. Due to the small group sizes, no statistical analysis was performed. Visually, however, it is evident that the range in the average number of steps taken by the 5 healthy elderly in Figure 3.4 B was similar to that of the overall young adult population. This is a reminder of the wide range of function among the older adult population. Figure 3.4 B also suggests that the increased level of stepping seen in Figure 3.4 A was greatly influenced by the increased frequency of steps taken by the frail older adults within the subject population. To evaluate this possibility, the 5 frail older adults were removed from the older adult study population and the data analysis was repeated; no significant difference was seen between single (2.2 ± 3.9) and dual (5.7 ± 15.6) task conditions ($p < 0.11$). Thus the significant increase in the number of steps between single

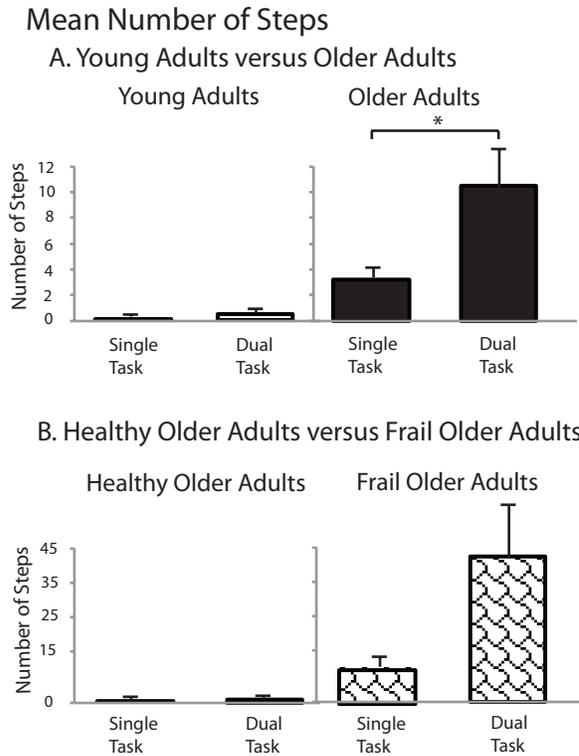


Figure 3.4: A. No significant difference was seen between single and dual task conditions for young adults ($p < 0.33$), however the number of steps taken between the two conditions was significant for older adults ($p < 0.05$). B. The mean number of steps taken during single and dual task conditions; 5 older adults were compared to 5 young adults. Error bars represent standard error of the mean (SE). (Note: * = $p < 0.05$)

and dual task conditions in Figure 3.4 A was influenced by the frail older adults within the older adult population.

Regression analysis was used to determine whether a correlation existed between the increase in average number of steps taken in the dual task compared to single task postural condition (perturbation) and the drop in K-scores between single task cognitive (control, sit) and dual task cognitive (cognitive plus perturbation). No correlation was seen for the young adults ($r = 0.10$; $p < 0.57$) or for the older adults ($r = 0.14$; $p < 0.45$).

Postural Measures

The stepping trials were not included in the overall analysis of postural variables as distinctly different force and neuromuscular response strategies are used for taking steps versus using an in place strategy to recover balance after a perturbation.

Kinematic data were evaluated to determine whether older adults used an alternative strategy, other than or in addition to an ankle or stepping strategy, during the recovery response. As seen in Figure 3.5, older adults showed a 50% increase ($p < 0.05$) in the mean number of trials in which they went up on toes as part of their postural recovery pattern when single task conditions (10 single task trials) were compared to dual task conditions (15 dual task trials); the young adults showed no significant difference ($p < 0.20$). Postural measures discussed below are limited to the trials in which subjects used an in-place (ankle or up on toes) strategy to recover balance; kinetic and kinematic variables and electromyographic measures are included.

Kinetic and Kinematic Variables

Figure 3.6 presents typical postural response patterns from the mean of 5 single and 5 dual task trials among young and older adults; it includes one young and one older adult who used an ankle strategy of postural recovery and one older adult who used an up on toes strategy.

Up On Toes: Mean Number of Trials Across Five Trial Sets

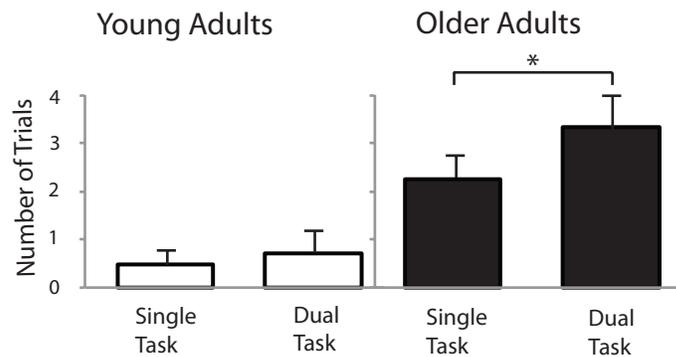


Figure 3.5: Older adults showed a significant increase in the mean number of trials in which they went up on toes as part of their postural recovery pattern when single task conditions (trials were combined from the single before and single after conditions) were compared to dual task conditions (trials were combined from the dual early, dual middle and dual late conditions). Young adults however, showed no significant difference between single and dual conditions ($p < 0.20$). Error bars represent standard error of the mean (SE). (Note: * = $p < 0.05$).

