The effect of perturbation warning on attention switching abilities during dual-task performance in young and older adults

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Abstract

This study examined whether providing an auditory warning would facilitate attention switching abilities in older adults during dual-tasking. Fifteen young and 16 older adults performed a tracking task while recovering their balance from a support surface translation. For half of the trials, an auditory warning was presented to inform participants of the upcoming translation. Performance was quantified through electromyographic (EMG) recordings of the lower limb muscles, while the ability to switch attention between tasks was determined by tracking task error. Providing warning of an upcoming loss of balance resulted in both young and older adults increasing their leg EMG activity by 10-165% ($p<0.05$) in preparation for the upcoming translation. However, no differences in the timing of attention switching were observed with or without the warning ($p=0.424$). Together, these findings suggest that providing a perturbation warning has minimal benefits in improving attention switching abilities for balance recovery in healthy older adults.

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1.0 Review of Literature

1.1 Balance Control

1.1.1 Overview

Balance or postural equilibrium can be defined as the process by which the body's center of mass (COM) is controlled with respect to its base of support (BOS). The COM is defined as the point where an individual's mass is equally distributed, while the BOS is the area of the body and any objects held by the body (i.e., cane or walker) that are in contact with the environment (Maki & McIlroy, 2005). Successful balance control requires both anticipatory and reactive mechanisms in order to maintain dynamic stability while counteracting different expected or unexpected forces to the body (Balasubramaniam & Wing, 2002). Anticipatory control occurs prior to a loss of balance, where a stabilizing response is initiated prior to an expected perturbation to the body. In contrast, reactive balance control involves sensory detection and a subsequent stabilizing response that occurs once a loss of balance is experienced (Balasubramaniam & Wing, 2002).

Anticipatory and reactive balance control is achieved through the continuous integration of sensory inputs and motor output (Lajoie, Teasdale, Bard, & Fleury, 1993). Sensory information regarding body position may come from the vestibular, visual, and somatosensory systems and is used to inform the body that balance reactions will be needed to prevent or restore a loss of balance (Howe & Oldham, 2001). Much of the somatosensory information is processed within the spinal cord, which is responsible for directly producing a reflex muscle response or sending signals to other segments within the spinal cord or to higher regions of the central nervous system (CNS) (Crow & Haas, 2001).

When more complex responses are required for balance control, higher centers within the CNS become involved. For example, the brainstem primarily functions as a relay station, processing sensory information and organizing motor output (Crow & Haas, 2001). It is also responsible for contracting musculature in the neck, proximal parts of the limbs and the trunk in order to keep the body in an upright position against gravity (Crow & Haas, 2001). The basal ganglia aids in the selective initiation or suppression of neural activities. Both the brainstem and basal ganglia are needed for complex balance reactions and the brainstem can directly influence the spinal cord through the descending pathways and indirectly through ascending pathways to higher centres of the CNS to produce or alter automatic movement (Crow & Haas, 2001). The cerebellum aids in balance control by monitoring and making corrective adjustments in motor activities to make for smooth, coordinated muscle movements through the comparison of the performance of the body with higher centres of the motor cortex (Crow & Haas, 2001). Lastly, the cerebral cortex integrates various sensations in order to successfully plan and execute many complex movements (Crow & Haas, 2001), including the sensory integration phase of balance control (Adkin, Quant, Maki & McIlroy, 2006; Redfern et al., 2001). The contribution of the cerebral cortex in balance control can vary. For example an increased contribution is observed when more demanding balance tasks are performed (Jacobs et al. 2008), and a decrease in activity has been observed when perturbations to the body are made predictable (Adkin et al., 2006) and when a secondary task is added to divert attentional resources away from the balance task (Quant et al., 2004).

1.1.2 Changes in Balance Control with Age

A decreased ability to maintain balance in older adults may be linked to the neuromuscular changes that occur with age. Age-related deteriorations have been found in central processing, as noted by reductions in reaction time (RT) and deteriorations within the three sensory systems (vestibular, somatosensory and visual) responsible for balance control (Rankin, Woollacott, Shumway-Cook & Brown, 2000; Leonard, Matsumoto, Diedrich, & McMillan, 1997; Maki & McIlroy, 2005). A decrease in the control and quality of movement with age may also be linked to a decline in the number of motor units, a decrease in the number of nerve cells, a slowing of peripheral nerve conduction velocity, a decrease in the synaptic connection effectiveness and an overall decrease in muscle mass making it more difficult to generate a forceful muscle contraction (Trew, 2001; Rankin et al., 2000).

These neuromuscular changes often require older adults to adopt alternate or compensatory strategies to maintain or recover balance (Rankin et al., 2000). Some of these compensatory strategies include the use of external cues, a wider base of support and an increased reliance towards the use of a stepping strategy to recover balance (Rankin et al., 2000). Impairments in balance control may also be related to older adults requiring greater attentional resources to maintain balance (Rankin et al., 2000). For example, on any given task older adults experience greater difficulty or require greater attentional resources than younger adults, which can be demonstrated through a slowing of a task response (Kramer, Larish & Strayer, 1995). Furthermore, as the complexity of the balance task increases, older adults require more attentional resources to maintain balance (Lajoie et al., 1993; Lajoie, Teasdale, Bard & Fleury 1996; Lajoie & Gallagher, 2004). Since the availability and reliance of attentional resources are altered with advanced age, it is important to consider the formulation of attentional resources and how these resources contribute to balance control in young and older adults.

1.2 Contribution of Attention on Balance

1.2.1 Attentional Resource Models

Attention is the mechanism by which information may or may not be chosen for further perceptual processing in the brain. Some of the neural structures involved in attention and related to movement preparation are the sensorimotor cortex, cerebellum, posterior parietal cortex, supplementary motor area, premotor cortex, thalamus and basal ganglia (Prochazka, 1989). Two models have been developed to help explain the formulation of attentional resources and the capacity to perform one or more tasks. The first is known as the “capacity model”, where attention is viewed as one limited pool of resources (Figure 1). This model suggests that when two or more tasks are simultaneously performed, the attentional demands of each task determine the amount of interference between tasks. When attentional demands exceed the total attentional capacity, performance of the second task deteriorates. This model also suggests that with age, there is a decrease in capacity limit (Young & Stanton, 2010). As a result, less attentional resources are available when trying to complete two or more tasks and consequently, this may lead to reductions in one or both of the tasks being performed.

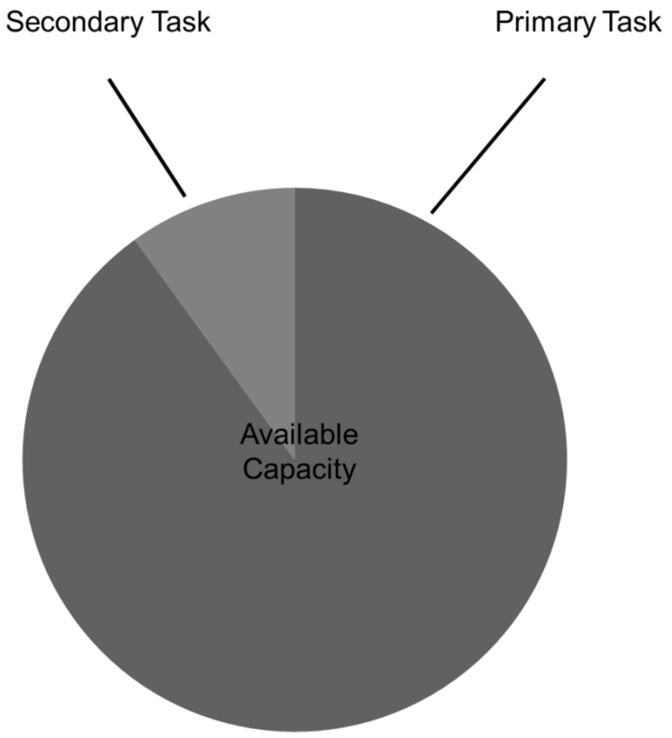


Figure 1: A diagram representing the "capacity model" of attentional resources. The outer limits of the circle represent the capacity limit or the amount of attentional resources available to complete one or more tasks. The area shaded dark grey represents an example of the amount of resources required to complete the primary task. The light grey represents an example of the amount of resources remaining that can be contributed to the completion of the secondary task.

The second model is the "multiple resource model", which proposes that there are separate pools of resources along with three divided dimensions (i.e., processing stages, input modalities and task response processing) (Figure 2).

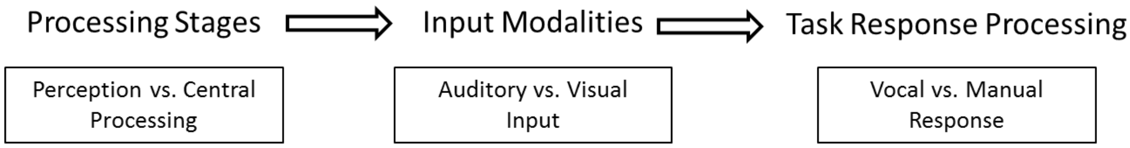


Figure 2: The multiple resource model dimensions. Each dimension refers to the different stage where interference can occur when initially processing the tasks to planning out an appropriate response.

The multiple resource model argues that interference is dependent on both resource demand (i.e., task difficulty) and resource competition (i.e., shared processing mechanisms) (Young & Stanton, 2010; Blom, Daams, & Nijhuis, 2001). In other words, if resources are shared during any of these three dimensions then the level of task difficulty will affect performance (Young & Stanton, 2010). This differs from the capacity model because the capacity model considers interference to be influenced by only task difficulty. Nevertheless, the two models both aid in explaining that when the attentional demands of two tasks becomes too difficult or overlap with one another, performance of one or both of the tasks will deteriorate unless attentional resources are shifted toward the most prominent task (Anderson, 2005).

The difficulty or interference observed when humans simultaneously perform two tasks has been studied using dual-task paradigms, where two stimuli, each requiring separate responses, are presented in succession to one another (Ruthruff & Johnston, 2001). These studies have shown that performance during dual-tasking is dependent on the temporal separation between two stimuli, or the stimulus onset asynchrony (SOA) (Ruthruff & Johnston, 2001). In most dual-task situations, the first task response is not affected by the SOA (Ruthruff & Johnston, 2001). However, when two tasks are performed at the same time (i.e., SOA of 0 ms), the greatest dual-task interference effect is observed (Müller, Jennings, Redfern & Furman, 2004). The reason for an association between SOA and the resulting dual-task interference effect can be explained by the central bottleneck model (Figure 3). This model states that the slowing of responses when two tasks are presented with a small SOA is caused by the inability to perform central operations on more than one task at a time. More specifically, the bottleneck or slowing of the second task response is created when two processes or response selections require the same neural pathways, thus causing a delay or difficulty in carrying out concurrent performance (Pashler, 1994).

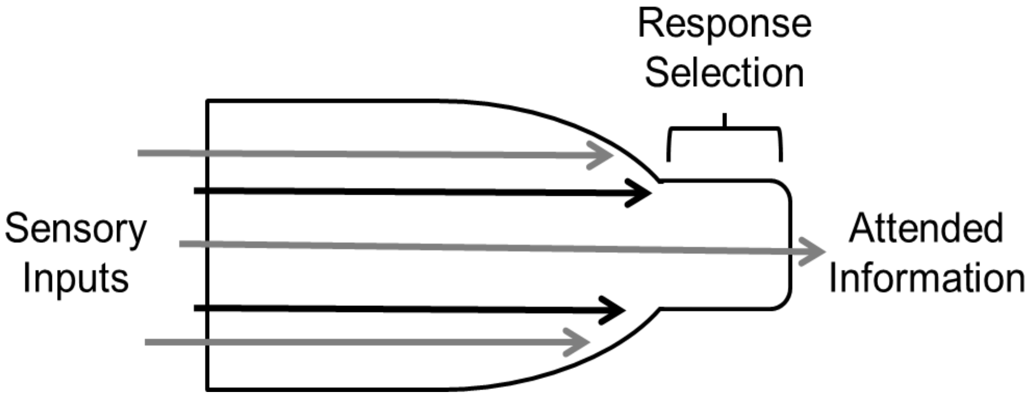


Figure 3: A diagram representing the "central bottleneck model" in response selection during dual-task performance. The arrows represent the sensory inputs entering the CNS by means of the three sensory systems. When two or more tasks require the same response mechanism a bottleneck is created causing a slowing of the second task response.