Visually, Figure 3.6 A shows a slight increase in COPx in bin1 and bin2 for this subject, as well as an increase in Fap in bin1 and a decrease in bin2. An increase in dorsal muscle activation was seen only in bin1 for ES. Rectus femoris was the single ventral postural muscle to show an increase (only in bin1).

Figure 3.6 B demonstrates the example of an older adult who used an ankle strategy for postural recovery; an increase can be seen in COPx (bin1 and bin2) and Fap (bin1

Representative Mean Postural Responses from Young and Older Adults

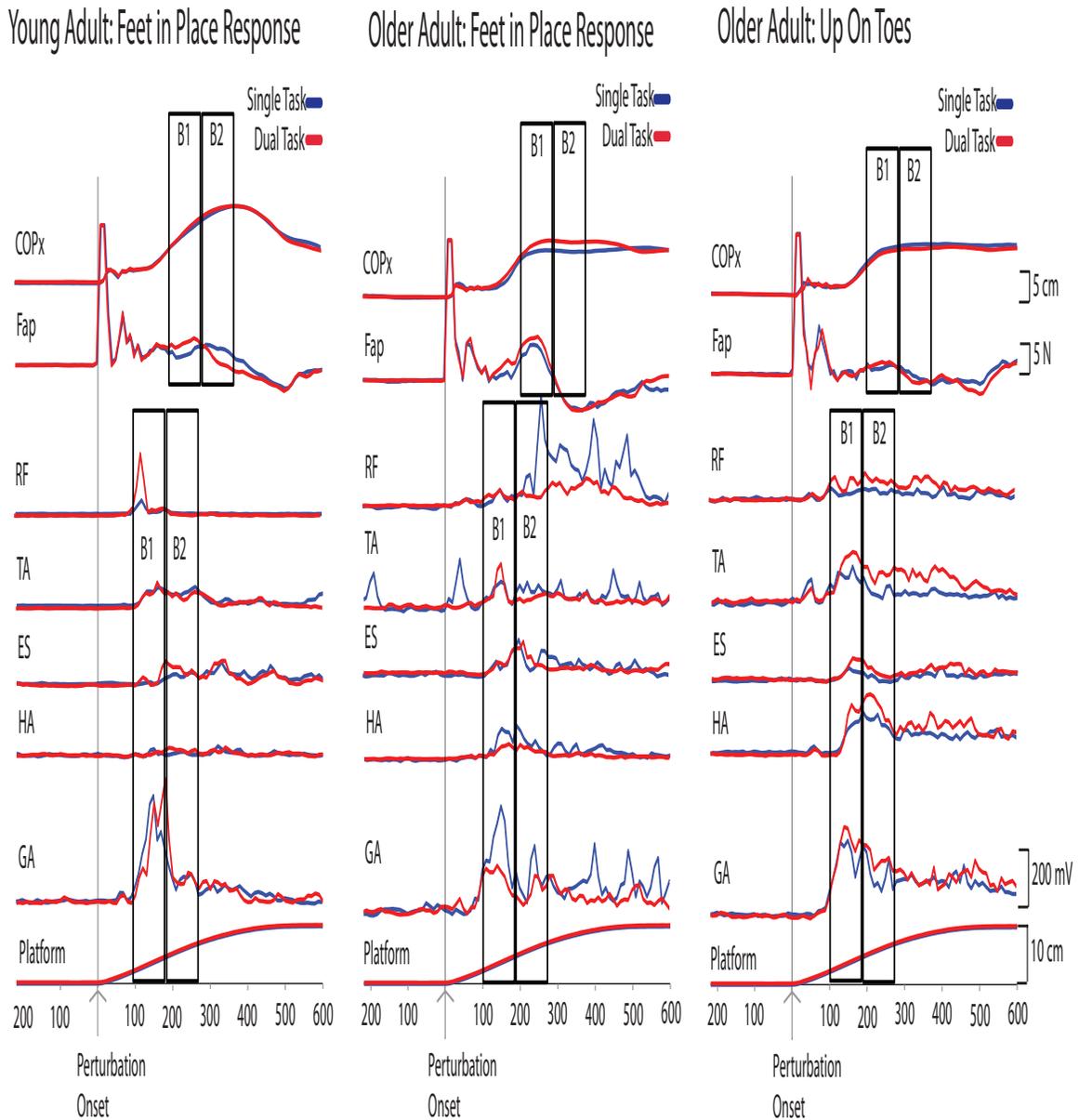


Figure 3.6: Typical postural response: A. young adult - feet in place response, B. older adult - feet in place response, and C. older adult - up on toes response. EMG bin1 and bin2 began at 90ms for young adults and 100ms for older adults whereas COPx and Fap bin1 and bin2 began at 190ms for young adults and 200ms for older adults.

but not bin2). A reduction in dorsal muscle activation amplitudes was seen in GA and HA (bin1 but not bin2), with no change in ES. Ventral muscles showed an increase in TA (bin1 but not bin2) and RF showed no change in bin1 and a decrease in bin2.

Figure 3.6 C reflects the response associated with an up on toes pattern of recovery for one older adult. No change was seen in COPx or Fap in either bin1 or bin2; however in this individual there are varying amounts of increases in EMG amplitudes in both bin1 and bin2 for all muscle groups.

When postural measures were compared across young adults a condition effect was present, ($F(20, 131) = 21.00$ (effect size = 0.76) $p < 0.001$). A condition effect was also seen across older adults, ($F(20, 117) = 10.86$ (effect size = 0.65)). Figure 3.7A shows a significant increase in nCOPx ($p < 0.01$) by 12% for bin1 but not for bin2 ($p < 1.000$) for young adults, with no difference between single and dual task conditions among older adults in bin1 ($p < 0.334$) or bin2 ($p < 0.669$). When regression analysis was used to determine whether there was a correlation between the time to recover for the COPx trajectory during the dual task and the drop in K-score between the control (sit) and perturbation conditions, no correlation was found for the young adults ($r = 0.08$; $p < 0.67$) and the older adults ($r = 0.13$; $p < 0.50$).

When pkCOPx% was evaluated, young adults showed no significant change between single and dual task conditions ($p < 1.000$) (Note: The pkCOPx was the peak displacement of the COPx during a perturbation of the force platform and pkCOPx% was calculated using the kinematic data from the foot in relation to the force platform expressed in terms of foot length. The 0 position was at the heel marker and the 100% position was the marker at the base of the 1st metatarsal joint. This measure provides an estimate of

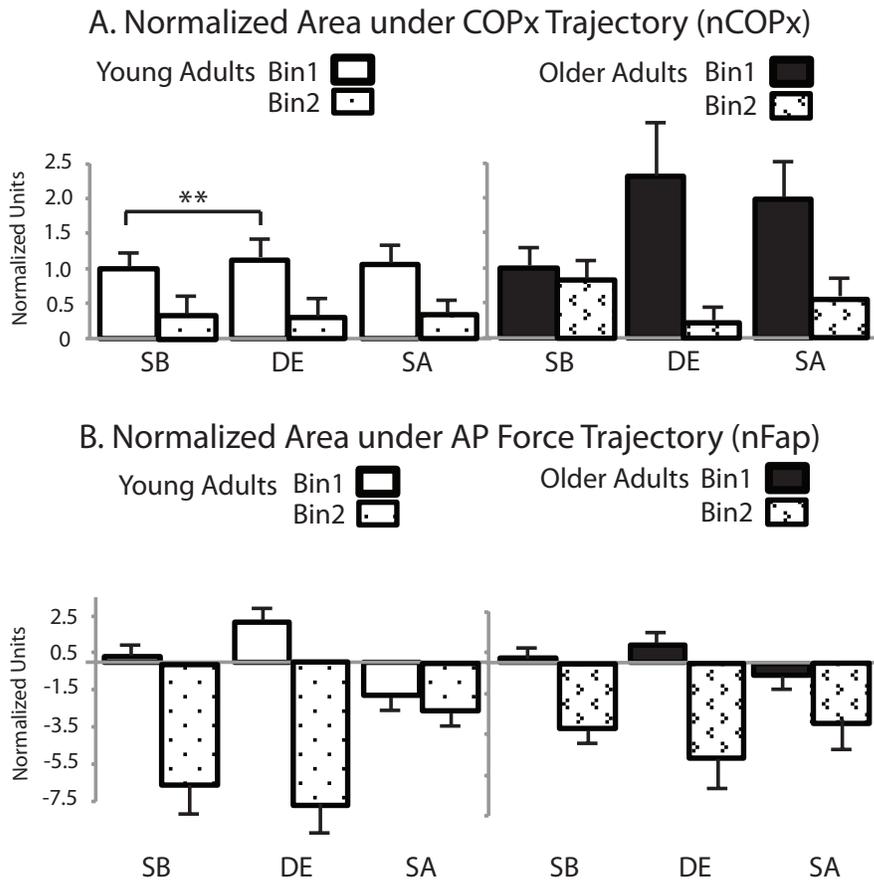


Figure 3.7: A. No significant increase in nCOPx was seen between single and dual task conditions among young adults in bin1, however not in bin2. No differences were seen in either bin1 or bin2 for the older adults. B. No difference in nFap was seen among young adults or older adults. Error bars represent standard error of the mean (SE).). (Note: ** = $p < 0.01$)

stability limit.) In both the single task and dual task conditions pkCOPx% was 103% (± 5) of this distance, as it moved slightly beyond the first metatarsal joint, but of course, stayed within the base of support, as subjects did not take a step. Likewise, older adults showed no significant change in pkCOPx% ($p < 1.000$) between the two conditions,