The presence of the bottleneck is dependent on the different stages of processing or with different types of mental operations. For example, balance control can be divided into three phases, the first involving input from the three sensory systems regarding body position, followed by the processing of the sensory information and finishing with the selection of a motor response to regain upright stance (Redfern, Jennings, Martin & Furman, 2001). It is suggested that attention is involved in the sensory integration phase of balance control, more specifically the rejection of sensory information that is either inaccurate or unnecessary for selecting an appropriate response (Redfern et al., 2001). The bottleneck appears to be present during sensory selection resulting in the delay for processing the information for the secondary task. Thus, to avoid interference during dual-task performance, the two tasks must involve different neural pathways or the two tasks must be performed separately (Pashler, 1994).

1.2.2 Dual-Tasking Involving a Balance Task

Previous research has incorporated dual-task paradigms to determine the involvement of attentional processes in human balance control. Different cognitive tasks have been used to test an individual's ability to maintain their balance. For example, Kerr, Condon & McDonald (1985) examined how two different cognitive tasks, a visual spatial task (i.e., remembering number-word pairs and mentally placing the numbers in an imaginary matrix) and a non-spatial verbal memory task (i.e., remembering number-word pairs and verbally repeating them), affected balance control. Since there was an increase in the number of errors in the visual spatial task but not the non-spatial verbal memory task during standing, the authors concluded that standing balance control was attentionally demanding and that cognitive spatial processing and balance regulation may require common mechanisms. Other researchers have relied on different visuomotor and reaction time tasks to demonstrate that performance on these cognitive tasks worsens when performed simultaneously with a balance task (Maki et al., 2001; McIlroy et al., 1999; Norrie et al., 2002; Redfern et al., 2002). These results indicate the need to divide attentional resources when completing a cognitive task at the same time as maintaining balance.

The attentional demands of balance control are also dependent on the complexity of the balance task. Static tasks such as sitting require minimal attentional resources and thus, the ability to perform a concurrent cognitive task while maintaining a sitting posture is minimally affected (Bardy & Laurent, 1991; Lajoie et al., 1993). However, as the difficulty of the balance task increases, such as during walking or recovering from a loss of balance, greater attentional demands are required to maintain stability (Lajoie et al., 1993; Lajoie & Gallagher, 2004). More attentional resources are needed to initiate and execute rapid, complex limb movements (Maki & McIlroy, 1994) and consequently, a decreased performance on the concurrent cognitive task occurs (Brown, Shumway-Cook & Woollacott, 1999; Maki & McIlroy, 2005; Maki, McIlroy & Fernie, 2003; Norrie et al., 2002).

The amount of attentional resources required is not necessarily constant within a given balance task. For example, three distinct phases of attentional requirements have been proposed when recovering from a loss of balance (Maki et al., 2001). The first phase is referred to as the automatic postural response and requires minimal attentional resources since performance on the secondary task has been shown to be relatively unaffected during this time (Maki et al., 2001; McIlroy et al., 1999; Norrie et al., 2002; Rankin et al., 2000). The second phase of balance recovery, occurring approximately 200-300 ms after perturbation onset, requires attentional resources in order to continue with the fixed-support reaction or to lift the swing foot or arms during change-in-support reactions (Maki, McIlroy & Fernie, 2003). During this time, errors or pauses in cognitive performance can be observed (Maki et al., 2001; McIlroy et al., 1999; Norrie et al., 2002). The final phase of balance recovery, occurring approximately 300 ms after perturbation onset, is associated with divided attention between the two tasks due to an attempt to complete the cognitive task at the same time as to regain upright stance (McIlroy et al., 1999; Norrie et al., 2002; Woollacott & Shumway-Cook, 2002). Therefore, for an individual to appropriately respond to an unexpected loss of balance, they must be able to rapidly allocate varying amounts of attentional resources within the different phases of balance recovery process.

1.2.3 Changes in Dual-Task Performance with Age

Ageing leads to greater attentional requirements for balance control. This has been illustrated by requiring young and older adults to perform different types of cognitive tasks while maintaining balance. Balance control was found to be improved with the presence of a cognitive task involving low levels of cognitive involvement as it switches attention away from balance control without creating resource competition. However, these positive effects disappear when the cognitive task becomes too difficult as resource competition becomes an important factor in dual-task performance (Huxhold, Schmiedek & Lindenberger, 2006). The type and complexity of the balance task can also play a role in dual-task performance. For example, both young and older healthy adults demonstrate greater RTs as balance task complexity increases from static (i.e., sitting) to dynamic balance tasks (i.e., standing to walking) (Lajoie et al., 1996). Further, for any given balance task, more attentional resources are required for older adults (Lajoie et al., 1996), as older adults demonstrated even slower RTs as the balance task complexity increased as well as a more secure gait developed through a slower walking speed and shorter stride length.

If maintaining balance becomes more attentionally demanding during dual-tasking with age, then the ability to switch attention between concurrent tasks may also be affected (Brauer, Woollacott & Shumway-Cook, 2001; Brown et al., 1999; Shumway-Cook et al., 2000). To study the difference in attention switching abilities between young and older adults, participants tracked a continuously moving target as part of the cognitive task while responding to unpredictable support surface translations for the balance task (Maki et al., 2001). Compared to young adults, older adults demonstrated a greater delay in tracking deviation relative to translation onset and greater delays in EMG onset latencies in response to a loss of balance, both of which suggest greater difficulties in attention shifting with age (Maki et al., 2001). This delayed ability to switch their attention to balance recovery may explain why older adults are unable to initiate and execute balance reactions effectively (Maki et al., 2001). However, since the majority of young and older participants were able to successfully return to performing the cognitive task following the initial perturbation, this suggested the presence of a bottleneck as the processing demands of the balance and tracking task only interfere with each other briefly and not continuously as would be expected in the capacity model.

1.2.4 Improving Attention Switching Through Perturbation Warning

Since older adults show a decreased ability to switch attention between tasks, especially to recovering balance, it is important to establish a method to better facilitate this attention switching process. One way to specifically facilitate attention switching abilities may be to provide warning of an upcoming balance disturbance (Jacobs et al., 2008). Prior warning may allow individuals to change one's central set and to modify the balance response for the upcoming perturbation. Central set is the task-dependent preparatory neural discharge within the CNS that modifies the balance response when in a state of readiness to receive the perturbation (Prochazka, 1989; Horak, Diener & Nasher 1989). Thus, when a warning of the upcoming perturbation is provided, this may cause a change in central set through an increased level of cortical activity prior to the perturbation as previously observed with increased expectation (Jacobs et al., 2008). Consequently, individuals will be able to initiate muscle responses even before information regarding the upcoming loss of balance is received from the periphery (Horak et al., 1989).

The specific benefits of advanced warning on balance control have been shown in young adults, where they anticipated and leaned forward prior to the loss of balance in order to minimize the upcoming balance disturbance (Maki & Whitelaw, 1993). Warning of an upcoming loss of balance has been provided through different means while individuals performed a balance task alone. Whereas Mochizuki, Sibley, Cheung &

McIlroy (2009) suggested that the method in which participants receive information about the perturbation may not be crucial when trying to optimize balance responses, others have found contrasting effects. For example, prior visual information regarding amplitude and/or direction of the platform tilt or translation resulted in participants stepping less to recover balance (Jacbos et al., 2008) but did not significantly change EMG onset latencies compared to when no advance information was provided (Adkin et al., 2006; Diener, Horak, Stelmach, Guschlbauer & Dichgans, 1991; Jacobs et al., 2008). This suggests that postural responses to rapid tilt perturbations do not benefit from advance visual information or that a 4 s precue-stimulus interval may have been too long (Diener et al., 1991; McChesney et al., 1996). Larger benefits to balance control, specifically a reduction in postural muscle onset latencies, have been observed when the warning is provided in the form of an auditory cue (McChesney et al., 1996). This could be because auditory information is not as important as vestibular, visual and proprioceptive information when recovering balance, resulting in less sensory pathway interference.

Providing warning of an upcoming perturbation during dual-task performance has also been shown to be beneficial for young adults. For example, earlier EMG onset latencies and improved cognitive task performance were observed when warning was provided to the participant (De Lima, Neto & Teixeira, 2010). However, only a limited amount of research has examined the effects of warning during dual-task performance in older adults. Using a reaction time task for the cognitive task, the results suggest that advance warning of an upcoming perturbation allows older adults to adequately prepare for a loss of balance and to improve attention switching abilities (Müller et al., 2004). This was believed to be achieved through the postural prioritization or bias towards preparing for the stimulus with the highest possible threat (Müller, Redfern & Jennings, 2007). Consequently, the earlier postural preparation allowed for a quicker facilitation of attentional resources back to the cognitive task. It is also theorized that providing a warning involves a change in the preparation for perceiving a stimulus and can aid in creating a state of readiness for achieving optimal performance in higher functioning tasks (Raz, 2004). That is, a warning signal allowed younger adults to take into account their prior experience with the perturbations and modify their responses based on previous effectiveness of their earlier responses (Horak et al., 1989).

Despite previous findings, these studies cannot comment on the time course of the attentional shifts occurring between tasks during dual-task performance. For example, improvements in a discrete RT task can demonstrate increased attentional resources being donated towards successful and earlier completion of this task following the balance disturbance, but it cannot illustrate when and for how long attentional resources are being shifted between the balance and cognitive task during the different phases of balance recovery. If advance postural preparation is occurring when a warning is provided then being able to continuously monitor attention shifts will allow us to see if and when this advanced preparation is occurring. This is important since attention switching to balance recovery is usually delayed in older adults and many falls may be due to this inability to shift attention to balance recovery (Brown et al., 1999; Shumway-Cook & Woollacott, 2000).

2.0 Rationale, Purpose, Research Questions & Hypotheses

2.1 Rationale

Many studies have demonstrated that ageing results in an increase in the amount of attentional resources needed to maintain balance and consequently, a decline in balance control (Lajoie et al., 1996; Maki et al., 2001; Redfern et al., 2002). This may explain why falls among the elderly are quite common, with at least one third of community dwelling individuals over the age of 65 experiencing one or more falls each year (Lajoie & Gallagher, 2004). Most falls that older adults experience are not solely due to balance deficits but rather, thought to be the result of an inability to effectively shift attention to maintaining balance in dual-task situations (Brown et al., 1999; Shumway-Cook & Woollacott, 2000).

One method to better facilitate attention switching and reduce processing delays between balance recovery and cognitive task performance is to provide advanced warning of an upcoming balance disturbance. By allowing for prior strategic postural preparation and facilitating an earlier switching of attention resources, older adults may no longer experience greater difficulty in initiating a postural response due to delayed attention switching abilities (Maki et al., 2001). This postural preparation may also reduce task interference caused by delays in processing of balance control information at the bottleneck within the CNS (Muller et al., 2004). While previous studies have incorporated discrete reaction time tasks as their cognitive tasks, our understanding of the benefits of warning on attention switching abilities may be extended by considering other forms of cognitive tasks.

Implementing a continuous cognitive task, when examining its influence on attention switching abilities, allows for a more objective determination of the time course and extent of attentional shifts during dual-task performance (McIlroy et al., 1999). A continuous cognitive task also differs from previously used reaction time tasks because it is a spatial task that requires constant attention to complete successfully (Young & Stanton, 2010). As a result, performance on a continuous task can illustrate the time course and extent of attentional shifts that discontinuous cognitive task may not be able to show as accurately (McIlroy et al., 1999; Norrie et al., 2002).

2.2 Purpose

The purpose of this study was to examine whether there is an age-related difference in the ability to switch attention from a continuous cognitive task to maintaining balance when warned of an upcoming balance disturbance.