(single: $103 \pm 5\%$); dual: $102 \pm 4\%$). In addition, Figure 3.6 B shows no difference in nFap among young adults (bin1 = $p < 0.13$ and bin2 = $p < 0.1.000$) or older adults (bin1 = $p < 1.000$) and bin2 = $p < 0.297$).

Electromyographic Variables

In the following section we will discuss muscle response changes between single and dual task conditions in young versus older adults. Figure 3.8 and 3.9 show normalized muscle response amplitudes for both young and older adults across conditions. Young adults showed a significant increase in amplitude in only one of the dorsal muscles, nES (Figure 3.8 C). The change occurred in bin1 (increase of 330% ($p < 0.01$)) but not bin2 ($p < 0.149$).

Older adults showed an increase in both the nHA and the nTA muscles across conditions. Figure 3.8 B shows a 19% increase between single and dual task conditions among older adults in nHA in bin1 that approached significance ($p < 0.074$) as well as a significant (14%) increase in bin2 ($p < 0.05$). No other dorsal muscles showed a significant change in activation level between conditions. Ventral surface postural muscles are presented in Figure 3.9. A significant (54%) increase in TA amplitude was seen in bin1 ($p < 0.01$) but not bin2 ($p < 0.262$) for older adults (see Figure 3.9 A); this was the only muscle to show significant changes on the ventral surface.

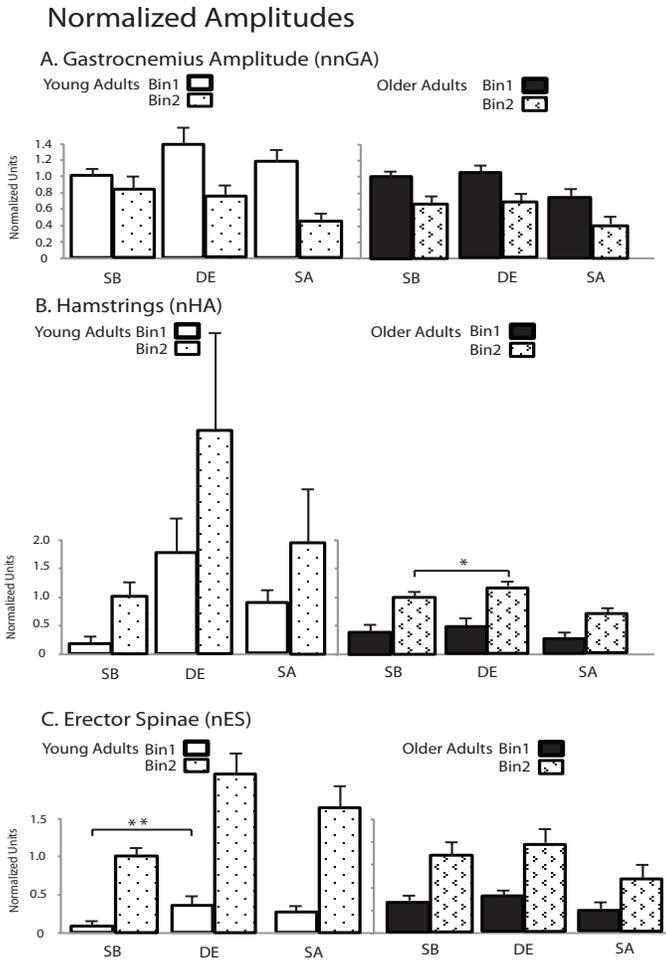


Figure 3.8: Dorsal surface postural muscle responses: A. nGA: no significant change in amplitude between single and dual task conditions for young or older adults. B. nHA: increased significantly in amplitude for bin2 for older adults but none for young adults in bin1 or bin2. C. nES: increased significantly among young adults in bin1 but not in bin2, but no change in older adults. Error bars represent standard error of the mean (SE). (Note: * = $p < 0.05$, ** = $p < 0.01$).