2.3 Research Questions

1) When warned of an upcoming perturbation, will older adults demonstrate greater improvements in balance recovery reactions compared to younger adults?
2) When warned of an upcoming perturbation, will older adults demonstrate greater improvements in cognitive (tracking) task performance during the balance recovery reaction compared to younger adults?

2.4 Hypotheses

1) It is hypothesized that warning will provide greater benefits for older compared to young adults. This will be demonstrated by greater decreases in the frequency of steps required to recover balance, an earlier EMG onset latency and smaller EMG amplitudes during the interval following the perturbation onset. It is also expected that older adults will demonstrate an increase in EMG amplitude prior to the perturbation to allow for postural preparation when given perturbation warning.
2) It is hypothesized that warning will result in an earlier initial deviation in tracking performance and a decrease in duration of the initial tracking deviation following perturbation onset. These changes in tracking task performance are hypothesized to be larger in older adults compared to younger adults as older adults experience greater delays in attention switching due to the physical and neural changes that occur with age, allowing for a greater possibility for improvement (Brown et al., 1999; Shumway-Cook & Woollacott, 2000).

3.0 Methods

3.1 Participants

Fifteen young adults (average ± 1 standard deviation age of 23.6±1.5 years), and 16 older adults (average ± 1 standard deviation age of 70.7±5.0 years) participated in this study. A summary of participants' characteristics and assessments is displayed in Table 1.

Table 1: Characteristics of young and older adults with values representing group means ± one standard deviation. ABC = Activity-specific Balance Confidence scale, TUG = Timed Up and Go, WART = Walking and Remembering Test.

	Young Adults (n = 15)	Older Adults (n = 16)
Sex	6 M, 9 F	3 M, 13 F
Age (y)	23.6 ± 1.5	70.7 ± 5.0
Height (cm)	173.2 ± 9.4	166.2 ± 9.3
Mass (kg)	71.2 ± 12.3	72.8 ± 14.7
Average number of falls	1.7 ± 2.5	1.4 ± 2.5
ABC (%)	94.4 ± 5.3	92.9 ± 6.0
$TUG_{original}$ (s)	6.2 ± 0.8	7.9 ± 0.8
TUG_{manual} (s)	7.2 ± 0.9	9.2 ± 0.9
$TUG_{cognitive}$ (s)	7.0 ± 1.6	9.6 ± 1.4
WART self-selected walking (s)	4.3 ± 0.7	4.7 ± 0.6
WART single task fast walking (s)	2.8 ± 0.4	3.6 ± 0.4
WART dual-task fast walking (s)	3.1 ± 0.5	4.1 ± 0.6
WART dual-task digit span accuracy (%)	85.9 ± 24.6	83.4 ± 18.0

All participants were recruited though word of mouth and by brief presentations given in different community centres within the Niagara Region. All participants did not report any known neurological or orthopedic disorders (e.g., Parkinson's Disease, stroke, severe joint pain limiting movement, etc.) that may affect their balance or the performance of any other task performed during the experiment. Informed consent was provided by each participant prior to participation and all procedures were approved by the Brock University Research Ethics Board (# 12-154) in accordance with the Declaration of Helsinki.

3.2 Questionnaires and Functional Assessments

Once informed consent was received, each participant provided their height, weight, age and sex. Participants indicated their preferred hand, which determined which hand the joystick would be held for the tracking task. Participants also reported the number of falls they experienced in the last year, with a fall being defined as “any event that led to an unplanned, unexpected contact with a supporting surface” (Shumway-Cook, Brauer & Woollacott, 2000, p.898). Finally, participants completed the Activity-specific Balance Confidence (ABC) Scale (Powell & Myers, 1995) to assess their situation-specific balance confidence.

Next, participants completed three versions of the Timed Up and Go (TUG) test (Shumway-Cook et al., 2000). The purpose of the two modified TUG tests was to assess dual-task ability and time to complete the task was used to quantify performance (Shumway-Cook et al., 2000). To start, each participant completed two trials of the $\text{TUG}_{\text{original}}$, where they stood up from a chair, walked 3 m as quickly and safely as possible to a red “X” marked on the floor, turned around, walked back and sat back down (Shumway-Cook et al., 2000). Participants were then asked to complete two trials of the TUG_{manual} task. This task required participants to walk the same distance as the $TUG_{original}$ test while also carrying a full cup of water. Participants were also instructed to try not to spill the water. The $TUG_{cognitive}$ was the last version of the three TUG tests. This required participants to complete the $TUG_{original}$ test while counting backwards by threes, starting from a number that was given at the start of the trial. Two trials of the $TUG_{cognitive}$ were completed, with a different starting number given at the start of each trial.

Following the completion of the TUG tests, participants performed a modified version of the Walking and Remembering Test (WART) (McCulloch, Mercer, Giuliani & Marshall, 2009). The WART is a reliable measure of dual-task memory with a cognitive task (forward digit span) that can be customized to each participant so that a similar level of challenge is presented for each participant (McCulloch et al., 2009). This test involved six trials of straight walking along a 6.1 m path (McCulloch et al., 2009). For the first trial, participants completed the walk at their everyday self-selected, normal walking pace. The second and third trials involved walking as quickly and safely as possible. Before completing the fourth and fifth trials, each participant’s forward digit span was assessed using the Weschler Adult Intelligence Scale-Revised (WAIS-R) test. This required participants to repeat back a sequence of digits in the same order as presented (Wechsler, 1981, p. 65). The sequence of digits started with a length of one number and when the participant could repeat it back successfully twice, the sequence length increased by one. This protocol continued until the participant could not repeat the digits back successfully or until the sequence length reached a maximum of nine digits. This sequence length corresponded to the participant's maximum forward digit span and was used for the next two walking trials. Before the initiation of the fourth and fifth walking trials, participants were given a string of digits (according to their maximum forward digit span). Participants walked the 6.1 m distance as quickly and safely as possible and upon reaching the end of the path, they recalled the digits out loud. The last (sixth) trial involved the fast walking without digit recall. Performance on trials 1, 2, 3 and 6 were assessed by recording the time to complete the walk, while for trials 4 and 5, the time to complete the walk and digit span accuracy after the walk were recorded.

3.3 Preparation

Upon completion of the functional walking tests, participants were seated in order to prepare the skin for electrode placement. The skin over the right elbow and the tibialis anterior (TA) and medial gastrocnemius (MG) of the right leg were lightly shaved, cleaned with isopropyl rubbing alcohol and a light abrasive to minimize skin-electrode impedance. Once the skin sites were prepared, pairs of disposable Ag-AgCl electrodes (10 mm diameter, 2 cm interelectrode distance, Kendall Meditrace 200, Mansfield, MA, USA) were placed over the right TA and MG, while a single electrode was be placed over the right elbow. Electrodes were only placed on the right leg because it was expected that EMG onset latencies and amplitudes would be similar between the left and right legs (Maki & McIlroy, 1993; McIlroy & Maki, 1995). Participants then put on a harness that attached, via a rope, to an overhead track to minimize the chance of a fall occurring.

3.4 Overview of experimental tasks

Once the preparation was complete, participants stood barefoot with their feet shoulder-width apart on a 1.6 m long by 0.9 m wide moveable platform that was bolted to a motor driven 4.3 m linear stage (Figure 4). A spotter was located on both sides of the platform to ensure that no falls occurred. Participants completed a total of four experimental conditions, with each condition involving a balance task, a cognitive (tracking) task or both the balance and tracking task together (Table 2).

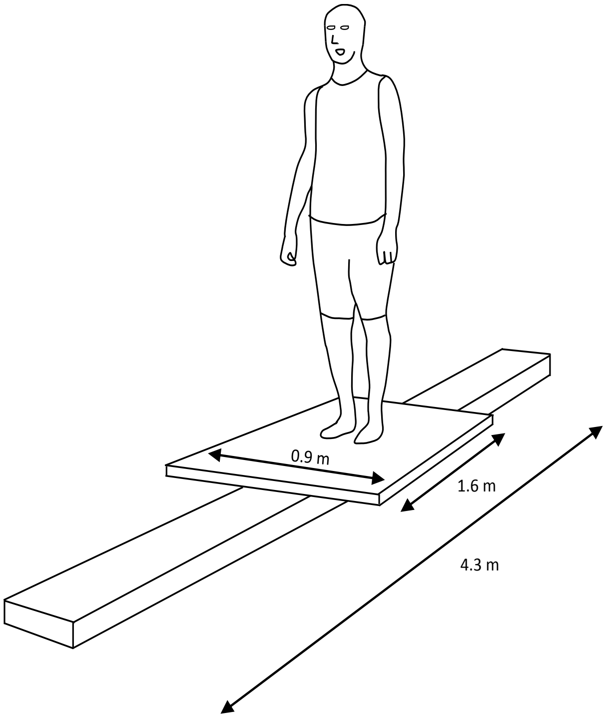


Figure 4: A diagram representing the moveable platform that delivered forward and backward surface translations. The overhead ceiling track and two spotters are not represented in this figure.

Table 2: The following table represents an overview of the instruction, number of trials and tasks completed in the four experimental conditions.

Experimental Conditions	Number of Trials	Task	Instruction
Practice Tracking Task (Condition 1)	10-18	Visuomotor tracking of a moving target with a cursor controlled by a hand-held joystick for 30s	Focus on keeping the cursor (red square) within the moving target (blue rectangle)
Single Balance Task (Condition 2)	10	Recovering balance from horizontal support surface translations in the backward and forward directions	Focus on maintaining an upright posture while also trying to keep feet in place during balance recovery
Single Tracking Task (Condition 3)	6	Visuomotor tracking of a moving target with a cursor controlled by a handheld joystick for 30s	Focus on keeping the cursor (red square) within the moving target (blue rectangle)
Dual-Task (Condition 4)	28	Tracking for 30 s with a single translation being delivered each trial and the presence of an auditory warning provided 2 s prior to 10 backward translations	Maintain tracking performance as best as possible even when the translation is delivered and try to keep feet in place both before and after the translation

The balance task required participants to recover their balance in response to a horizontal support surface translation (perturbation). The initial platform movement accelerated for 0.25 s (peak acceleration of 2.0 m/s^2) before reaching a constant velocity of 0.4 m/s for 1.25 s and then decelerated for 0.25 s (peak deceleration of 2.0 m/s^2). The platform translation had a total displacement of 0.6 m. This initial movement was followed by a second movement 3 s later in the opposite direction in order to bring the platform back to its original position. Participants were instructed to stand relaxed prior to the platform movement and to try their best not to step when recovering their balance from the surface translation. Participants held the joystick used for the cognitive task in their dominant hand to ensure constancy between experimental conditions.

The cognitive task was comprised of a visuomotor tracking task. This task required participants to track a moving target on a computer monitor with a cursor controlled by a hand-held joystick (Nintendo Wii Nunchuk, Nintendo Co., Ltd., Kyoto, Japan) held in their dominant hand (Figure 5). The monitor was placed approximately 1.7 m in front of the participant. Participants controlled a 0.7 cm x 0.7 cm red square using their joystick within a 4.5 cm x 1.5 cm blue rectangle (target) that moved along the vertical axis. The target moved with a waveform that was the average of four sine waves with a mean frequency of 0.5 Hz for a duration of 30 s. Participants were instructed to track the target as accurately as possible while holding the joystick at their side.

Figure 5: A photo of the hand-held joystick that participants used to track the target during the tracking trials.

Participants dual-tasked by performing the balance and tracking task at the same time. During the dual-task condition, the balance task was considered the primary task because the attentional demands of recovery from the perturbation were inferred by changes in tracking task performance (Woollacott & Shumway-Cook, 2002). The tracking task was considered the secondary task, with changes in tracking performance demonstrating attention switching to the balance task when balance recovery required attention (Woollacott & Shumway-Cook, 2002).