Normalized Amplitudes

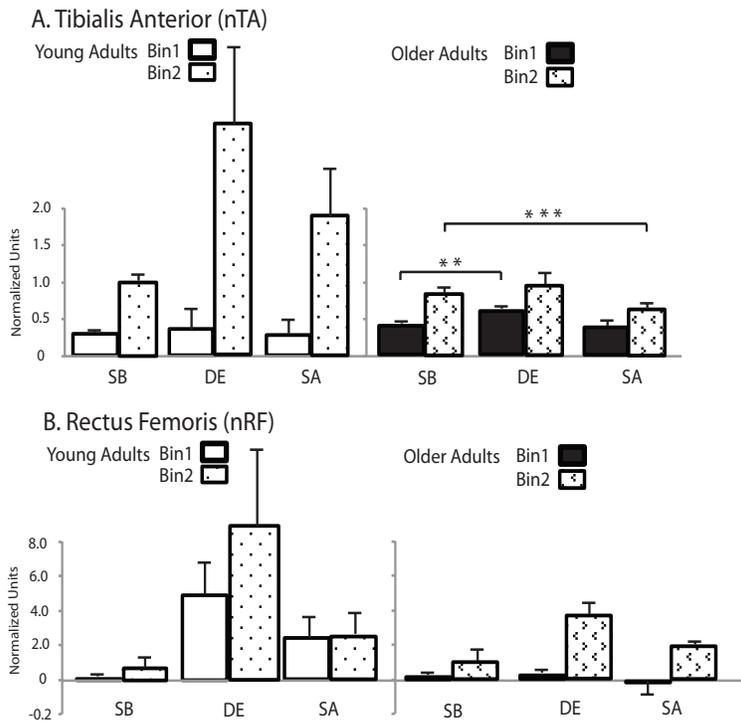


Figure 3.9: Ventral surface postural muscles responses: A. nTA: no significant increase in amplitudes between single and dual task conditions among young adults, however, older adults showed a significant increase in activation in bin1 but not bin2. Of note is the fact that there was a significant decrease in nTA amplitude between early and late single task trials for bin2. B. nRF: no significant increase in amplitude between single and dual task conditions for either young or older adults. Error bars represent standard error of the mean (SE). (Note: ** = $p < 0.01$, *** = $p < 0.001$).

Discussion

In summary, in the dual task condition young adults showed a decline in memory capacity compared to the control but no significant change in postural capacity, even in the most difficult task of the response to rapid perturbation of the support surface. Older

adults showed an even greater decline in memory capacity in the dual task condition, along with some difficulty regaining balance following perturbation as evidenced by the increased use of an up on toes pattern and stepping. These results suggest that the visual memory task and postural control share a common attentional resource that is limited, and that postural control is favored over the cognitive task in young adults. The lack of a correlation between the increase in number of steps taken between single and dual task conditions and the drop in K-scores between single and dual task conditions suggests that there was no consistent strategy among all subjects in the task they chose for their primary focus in the dual task condition.

In older adults, both postural control and the cognitive task were impaired in the dual task condition, suggesting that this attentional resource is significantly reduced with aging and competition for an isolated set of attentional resources can negatively affect balance under challenging postural conditions.

The advantage of the visual working memory task used in this study is its simplicity in that it targets an isolated attentional resource and does not require further processing beyond recognition and storage of color and position of simple squares. The measure of memory capacity, K, allowed us to quantify the upper limit of performance for this cognitive task. Any reduction in K is, therefore, interpreted as an indication of competition related to the change in conditions. In addition we presented evidence that the identification of no change in colored squares (correct rejection) demands more attentional resources than the identification of a change of one of the colored squares (hit rate) during the change detection task. Thus it appears that identification of no change in squares had the greatest influence on the interaction between visual working memory capacity and the

automatic postural response. Figures 3.3 A and 3.3 C show decreases in hit rate ratios across postural conditions to some degree with higher levels of set sizes.

The variety of postural conditions allowed us to sample a wide range of balance challenges from independent stance to the response to a sudden, very challenging perturbation. The latter task was designed to push subjects near to their limits of their stability, as evidenced by the fact that the COPx was displaced as far as the toes in both young and older subjects in the single task condition. Thus, we expected that any decrement in the ability to perform the postural task would be evident in our postural measures.

Young adults responded to the perturbation in the single task condition primarily with a feet-in-place response that restored upright stance although in some trials, a stepping response was used, indicating that the perturbation was relatively challenging as a balance task. However, young adults showed no remarkable change in postural response following the shift from the single to the dual task condition, and no significant increase in stepping responses. Although nCOPx showed a small increase in bin1 and none in bin2, the peak COPx did not increase. This could be due to an increase in the rate of rise of the COPx trace, however this was not directly measured. If so, one would expect an increase in the rate of rise of the initial GA burst (not measured) but not necessarily an increase in EMG area. Increased rate of rise of GA and COPx implies faster development of ankle torque and, therefore, the reactive torques at other joints. The observed increase in nES in bin1 would counteract the reactive hip flexor torque as the body is returned to the upright position. The lack of significant change in postural response to perturbation along with the decline in visual memory capacity during the dual task condition suggests

that attentional resources are operating near their limits and that body stability is favored over execution of the cognitive task among young adults.