3.5 Experimental protocol

The first condition involved participants performing 10-18 practice trials on the tracking task alone. The purpose of this condition was to ensure that the participant could perform the tracking task accurately and consistently before commencing with the experimental trials. Performance on these practice trials was quantified by calculating the root mean square (RMS) error. The RMS error measured tracking accuracy, which was defined as the average difference in position between the target and the participant’s cursor over the 30 s trial. The RMS error was used to determine when performance had plateaued before commencing with the remaining three experimental conditions (McIlroy et al., 1999; Norrie et al., 2002; Quant et al., 2004). A general statement of performance and encouragement was given at the end of each trial to help motivate participants to track as accurately as possible. A 10-15 s break was given between trials. Additional breaks were given if requested by the participant.

The second experimental condition consisted of only the balance task. Participants experienced ten horizontal support surface translations, with four forward and six backward directed perturbations presented in a random order. Participants were asked to try to recover their balance without taking a step. This condition was implemented in order for participants to become familiarized with the balance task and to record EMG onset latencies and amplitudes that could be compared to the dual-task trials (see section 3.6.1). A 10-15 s break was presented between trials to allow the participant to realign their feet and prepare for the next trial. Additional breaks were given if requested by the participant.

The third experimental condition consisted of only the tracking task. A total of six trials were performed. Similar to the practice trials, the participants stood on the platform and tracked the moving target with their cursor for duration of 30 s. Participants were given a general statement of encouragement to follow the target cursor as accurately as possible and given a 10-15 s break between trials. These trials were implemented so that a baseline tracking that could be compared to the dual-task trials.

Lastly, participants performed a dual-task condition where they simultaneously performed the tracking and balance task. For this last condition, participants stood on the perturbation platform and performed the tracking task. Sometime during the 30 s tracking trial, a perturbation was delivered to disturb the participant’s balance in either the forward or backward direction. Even though the perturbation was delivered at a different time during the 30 s trial, the perturbation was always initiated when the tracking target was at a position, velocity and acceleration of approximately zero. This was chosen because when the target is in this position, it is difficult for participants to predict the direction of target movement and therefore, allows for an easier detection of tracking deviations (Maki et al., 2001). Participants were asked to try their best to stand relaxed and not anticipate the perturbation.

For ten of the dual-task condition trials, a warning was provided to notify participants that the platform would move backwards in two seconds (deLima et al., 2010; Jacobs et al., 2008). The warning was a single auditory tone and allowed participants to alter their upright posture to prepare for the upcoming backward perturbation (McChesney et al., 1996). Participants were given the freedom to do whatever was needed to prepare for the backward translation as long they kept their feet in place and tried to maintain tracking. All participants confirmed that the auditory tone could be heard clearly. Figure 6 illustrates the timeline of a dual-task trial with or without perturbation warning.

There were a total of 28 trials in the dual-task condition, with each trial consisting of tracking and a single platform perturbation. Eight trials contained a forward perturbation, ten trials with a backward perturbation with no warning provided, and ten trials with a backward translation with warning provided. These 28 trials were presented in a random order. Breaks were provided every 10-15 s between trials and additional breaks were given whenever requested. Instruction for this condition was to try to maintain tracking throughout the entire 30 s trial while also trying not to take a step when the perturbation is delivered.

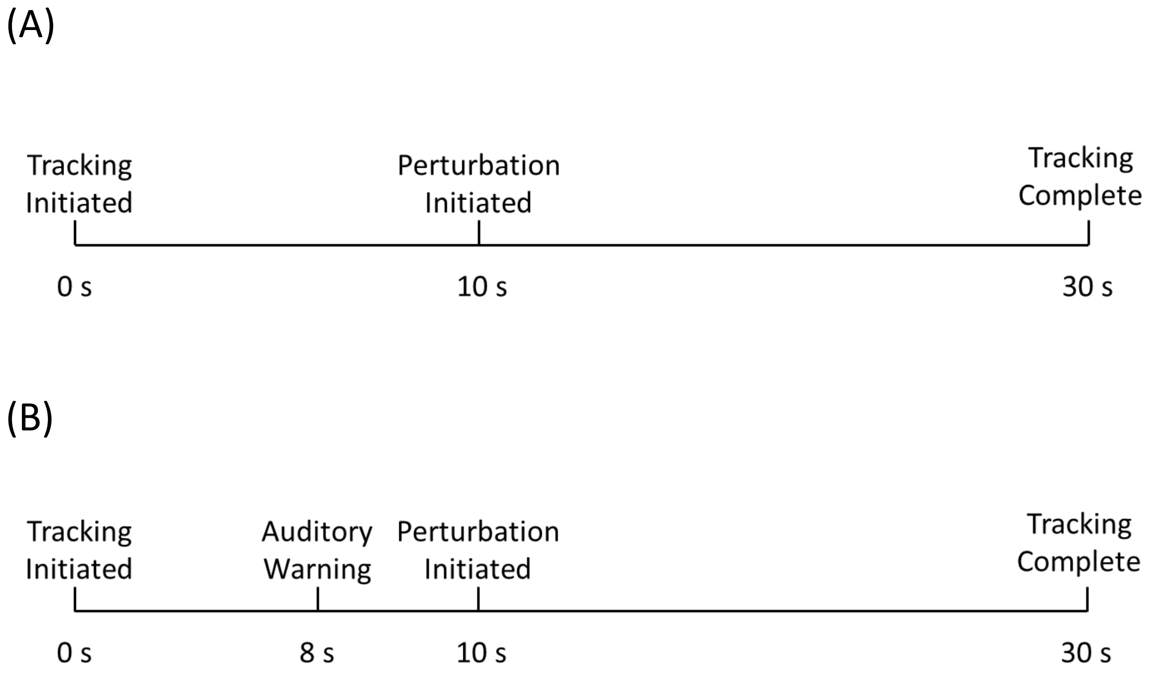


Figure 6: Timelines representing an example of the timing of events that occur when (A) no perturbation warning is given and when (B) perturbation warning is given in the dual-task condition.

Each participant performed the practice tracking trials first, followed by the single balance task and then the single tracking task. This allowed for task familiarization and for baseline measures to be collected for each task (McIlroy et al., 1999; Muller, Jennings, Redfern & Furman, 2004; Quant et al., 2004). These three single task conditions were always followed by the dual-task condition.

3.6 Data Collection

3.6.1 EMG Data

In response to each surface perturbation, balance responses were quantified from the TA and MG EMG recordings in the form of EMG onset latencies and amplitudes. All EMG signals were amplified 350 times (MA-300, Motion Systems Inc., Baton Rouge, LA, USA) and analog-to-digitally converted at a sampling rate of 1,000 Hz and band-pass filtered offline between 20-300 Hz (micro1401, Cambridge Electronics Design, Cambridge, UK).

EMG onset latencies for the TA and MG during backward directed perturbation trials were determined using an algorithm written within commercially available software (Spike2, Cambridge Electronic Design, Cambridge, UK). First, baseline mean and standard deviations values were calculated from a 1 s interval starting 3 s prior to perturbation onset to limit any influence of the perturbation warning. EMG onset latencies were then determined as the time at which the rectified EMG signal exceeded a threshold of 1 standard deviation above this mean baseline activity for a period of at least 25 ms, while allowing for a drop below the threshold for no longer than 3 ms

(Tokuno, Carpenter, Thorstensson, & Cresswell, 2006). Each onset latency was confirmed through visual inspection to ensure that the algorithm correctly determined the EMG onset.

TA and MG EMG amplitudes were determined by calculating the RMS amplitude of the rectified EMG signal during three time intervals for all backward directed perturbation trials. The first time interval consisted of the 300 ms 1 s from the auditory warning onset. This determined if there were any differences in background EMG amplitude (i.e., prepatory muscle activity) between the dual-task with and without warning trials. The second interval consisted of 300 ms preceding the perturbation onset. This encompasses any additional preparatory activity caused from anticipation in both the single balance task and the dual-task with and without warning condition. The third interval was 300 ms following muscle onset to note any difference in magnitude of the balance response following the perturbation as the tracking task was added and when perturbation warning was given. This third interval was measured in the single balance task, as well as the dual-task with and without warning conditions. The onset of each muscle was chosen so that any differences in EMG amplitudes were independent of any changes in muscle onset (Tokuno et al., 2006). If an onset could not be identified for a given trial, EMG amplitude measures were limited to the two intervals preceding perturbation onset. All EMG amplitudes were normalized as a percentage of isometric maximal voluntary contraction (MVC). MVCs were obtained following the completion of the experimental conditions, with participants maximally contracting the TA and MG for approximately 2-3 s against resistance. The MVC was measured as the largest recorded EMG amplitude occurring over a 300 ms interval for the duration of the contraction.

3.6.2 Tracking Data

For each participant, their three best trials from the single tracking task condition were used to determine the error threshold that was used for their dual-task condition. For the error threshold calculation, each of the three best trials from the single tracking task used for analysis consisted of the point-by-point difference in position between the target waveform and the participant's cursor path. For each 30 s trial analysis was limited to the 3 s prior to until the 12 s following perturbation onset, giving a total of 15, 000 data points used for the error threshold calculation. For each of the 15, 000 data points the mean and standard deviation were calculated across the three trials. The point-by-point error threshold was then created as the mean ± 1.5 standard deviations. A point-by-point method was used for each participant so that their error thresholds reflected their performance throughout the different phases of the tracking task.

During all backward directed dual-task trials any deviations in tracking performance that exceeded the error threshold for more than 200 ms was deemed as a tracking deviation (Figure 7).

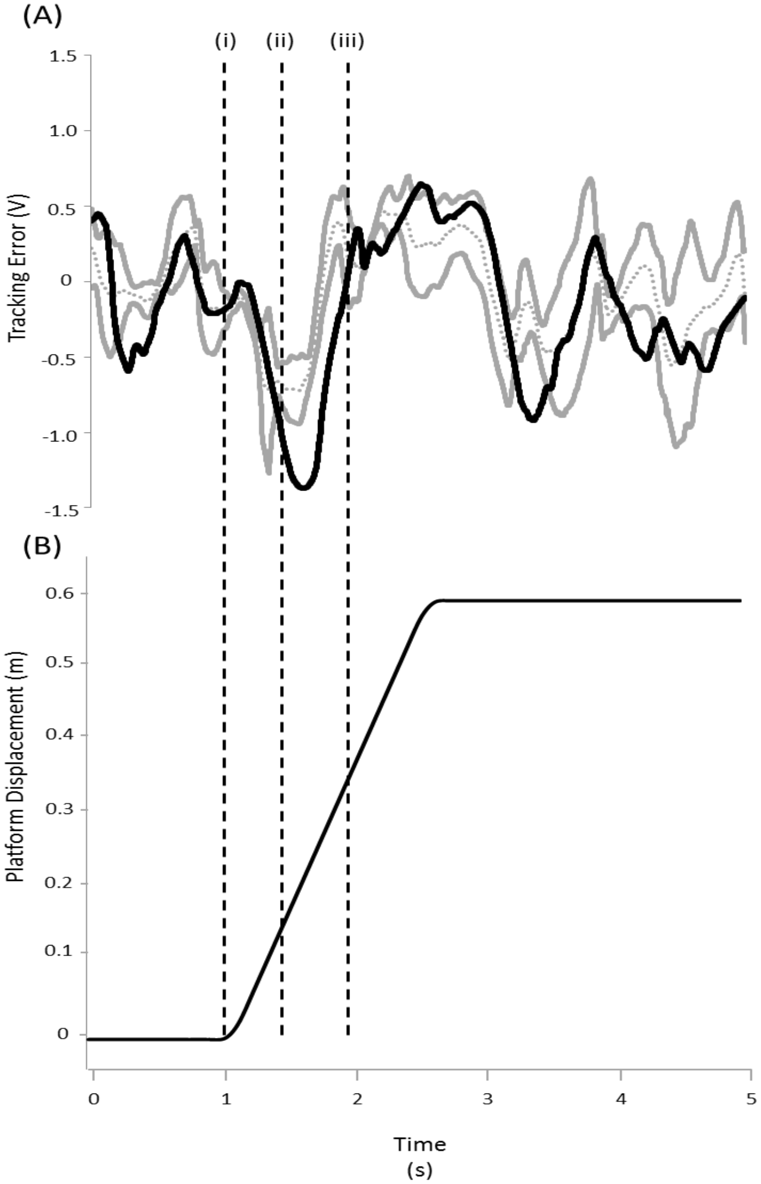


Figure 7: (A) Tracking performance from a representative trial before and during recovery from a support surface perturbation. The black line represents the participant's tracking performance during a trial from the dual-task without warning condition. Their performance was compared against the error thresholds that were determined as the mean difference in tracking position (grey dashed line) plus or minus 1.5 standard deviations (solid grey lines) from the single tracking task trials. (B) The platform displacement over the course of the trial, with movement initiating at time of approximately 1 s (line i). 413 ms after perturbation onset, a deviation in tracking performance is observed suggesting that attention was being switched from the tracking to the balance task (line ii). Tracking performance returns within the error thresholds at 942 ms following perturbation onset (line iii). The duration of the first tracking deviation was defined as the time from the onset of tracking deviation to when tracking performance returned within the error thresholds (i.e., 529 ms).