Older subjects appeared more challenged by the postural perturbation than did the young subjects and responded with a greater incidence of stepping and rising to toes. The frail elderly had even more difficulty than healthy elderly according to these same measures. This correlated with the Fullerton Advanced Balance scale in which the older adults scored significantly lower than the young adults, suggesting degradation in functional balance performance. Older adults generally have reduced ability to generate ankle torque and increased sensory and motor conduction times, resulting in delays in initiation of the automatic postural response (Horak et al. 1988; Horak and Nashner 1986; Woollacott et al. 1986).

Unlike the young adults, older adults had greater difficulty with the postural perturbation in the dual task condition as shown by the increase in stepping and up on toes compared to the single task condition. EMG changes in the dual compared to single task condition included increased TA and HA activation. This TA response has been shown to be characteristic of the rise from a flat-footed stance position to a stable posture standing on toes (Nardone and Scheipati 1988). Of note is the fact that the older adults in our study recruited HA in the late phase of the automatic postural response in addition to TA. Nardone and Scheipati (1988) included hamstrings in their data collection but no increase in amplitude was seen during the up on toes position. It may be that the older adults recruited the HA to maintain knee and hip extension during recovery as part of their strategy.

Stepping responses were excluded from analysis due to the inability to compare force data from in-place and stepping strategy trials; therefore we have eliminated those trials in which the older adults had the most difficulty in maintaining stability in the dual task situation. Thus any changes we have seen in force and EMG response characteristics between older and younger adults are a conservative estimate.

The combination of reduced memory capacity and reduced postural performance in older subjects performing the dual tasks suggests that their attentional resource capacity is severely strained by the requirements of the dual task and that subjects may choose to use more secure strategies rather than rely on the feet-in-place response. The greater decline in visual working memory capacity in older adults compared to the young, along with the greater difficulty in the postural task suggests that older adults have a reduced level of attentional capacity which puts this group at a greater disadvantage when trying to perform cognitive and balance task simultaneously.

Our results differ from the Rankin et al. (2000) study that paired backward perturbations of the support surface with a cognitive task. They reported a reduction in GA and TA amplitudes when comparing dual and single task conditions, late in the recovery phase following the perturbation, 350-500ms. Two reasons could account for the difference in their results from those reported here. First, they reported only data from older adults who used an ankle strategy during recovery. As the increased TA amplitudes in our study were associated with subjects coming up on toes during recovery, it is clear that many of our older adults were using an alternative recovery strategy to the more common ankle strategy. In addition, the 350-500ms time period is sufficiently long to include cortically influenced voluntary response activation (>200ms). In the current study

the increases in TA and HA amplitudes were seen during the early, automatic phase of the postural response.

In summary, both young and older adults exhibited a decrease in capacity when performing a visual working memory and a postural task concurrently, with the memory task affected in the young and both tasks affected in the older subjects. The general capacity theory for attention suggests there is a finite amount of processing space available in the central nervous system to perform tasks and this study provides further evidence to the theory that attentional resources decline with aging. With reduced attentional processing capacity and limited postural control abilities, older adults are less able to recover and are forced to shift the postural strategy used for balance recovery in dual task conditions from higher frequencies of an ankle strategy to either up on toes or stepping strategies. However, it is possible that this shift in strategy may actually increase the risk of falls for older adults in dual task situations, as previous research has shown that using a step in balance recovery requires more attentional resources than remaining in place (Brown et al. 1999). We recommend that rehabilitation strategies to reduce falls in older adults should not be limited to physical therapy for balance control in isolation, but be practiced in dual task conditions, in order to improve the ability to appropriately allocate attentional resources to balance in these complex task conditions (Silsupadol et al. 2006). Specifically, our results indicate the importance of developing dual task training activities that include up on toes and stepping strategies to help broaden the elective choices available to older adults such that they improve their ability to navigate complex postural situations within their environment to prevent a fall and avoid hospitalization or death.

CHAPTER IV

GENERAL DISCUSSION

The broad goal of this research was to prevent falls among older adults. A key issue of clinical practice relates to working with patients across a variety of age groups, whose skills include a continuum of functional levels, from very poor balance and gait skills to those with nearly optimal function. The current work attempts to evaluate neural mechanisms underlying balance control in complex task conditions and to identify associated mechanism changes underlying balance control across the continuum from healthy young to older adults. The experimental protocol used in this research was that of a dual task paradigm (performance of two tasks at once). As stated earlier, young adults readily perform motor and cognitive tasks simultaneously (e.g. reading e-mail on a hand held device while walking) with little impact on performance of either task; however similar activities among older adults more commonly result in a fall (Beauchet et al., 2008; Faulkner et al., 2007).