During the backward directed trials within the dual-task with and without warning conditions, two measures were used to quantify tracking task performance and to infer when attentional resources were being allocated to the balance task (Maki et al., 2001) (Figure 7). First, the time from perturbation onset to the first instance of tracking deviation was measured (i.e., from line (i) to line (ii) in Figure 7). Second, the time at which the first instance of tracking deviation ended was measured. This was defined as the time at which the first deviation of tracking dropped within the error thresholds for at least 400 ms. The second measure was then subtracted from the deviation onset time to determine the duration of the initial deviation (i.e., from line (ii) to line (iii) in Figure 7). A deviation onset and duration were not considered to have occurred if a clear deviation was not present 200-600 ms following perturbation onset. Measurement of both tracking deviation onset time and duration from the perturbation inferred when attention switching was occurring between the tracking and the balance tasks following the perturbation onset (Maki et al., 2001). These measures have been shown to change with age and thus, may help to establish any improvements in attention switching when perturbation warning is provided (Maki et al., 2001). These two tracking task performance measures also aid in identifying the attentional demands needed to perform the balance task (Simoneau, Begin & Teasdale, 2006).

3.7 Statistical Analysis

Two independent samples T-tests were conducted to compare the scores on the ABC scale and the number of falls experienced each year between young and older adults. To compare the walking time results of the WART and TUG walking tests two 2 x

3 mixed model analysis of variance's (ANOVAs) were carried out with age group (young vs. older adults) as the randomized factor and walking condition for the TUG ($TUG_{original}$ vs TUG_{manual} vs. $TUG_{cognitive}$) and the WART (self-selected walking vs. single task fast walking vs. dual-task fast waking) as repeated factors. For any significant interactions independent samples t-tests were performed to compare between young and older adults for each walking condition. As well, one-way repeated measures ANOVAs with Bonferroni-corrected pairwise comparisons were calculated for the TUG and WART walking times to test for differences within each age group across all three walking conditions. A significance level of $p \leq 0.05$ used.

Perturbations were experienced in both the forward and backwards direction, however data corresponding to only the backward trials were analyzed as this direction leaves the greatest range of movement for improvement in balance recovery. Changes in balance task performance were studied through the number of steps needed to recover balance, EMG onset latencies in the TA and MG and EMG amplitudes in the TA and MG during the three intervals discussed in section 3.6.1. Each variable was examined by conducting two 2 x 2 mixed model ANOVAs. The first 2 x 2 ANOVA consisted of age (young vs. older adults) as the randomized factor and condition (single balance task vs. dual-task without warning) as the repeated factor. This ANOVA was conducted to examine the effect of adding the concurrent tracking task on the balance task performance. The second 2 x 2 ANOVA consisted of age and condition (dual-task without warning vs. dual-task with warning) to establish the effect of perturbation warning on balance preparation and recovery. For each ANOVA a significance level of

$p \leq 0.025$ was used to adjust for performing two 2 x 2 ANOVAs per dependent measure. To assess significant age x condition interactions independent-sample t-tests were used to examine differences between young and older adults for each condition. Paired-sample t-tests were conducted to compare differences between conditions for young and older adults separately. A significance level of $p \leq 0.05$ was used.

Changes in tracking task performance were assessed through tracking deviation onset and duration following perturbation onset during all backward-directed perturbations in the dual-task with and without warning conditions. The effect of warning on the tracking deviation onset and duration was examined by a 2 x 2 mixed model ANOVAs, with age (young vs. older adults) as the randomized factor and condition (dual-task without warning vs. dual-task with warning) as the repeated factor. A significance level of $p \leq 0.025$ was used to adjust for performing two 2 x 2 ANOVAs per dependent measure.

In analyses where the assumption of sphericity was violated ($p \leq 0.05$) values were adjusted according to the Greenhouse-Geisser correction. Commercially available software (SPSS, Chicago, IL, USA) was used for all statistical calculations. All data are presented as the mean ± one standard error of the mean.

4.0 Results

4.1 Questionnaires and Functional Assessments

A summary of the participants' characteristics and functional assessment scores is shown in Table 1. There was no difference in the number of falls (t_{29}=0.33; p=0.743) or the level of balance confidence between young and older adults (t_{29}=0.71; p=0.484).

Walking time on the TUG walking tests was influenced by an age x condition interaction effect ($F_{1.53,44.35}$=4.91; p=0.019). Post-hoc analysis revealed that older adults had longer walking times during the $\text{TUG}_{\text{original}}$ (t_{29}=-5.90; p<0.001), the $\text{TUG}_{\text{manual}}$ (t_{29}=-6.01; p<0.001) and the $\text{TUG}_{\text{cognitive}}$ (t_{29}=-4.93; p<0.001). However, larger differences between age groups were found during the more difficult $\text{TUG}_{\text{cognitive}}$ (mean difference of 2.6 s) and the $\text{TUG}_{\text{manual}}$ (mean difference of 2.0 s) than the $\text{TUG}_{\text{original}}$ (mean difference of 1.5 s). Since both young and older adults required less time to complete the single-task $\text{TUG}_{\text{original}}$ than the two dual-task TUG tasks ($\text{TUG}_{\text{manual}}$: p<0.001 for young and older adults; $\text{TUG}_{\text{cognitive}}$: p=0.033 for young adults and p<0.001 for older adults), it is evident that the dual-tasking TUG tasks affected the older adults more so than the young adults (Table 1).

Walking time on the WART walking tests was influenced by an age x condition interaction effect ($F_{1.37,39.64}$=4.83; p=0.024). Post-hoc analysis revealed that older adults had a longer walking duration during the single task fast walk (t_{29}=-4.96; p<0.001) and the dual-task fast walk (t_{29}=-5.29; p<0.001) trials. However, a greater difference between older and young adults was found during the more challenging dual-task fast walk (mean difference of 1 s) than the single task fast walk (mean difference of 0.8 s) (Table 1). In contrast, there was no difference in walking time during the self-selected walking pace trials (t_{29}=-1.67; p=0.105) or on digit span accuracy (t_{29}=-0.33; p=0.742) between young and older adults (Table 1).

Repeated measures one-way ANOVAs were also conducted to assess how walking times differed between the three WART conditions for each of the young and older adults. Significant results were found for both young ($F_{1.17,16.41}$=51.11; p<0.001) and older adults ($F_{1.43,21.38}$=30.62; p<0.001). More specifically walking times during the self-selected walking trials were longer than the single task fast walk (t_{14}=-9.18; p<0.001) and the dual-task fast walk (t_{14}=6.03; p<0.001) in the young adults. Older adults were similarly affected with walking times during the self-selected walking trials being longer than the single task fast walk (t_{15}=-10.41; p<0.001) and the dual-task fast walk (t_{15}=3.19; p=0.018). As well, both young (t_{14}=-3.23; p=0.018) and older adults (t_{15}=-4.17; p<0.001) had longer walking durations during the dual-task fast walk in comparison to the single task fast walk (Table 1).

4.2 Single Tracking Task Performance

The single task tracking trials were used to create error thresholds for each participant for the dual-task trials. Analysis of the error threshold magnitude revealed that the threshold magnitude was greater for the older (0.6±0.1 V) compared to the young adults (0.4±0.0 V) ($t_{17.01}$=-4.15; p=0.001).

4.3 The Effects of Dual-Tasking on Balance Task Performance

The following analyses compared balance performance measures between the single balance task with the dual-task without warning conditions in order to assess the effects of a concurrent task (i.e., tracking task) on balance recovery. The functional outcome was assessed by the number of steps needed to recover balance and muscle responses were assessed by the TA and MG EMG onset latencies and amplitudes.

4.3.1 Steps to Recover Balance

The number of steps needed to recover balance during the single balance task and the dual-task without warning conditions demonstrated a condition main effect ($F_{1,29}$=25.68; p<0.001). Regardless of age, participants required fewer steps to recover their balance during the dual-task condition without warning (1.1±0.1 steps per trial) compared to the single balance task (1.4±0.1 steps per trial) condition.

4.3.2 EMG Onset Latencies

TA and MG EMG onset latencies between the single balance task and dual-task without warning conditions were influenced by an age main effect ($F_{1,29}$=5.88; p=0.022 for TA; $F_{1,29}$=11.32; p=0.002 for MG). In response to the surface translation, older adults did not initiate their lower limb muscles as early as the young adults. Compared to the young adults, older adults demonstrated a 13 ms and an 8 ms delay in EMG onset latency for the TA and MG, respectively (Figure 8).

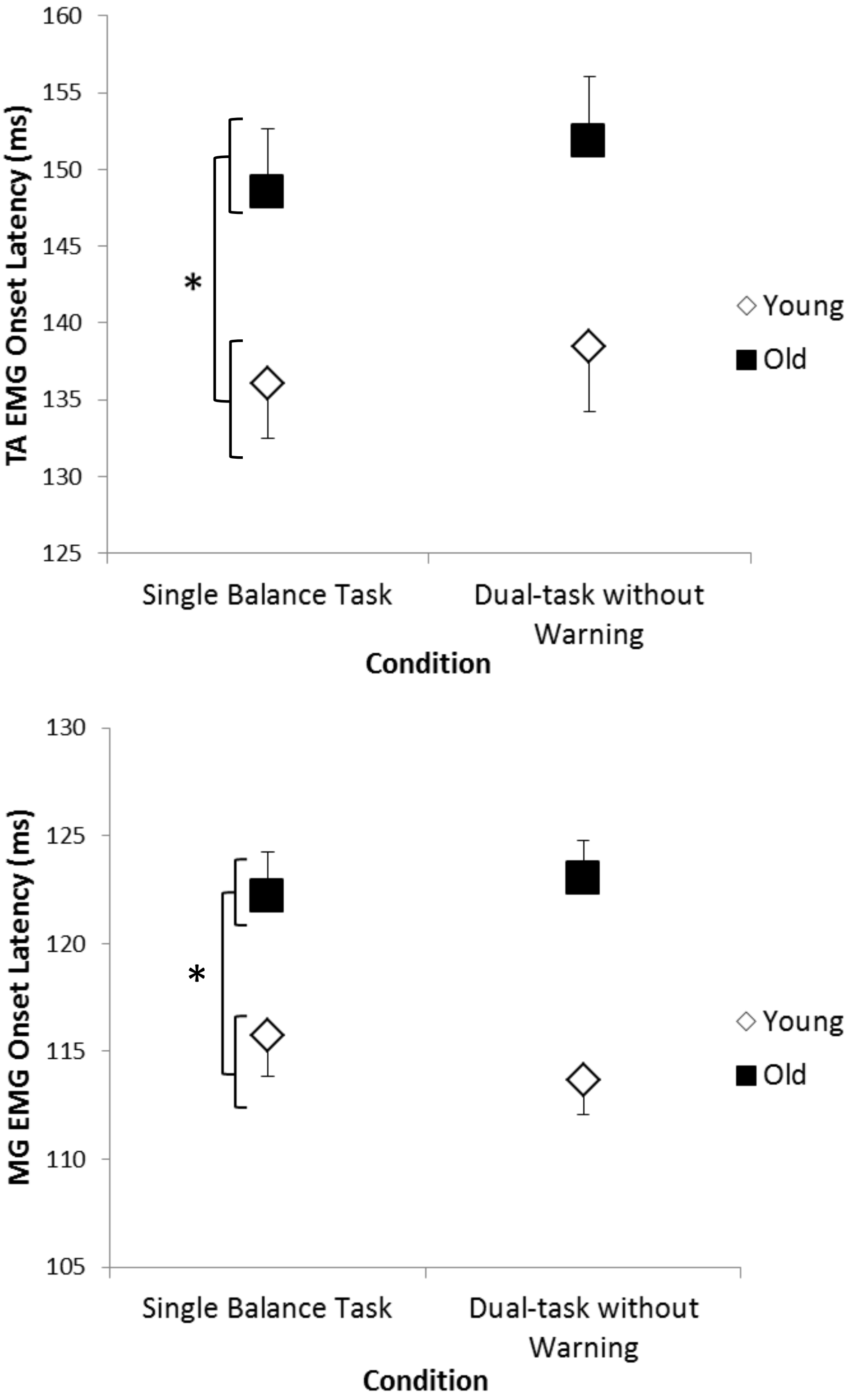


Figure 8: Mean TA (top) and MG (bottom) EMG onset latencies for the young (open diamonds) and older adults (closed squares) during the single and dual-task without warning trials. Error bars represent one SE. An age main effect was observed for both muscles, with longer EMG onset latencies occurring in the older compared to the young adults.