The dual task experimental paradigm was originally developed in the area of cognitive psychology research (pairing two cognitive tasks) to study neural processing associated with attention and memory; it was used specifically to investigate the nature of the attentional resource store, and to determine whether two modalities shared a common central resource or accessed separate resource stores concurrently (Baddeley & Hitch, 1974; Baddeley, 1986; Logie, Zucco, & Baddeley, 1990; Della Salla et al., 2010; Borst, Niven, & Logie, 2012). When the dual task paradigm was adopted in the area of postural control research (postural task paired with a cognitive task), interference patterns were

seen when both tasks were performed simultaneously, demonstrating a reduction in performance of the cognitive task, the postural task or both tasks (Kerr, Condon, & McDonald, 1985; Lajoie et al., 1993; Teasdale et al., 1993; VanderVelde, Woollacott, & Shumway-Cook, 2005). These results suggested an association between high-level cognitive processing and the control of posture and gait (Kerr, Condon, & McDonald, 1985; Lajoie et al., 1993; Teasdale et al., 1993; Maylor, Allison, & Wing, 2001; Siu et al., 2008; Woollacott & VanderVelde, 2008). Not all of the dual task research, in the area of psychology or the control of posture, however, showed interference in the performance of postural and/or cognitive tasks (Dault, Frank, & Allard, 2001; Woollacott & VanderVelde, 2008; Shumway-Cook et al. 1997; Cocchini et al., 2002; Darling, Sala, & Logie, 2007). Researchers reasoned that ambiguities of the reported results were influenced by 1) the degree of difficulty of the two tasks and/or 2) the type of cognitive task, which related to the type and amount of attentional resources utilized or targeted by the task and whether these resources overlapped with those required for the postural task. As such both of these issues were addressed in the design of the current study.

Establishing the Relationship Between Visual Working Memory and the Control of Posture

As seen in Chapter II a visual working memory task (change detection for simple features – colored squares) was used in the dual task postural paradigm in this research. The advantage of the visual working memory task is its simplicity in that it targets an isolated attentional resource and does not require further processing beyond recognition and storage of color and position of simple squares (Luck & Vogel, 1997; Pashler 1988). In addition, it is a robust measure that provides an estimate of visual working memory

capacity and its performance does not appear to be influenced by perceptual processes (Luck and Vogel 1997; Sperling, 1960; Vogel & Machizaea, 2004). Since no previous research had shown an interaction between attentional resources associated with visual working memory capacity and postural tasks, the first experiment sought to not only demonstrate that the use of a change detection task for simple features could be replicated within a postural paradigm but also establish the presence of an interference pattern between visual working memory capacity and the control of posture.

Experiment 1, outlined in Chapter II identified an inverse relationship between visual working memory capacity and postural challenge in young adults; specifically, a significant reduction in working memory capacity was observed, only after a threshold point of increased postural demand in these subjects. The greatest decline in visual working memory capacity was seen in the perturbation condition, which required the use of an automatic postural recovery pattern to maintain upright stance. This initial result, although promising, needed further investigation to determine if the decline in visual working memory capacity had indeed resulted from the competition for a common set of attentional resources or from an interruption in encoding the information into working memory (encoding phase).

The second experiment presented in Chapter II was designed to address the nature of the interference seen in Experiment 1. Since the time for completion of the encoding phase has been shown to take approximately 250-300ms, the initial presentation of the squares in the memory array was increased in Experiment 2 from 100ms to 500ms in order to allow sufficient time for all information to be encoded (Vogel, Woodman, & Luck, 2006). In addition, the number of squares in each set size was changed from 4, 6,

and 8 to 2, 4, and 6 to determine whether the level of difficulty of the visual working memory task also played a role in the interference that resulted in Experiment 1. The results from Experiment 1 were replicated in Experiment 2; reductions in working memory capacity were observed between sitting (the control or baseline condition) and the threshold point of increasing postural challenge, which was backward perturbation of the support surface (activating the automatic postural response for balance recovery). These results provide robust evidence supporting the interference pattern between visual working memory and postural recovery from an unexpected perturbation of the support surface in young adults; there is strong evidence of sharing of a common set of attentional resources between the two modalities (Kahneman, 1973; Norman & Bobrow, 1975; Wickens, 1983). This also shows that postural recovery in young adults requires attentional resources, as the performance on the cognitive task was significantly reduced during postural recovery. After establishing the fact that there is processing interference between a visual working memory task and the control of balance recovery in young adults, experiments in Chapter III used the visual working memory task and postural tasks of different levels of difficulty to examine the effect of aging on the performance of concurrent cognitive and postural tasks by comparing postural and cognitive task performance in single and dual task contexts in young and older adults.

Dual Task Effects: Young Adults versus Older Adults

The research presented in Chapter III compared and contrasted cognitive and postural performance of young and older adults using the above research paradigm. In general, young adults showed a decline in memory capacity in the dual task condition compared to the control but no significant change in postural performance in any of the postural

conditions, including the most difficult task requiring a response to rapid backward perturbation of the support surface. Older adults showed an even greater decline in memory capacity in the dual task condition than the young adults, along with increased difficulty regaining balance following perturbation as evidenced by a significantly increased use of up on toes and stepping strategies.