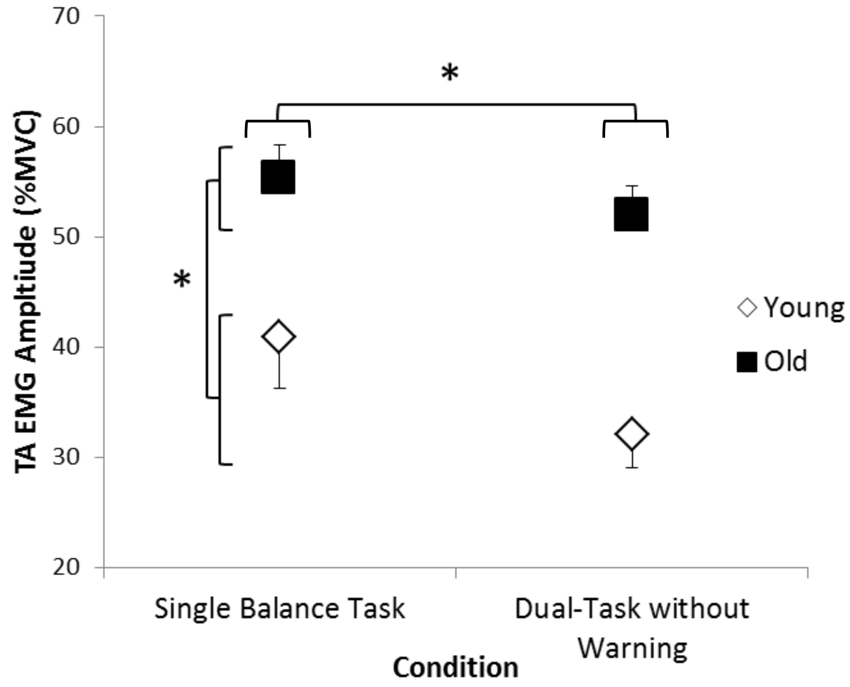
4.3.3 EMG Amplitudes

To assess for any changes in preparatory muscle activity between the single balance task and the dual-task without warning conditions, the background TA and MG EMG activity during the 300 ms interval prior to perturbation onset was measured. During this interval, the TA EMG amplitude was influenced by an age main effect ($F_{1,29}$=12.32; p=0.001), with older adults demonstrating larger EMG activity than the young adults (7.2±0.8 and 3.2±0.4 %MVC, respectively). The background MG EMG activity was influenced by a condition ($F_{1,29}$=5.63; p=0.025) and an age main effect ($F_{1,29}$=16.35; p<0.001). The condition main effect arose because there was a smaller MG EMG amplitude generated during the dual-task without warning compared to the single balance task condition (9.2±0.8 %MVC and 10.6±0.9 %MVC, respectively). The age main effect was due to older adults (12.3±0.8 %MVC) generating a greater MG preparatory muscle response in comparison to the young adults (7.3±0.5 %MVC).

The effect of dual-tasking on the balance recovery response was examined in the TA and MG during the 300 ms interval following muscle onset. For the TA, the EMG amplitude was influenced by a condition ($F_{1,29}$=12.67; p=0.001) and an age main effect ($F_{1,29}$=15.24; p=0.001). Across all participants, dual-tasking resulted in a 12 % decrease in TA EMG activity compared to the single balance task. Further, regardless of the experimental condition, older adults (53.6±2.0 %MVC) generated a larger TA response amplitude compared to the young adults (36.5±2.8 %MVC).

Similar to the TA, the MG EMG amplitude was influenced by a condition ($F_{1,29}$=9.22; p=0.005) and an age main effect ($F_{1,29}$=7.46; p=0.011). There was an 8 %

decrease in MG EMG activity following the perturbation during the dual-task without warning compared to the single balance task condition. The age main effect occurred because older adults (81.8±4.6 %MVC) generated larger MG EMG responses than the young adults (61.8±2.6 %MVC) (Figure 9).



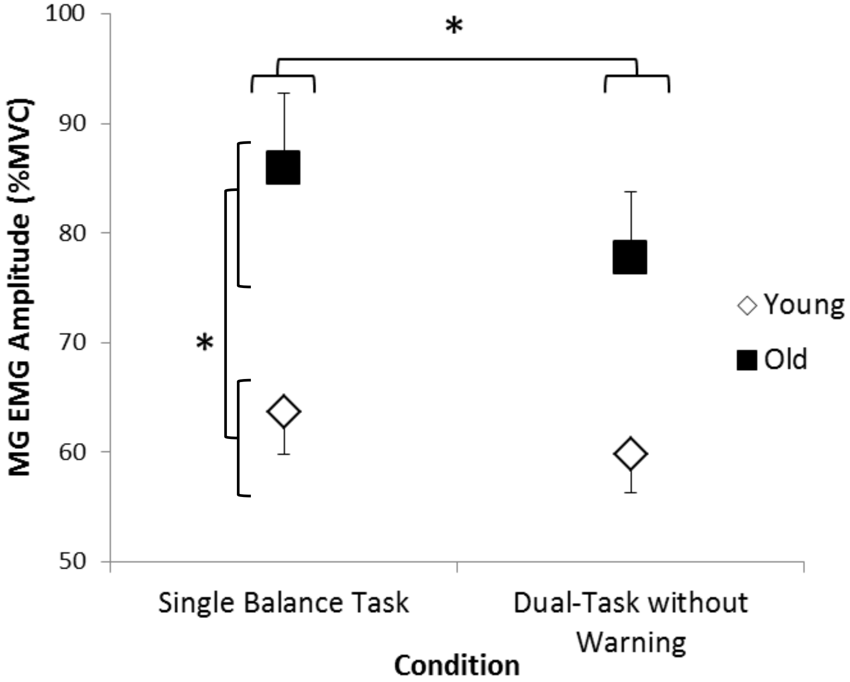


Figure 9: Mean TA (top) and MG (bottom) EMG amplitudes during the 300 ms following muscle onset. Error bars represent one SE. Data are from the young (open diamonds) and older (filled squares) adults during the single and dual-task without warning trials. For both muscles, smaller EMG amplitudes were observed during the dual-task without warning compared to the single balance task condition. Further, regardless of the experimental condition, older adults activated the TA and MG to a greater extent than the young adults.

4.4 The Effect of Perturbation Warning on Dual-Task Performance

The following analyses examined whether providing a warning of an upcoming perturbation facilitates quicker attention switching to balance recovery following the perturbation. Changes in attention switching were assessed through deviation onsets and durations on the tracking task (McIlroy et al., 1999; Maki et al., 2001; Norrie et al., 2002). Balance preparation responses were assessed by quantifying EMG amplitudes prior to the perturbation and balance recovery responses were examined through the number of steps needed to recover balance as well as TA and MG EMG onset latencies and amplitudes following the perturbation. These analyses compared the tracking and balance task measures between the dual-task with and without warning trials.

4.4.1 Tracking Data

The time of tracking deviation onset, relative to perturbation onset, was not influenced by any significant interaction or main effects. Both young and older adults switched their attention towards the balance task at a similar time regardless of whether the warning was absent (young: 371±12 ms vs. older: 375±14 ms) or present (young: 364±12 ms vs. older: 363±12 ms).

Following the initial tracking deviation, participants returned their attention from recovering balance back to the tracking task. This was reflected by the tracking deviation duration, which was influenced by a condition main effect ($F_{1,24}$=10.71; p=0.003). There was an average of 0.2 s shorter deviation duration during the dual-task without compared to with warning (1.1±0.1 s and 1.3±0.1 s, respectively) trials, indicating that the presence of the perturbation warning did not facilitate an earlier attention switch back to the tracking task.

4.4.2 Steps to Recover Balance

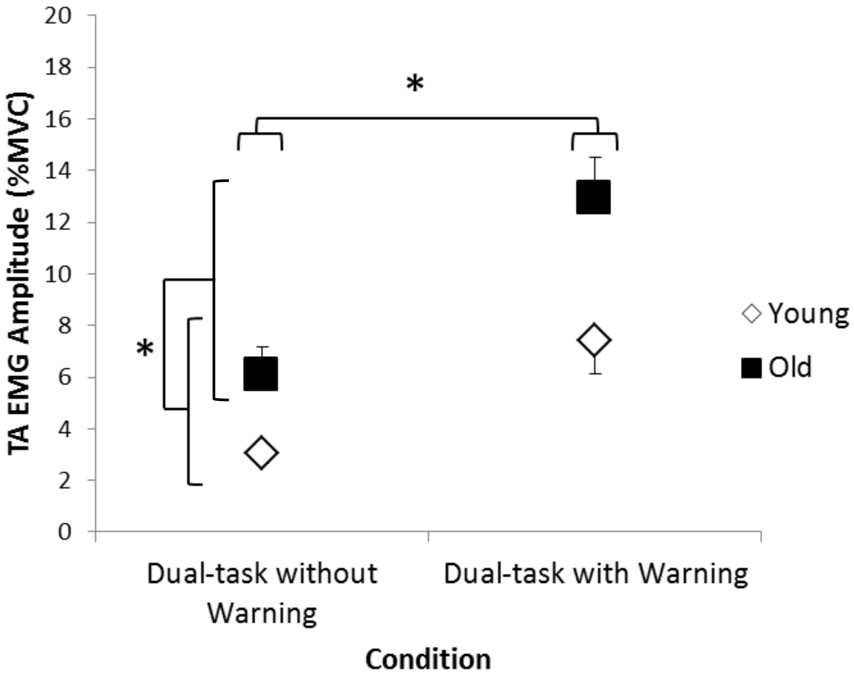
The number of steps needed to recover balance between the dual-task with and without warning conditions trended towards a condition main effect ($F_{1,29}$=-3.81; p=0.061). Both younger and older adults tended to require fewer steps to recover their balance when perturbation warning was present (1.0±0.1 steps per trial) compared to absent (1.1±0.1 steps per trial).

4.4.3 EMG Onset Latencies

Providing warning of an upcoming perturbation did not aid participants in initiating earlier EMG activity following a loss of balance. However, a trend towards an age main effect ($F_{1,29}$=3.93; p=0.057) was found for the TA onset latencies, with young adults (140±3 ms) activating the TA earlier than the older adults (151±3 ms) following perturbation onset. Similarly, the MG EMG onset latency was influenced by an age main effect ($F_{1,29}$=9.35; p=0.005), with young adults demonstrating earlier EMG onset latencies compared to the older adults (114±1 ms and 122±2 ms, respectively) across both dual-task conditions.