These results give additional support for the hypothesis that the visual memory task and postural control share a common attentional resource that is limited. It also demonstrates that attention to postural control is favored over the cognitive task in young adults, in that the young adult group showed a decline in the cognitive but not the postural task performance in the dual task context.

In older adults both postural task and cognitive task performance were impaired in the dual task condition, suggesting that attentional resources are significantly reduced with aging. It also shows that older adults were not able to give attentional resources preferentially to the postural task, as competition for this isolated set of attentional resources negatively affected both cognitive and balance performance under the challenging postural conditions. The fact that the visual working memory task targeted an isolated set of attentional resources involved in working memory improved the technical aspect of the current dual task postural paradigm over many previous studies, as it showed that isolation of the specific attentional processing requirement underlying this simple visual working memory task caused interference with simultaneous performance of postural and cognitive tasks. In addition the experimental paradigm pushed participants near to their limits of stability, even in the single task condition, with the rapid backward perturbation of the support surface. This necessitated the use of an

alternative postural recovery pattern (up on toes or stepping), if they could not recover postural control in the dual task context as efficiently as in the single task context.

Due to reduced attentional processing capacity and limited postural control abilities, older adults were less able to recover from perturbation of the support surface in the dual task context and were forced to shift the postural strategy used for balance recovery from an ankle strategy to either up on toes or stepping strategies. It is possible that this shift in strategy may actually increase the risk of falls for older adults in dual task situations, as previous research has shown that using a step in balance recovery requires more attentional resources than remaining in place (Brown et al, 1999).

Within the group of 30 healthy older adults in the study were 5 participants who had the lowest scores on the Fullerton Advanced Balance test, and thus had poorer balance than the other subjects (Hernandez and Rose 2008; Shumway-Cook et al. 1997). We compared their abilities to those of the 5 older adults with the highest balance scores on the same test. Due to the fact that we had only 5 subjects in this functionally lower balance performance category we could not compare their performance to those of the higher functioning older adults statistically, due to lack of statistical power. Thus it could be considered that the reduced number of frail elderly adults who participated in the experiment was a limitation of the study. One difficulty that is found in recruiting older adults with lower balance performance abilities is that they do not like their balance challenged in the laboratory situation, out of fear. For example, in this study, three elderly adults with lower balance abilities declined to participate in the study once they completed the screening process (clinical test) and two individuals asked to stop their participation in the experiment mid-way through citing fear of falling as the reason for

stopping. When mean stepping data from the 5 frail elderly adults who did complete the data collection session were compared with 5 older adults whose level of balance function was similar to young adults, it appeared that the frail elderly primarily used a stepping strategy to recover balance in the dual task condition; the use of an up on toes strategy did not appear to be an elective choice.

In terms of future research, the use of electroencephalography (EEG) to evaluate differences in event related potential (ERP) magnitudes in the sensori-motor cortex during perturbations of the support surface alone, versus perturbations in the dual task has the potential to provide further insight into the site of attentional interference between postural and secondary cognitive tasks in young versus older adults (Quant et al., 2004, 2005). Since older adults showed reduced attentional processing capacity and limited postural control abilities in the dual task context we would expect to see attenuation of ERP signals in electrodes over the sensori-motor cortex elicited during disturbance of balance in the dual task context. The neural correlate of attentional processing associated with visual working memory has already been identified under single task conditions by ERPs in normal young adults (Vogel & Machizawa, 2004). Modification of the current experimental paradigm to isolate the ERP associated with the onset of the initial memory array between single and dual task conditions may shed light on where the interference is actually occurring within the cortex.

Ultimately, results from this research will be incorporated into fall prevention programs for older adults within both clinical and community settings; to educate the general population as to the role attention (high-level cognitive processing) plays in fall avoidance in complex settings. Traditionally, rehabilitation programs emphasize training

balance under single-task conditions to improve balance and reduce risk for falls. We recommend that rehabilitation strategies to reduce falls in older adults should not be limited to physical therapy for balance control in isolation, but be practiced in dual task conditions, in order to improve the ability to appropriately allocate attentional resources to maintain balance in these complex task conditions (Silsupadol et al., 2006).

Specifically, our results indicate the importance of developing dual task training activities that include a variety of postural recovery strategies in response to slips and trips. For example, older adults could be trained to respond to a variety of magnitudes of balance threat, from small low velocity to large higher velocity support surface movements, and encourage to shift efficiently from ankle, to up on toes, to stepping or reaching strategies. Extensive practice in these contexts would help reduce the attentional requirements of postural recovery and broaden the elective choices available to older adults; this would allow them to improve their ability to navigate complex postural situations within their environment to prevent a fall and thus avoid the possible consequences of falls, including hospitalization or death.

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