4.4.4 EMG Amplitudes

To assess the effect of the auditory warning on the balance preparation response, the TA and MG EMG amplitudes were measured during the 300 ms interval 1 s from the warning onset. This time was before perturbation onset. During this interval, the TA EMG amplitude was influenced by a condition ($F_{1,29}$=56.14; p<0.001) and an age main effect ($F_{1,29}$=7.89; p=0.009). When warning was provided, there was a 124 % increase in TA amplitude compared to when no warning was given. The age main effect arose because regardless of the absence or presence of the warning, older adults generated an 83 % greater TA preparatory response in comparison to the young adults (Figure 10). Analyses of the MG EMG amplitude revealed an age x condition interaction effect ($F_{1,29}$=9.21; p=0.005). Post-hoc analysis revealed that older adults generated a greater preparatory response than young adults when perturbation warning was present ($t_{21.02}$=-4.12; p<0.001) and absent (t_{29}=-3.19; p=0.003). However, there was a greater difference in EMG amplitude between young and older adults when a warning was present (mean difference of 8.5 %) compared to when it was absent (mean difference of 4.7 %). This increase in difference between young and older adults occurred because young adults demonstrated no difference in MG amplitude regardless of whether warning was present or not (t_{14}=0.81; p=0.432), whereas older adults increased their MG amplitude when warning was presented compared to absent (t_{15}=-3.07; p=0.008) (Figure 10).



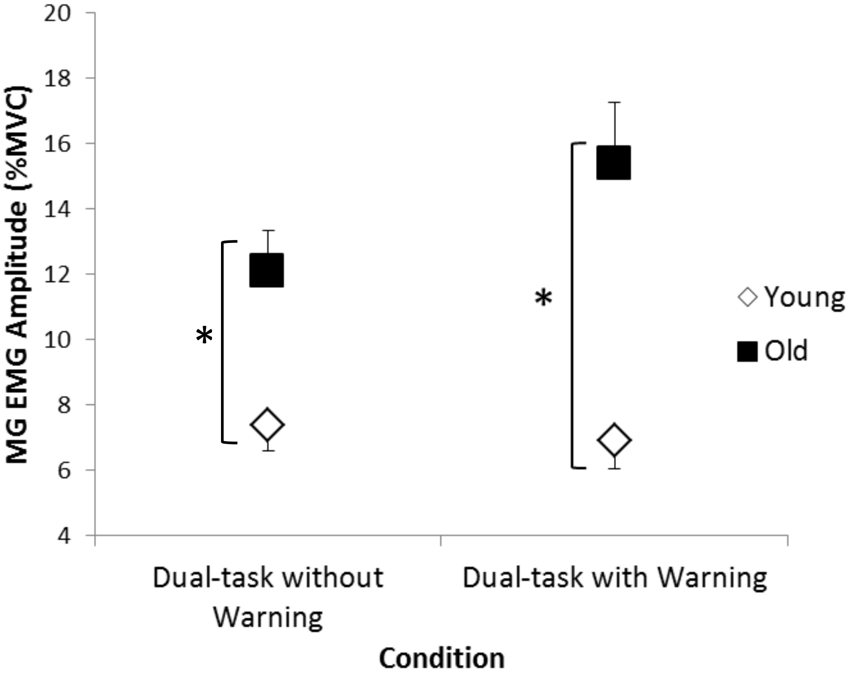
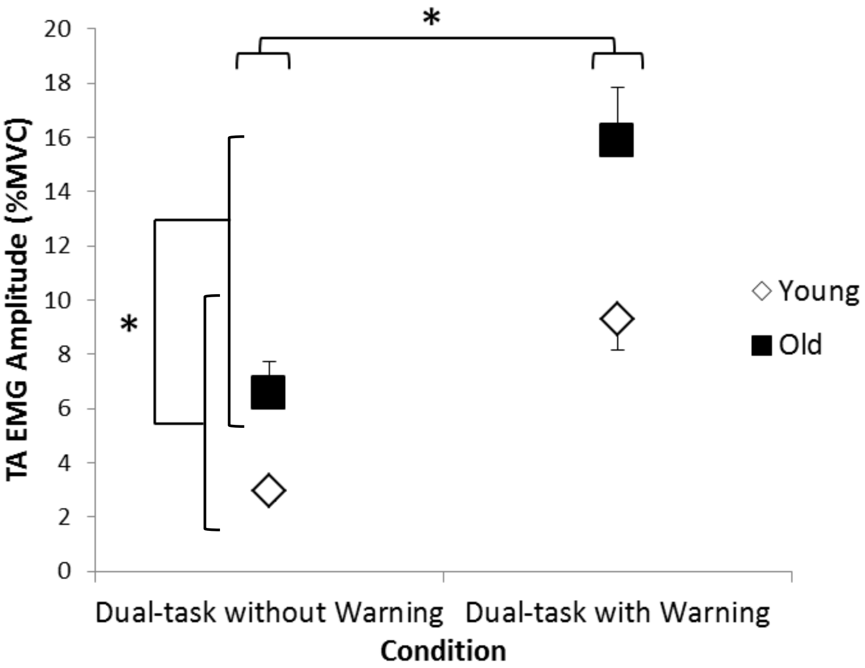


Figure 10: Mean TA (top) and MG (bottom) EMG amplitudes following the warning onset during the dual-task with and without warning conditions. Error bars represent one SE. Larger TA EMG amplitudes were observed when the warning was provided compared to when no warning was given. Regardless of the warning condition, older adults (filled squares) demonstrated larger TA and MG activity than young adults (open diamonds).

The effect of warning on the balance preparatory response was also examined by comparing the TA and MG EMG amplitudes just prior to perturbation onset (i.e., 2 s after the warning was presented). A condition ($F_{1,29}$=85.97; p<0.001) and an age main effect ($F_{1,29}$=9.02; p=0.005) were observed in the TA EMG amplitude. More specifically, participants exhibited a 165 % increase in TA muscle activity during the dual-task with compared to the without warning condition. Across both dual-task conditions, older adults (11.2±1.4 %MVC) also generated a greater TA preparatory response compared to the young adults (6.1±0.8 %MVC). For the MG EMG amplitude, an age x condition interaction was observed ($F_{1,29}$=28.32; p<0.001). Post-hoc analysis revealed that older adults showed greater MG activity than the young adults during both the dual-task without warning (t_{29}=-3.32; p=0.002) and with warning conditions ($t_{18.18}$=-5.53; p<0.001). However, greater age differences were observed when warning was present (mean difference of 9.9 %) compared to absent (mean difference of 4.5 %). This was a result of young adults demonstrating less MG amplitude with compared to without warning (t_{14}=2.89; p=0.012), whereas older adults increased their MG amplitude when warning was presented compared to when it was absent (t_{15}=-4.57; p<0.001) (Figure 11).



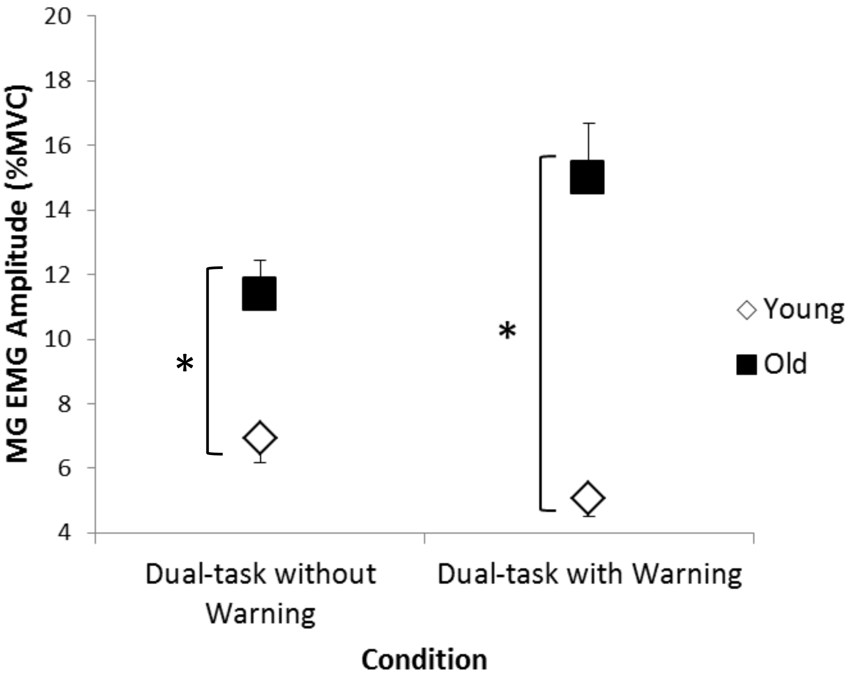


Figure 11: Mean TA (top) and MG (bottom) preparatory EMG amplitudes immediately prior to the perturbation onset for the young (open diamonds) and older adults (filled squares) during the dual-task with and without warning conditions. Error bars represent one SE. Larger TA EMG amplitudes were observed when warning was provided in both young and older adults. Older adults also activated the TA and MG to a greater extent during both dual-task conditions.

The effect of warning on the balance recovery response was examined by quantifying the TA and MG EMG amplitudes in response to a loss of balance during the 300 ms interval following muscle onset. The TA EMG amplitude was influenced by an age main effect ($F_{1,29}=18.59$; $p<0.001$), with greater EMG activity observed in the older (53.3±3.0 %MVC) compared to the young adults (32.7±2.4 %MVC) for both dual-task conditions. For the MG, the EMG amplitude was influenced by an age x condition interaction effect ($F_{1,29}=7.10$; $p=0.012$). During balance recovery, older adults generated a greater MG response compared to the young adults during both the dual-task without ($t_{29}=-2.49$; $p=0.019$) and with warning ($t_{29}=-3.68$; $p=0.001$) condition. However, there was a greater age-related difference in the amount of MG activity during balance recovery in the trials with warning (mean difference of 25.8 %) compared to without warning (mean difference of 17.9 %). This arose because young adults demonstrated a decreased MG amplitude when warning was present compared to absent ($t_{14}=2.32$; $p=0.036$), whereas older adults showed no change in MG amplitude with or without the warning ($t_{15}=-1.32$; $p=0.207$) (Figure 12).

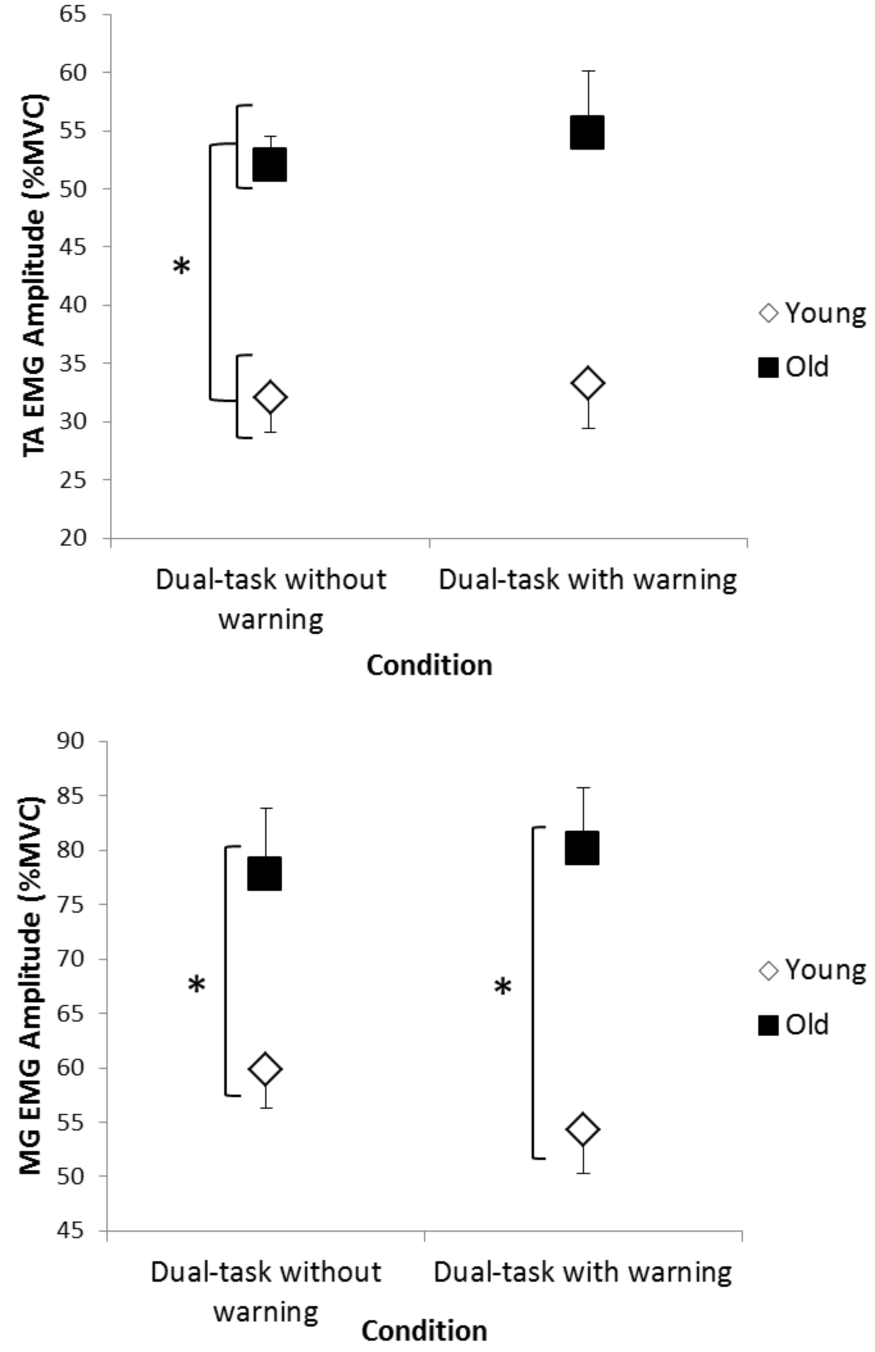


Figure 12: Mean TA (top) and MG (bottom) EMG recovery response amplitudes following muscle onset for the young (open diamonds) and older adults (filled squares) during the dual-task with and without warning conditions. Error bars represent one SE. Larger TA EMG amplitudes were observed in older adults in both dual-task conditions. No change in MG EMG amplitude was observed in older adults between the two warning conditions.

5.0 Discussion

Previous research has suggested that some falls experienced by older adults may be due to the inability to effectively shift attention to maintaining balance during dual-task performance (Brown et al., 1999; Shumway-Cook & Woollacott, 2000). To better facilitate attention switching and reduce processing delays between balance recovery and cognitive task performance, researchers have begun to examine the benefits of providing advanced warning of an upcoming balance disturbance (Müller et al., 2004). The purpose of this thesis was to examine whether there is an age-related difference in the ability to switch attention from a continuous cognitive task to maintaining balance when warned of an upcoming balance disturbance. Contrary to the hypotheses, it was found that the perturbation warning did not help participants shift their attention any faster during dual-task performance. However, the warning enabled both young and older participants to better prepare for an upcoming perturbation. This resulted in a reduction in the magnitude of the balance response in the young but not older adults.

5.1 The Effects of Dual-Tasking on Balance Task Performance

The effect of dual-tasking on balance recovery was examined in young and older adults by comparing muscle onset latencies, amplitudes and number of steps taken between the single balance task and the dual-task without warning condition. Requiring participants to perform two concurrent tasks had the desired effect of challenging the availability of attentional resources for balance control. This was evidenced by changes in EMG amplitudes. With the addition of the tracking task, participants activated less MG activity prior to the upcoming perturbation. Since the two tasks compete for the same pool of attentional resources, it is likely that less attentional resources were dedicated towards standing and consequently, there was a reduction in balance control (i.e., less muscle activity during standing) (Melzer, Benjuya & Kaplanski, 2001; Kang & Lipitz, 2010).

Dual-tasking also resulted in participants activating less TA and MG EMG activity following the perturbation. This result supports findings from previous dual-task studies (Maki & McIlroy, 2007; Woollacott & Shumway-Cook, 2002) and further supports the notion that recovering one's balance from a surface translation requires attentional resources (Maki et al., 2001; McIlroy et al., 1999; Norrie et al., 2002; Rankin et al., 2000). Specifically, the reduction in muscle response amplitude in the dual-task without warning compared to the single balance task conditon may have arisen due to a limited capacity of attentional resources available to share between the two tasks as stated in the capacity theory (Rankin et al., 2000; Young & Stanton, 2010).

In contrast to the EMG amplitudes being altered with the introduction of the tracking task, there were no differences in the EMG onset latencies between the single balance task and dual-task without warning condition. This indicates that increasing attentional load does not influence how quickly a muscle can be activated following a loss of balance. This may be due to the earliest phase of the balance response being an automatic response, unaffected by the presence of a concurrent task (Brauer et al., 2001; Rankin et al., 2000; Redfern et al., 2002; Norrie et al., 2002). The initial muscle response is believed to be elicited through stretch reflex pathways (Taube et al., 2006) and thus, processing of information at the spinal level should not be dependent on attentional load.

Not all data pointed toward a task interference effect during dual-tasking. For example, a reduction in the number of steps needed to recover balance was observed during the dual-task without warning compared to the single balance task condition. This result would suggest that participants were more stable when performing the two concurrent tasks. Since responses to unexpected perturbations become smaller and more efficient during the later compared to the initial trials of the same perturbation due to practice and habituation (Horak, 1996), it is possible that the reduction in the number of steps needed to recover balance in the dual-task condition was simply the result of participants always performing the single balance task condition first. However, it is important to acknowledge that the difference in the number of steps needed to recover balance between the single balance and the dual-task without warning condition was only 0.3 steps per trial. Thus, although this result was statistically different between the two experimental conditions, it is difficult to attribute this finding to specific functional or mechanistic effects of dual-tasking.

5.2 The Effects of Perturbation Warning On Dual-Task Performance

Few researchers have examined how to facilitate quicker attention switching, particularly for balance control, in older adults. Studies examining the effects of a perturbation warning have relied on discrete tasks as their cognitive task (Müller et al., 2004), but this makes it difficult to assess the time course of attentional shifts from the cognitive task to balance recovery. Therefore, to address this limitation, a continuous tracking task was used so that the time and duration of the initial attention switching could be more accurately determined.

Young and older adults did not demonstrate earlier tracking deviation onset times and thus, did not switch their attention to balance recovery (McIlroy et al., 1999; Maki et al., 2001; Norrie et al., 2002) any earlier when warning was provided. Further, the tracking deviation duration, an indicator of how long attention was dedicated towards balance recovery (Maki et al., 2001; McIlroy et al., 1999; Norrie et al., 2002), increased by 19% when the perturbation warning was given compared to when it was not given. Both results were unexpected because providing a perturbation warning has been shown to reduce the task interference caused by delays in processing of balance control information and increase the balance preparation response (Müller et al., 2004).

Perturbation warning was intended to allow for a quicker attention switching between the two tasks. By generating a balance response prior to the perturbation, participants should have been able to minimize the balance response selection phase following the loss of balance and therefore, reduce the amount of interference with the tracking task (Pashler, 1994). However, the lack of change in tracking task performance suggests that the perturbation magnitude was too large for the study participants. Thus, they may have been required to select and generate an unexpected step to successfully recover their balance. As a result, the response selection interference may still have been present following the perturbation.

The perturbation warning was intended to facilitate changes in central set by allowing individuals to prepare for and modify their postural response by taking into account prior knowledge and past experiences of the perturbation (Horak et al., 1989). However, few changes in balance recovery, as assessed by EMG onset latencies, EMG amplitudes and number of steps, were found between the dual-task with and without warning conditions. Although the lack of change in EMG onset latencies contrasts with previous work observing earlier onset latencies when a warning is provided (De Lima et al., 2010; McChesney et al., 1996), it supports the work of others, who found no change in muscle onset when a warning is present (Adkin et al., 2006; Diener er at., 1991; Jacobs et al., 2008) due to the automaticity of the initial muscle response (Brauer et al., 2001; Melzer et al., 2001; Rankin et al., 2000; Redfern et al., 2002; Norrie et al., 2002; Taube et al., 2006). Most surprising however was the lack of change in balance recovery-related EMG amplitude in older adults and the small decrease seen in the young adults' EMG amplitude when the warning was provided. This may have occurred because there was no change in attentional load placed on the participants (Rankin et al., 2000) following the perturbation onset compared to the dual-task without warning trials. If this were the case, this may also explain why the number of steps needed to recover balance was also unaltered between the two dual-task conditions.

It is not clear why the current results, particularly with regards to tracking task performance and EMG amplitudes, oppose previous findings. It is possible that the perturbation warning used in this study primarily facilitated attention switching after the auditory warning but prior to the perturbation onset (i.e., the balance preparation response). Specifically, participants may have prepared for and prioritized the upcoming loss of balance by placing a greater amount of attention on balance recovery (Müller et al., 2007). To a certain extent, this was evidenced by an increased TA EMG activity prior to the perturbation. This increase in postural preparation supports the measured tracking task performance, where there were tracking deviations present during the interval between the auditory warning and perturbation onset, indicating a switch of attentional resources over to preparing for the upcoming balance perturbation. Thus, future studies should focus on how a perturbation warning influences attention shifting and alters balance preparation strategies prior to an upcoming loss of balance.

5.3 Age-Related Differences in Dual-Task Performance

Compared to the young adults, older adults demonstrated delayed EMG TA and MG onset latencies, greater EMG amplitudes during both the single balance task and the dual-task without warning conditions. The inability of older adults to activate the initial muscle response as early as young adults supports previous findings (Maki et al., 2001; Rankin et al., 2000) and may be explained by various normal age-related neuromuscular deteriorations such as a decline in the number, speed and synaptic connection effectiveness of nerve cells (Rankin et al., 2000; Trew, 2001). However, the greater EMG amplitudes observed in older adults was unexpected because older adults experience deficient muscle recruitment resulting in a greater reliance of the stepping strategy for balance recovery (Rankin et al., 2000). The greater muscle response amplitude utilized by the older adults in this study may have been the result of trying to compensate for their delayed ability to allocate attentional resources to recovering balance and generating a stabilizing response (Maki et al., 2001; Rankin et al., 2000). Generating a greater muscle response amplitude would have helped older adults better decelerate the COM while attempting to recover balance without taking a step and avoid a fall.

Age similarly affected EMG onset latencies and EMG amplitudes between the single balance task and the dual-task without warning condition. Due to the lack of age x condition interaction effects, it can be concluded the older adults did not perform any worse when they were distracted with a concurrent task. This contrasts with previous work suggesting that older adults require a greater amount of attentional resources in order to maintain balance (Lajoie et al., 1996; Maki et al., 2001; Redfern et al., 2002) and consequently, delayed attention switching to balance recovery (Maki & McIlroy, 2007; Maki & McIlroy, 2005; Woollacott & Shumway-Cook, 2002). The lack of an interaction effect from the single balance to the dual-task without warning condition is particularly surprising given that the older adults of this study exhibited longer walking durations in the WART and TUG dual-task functional assessments. One possible reason for the similar effects seen in the dual-task without warning condition between the young and older adults could be that the community-dwelling older adult participants were quite healthy, demonstrating high levels of balance confidence, high mobility and little or no fall history. It would be of interest to conduct a similar study on older adults who are at a greater risk of falls. Older adults with balance impairments require an even greater amount of attentional resources to recover balance compared to healthy older adults as evidenced by decrements in balance control while performing a concurrent cognitive task (Brauer et al., 2001).

Despite the lack of dual-task effects between young and older adults, there were some differences in dual-task performance when a perturbation warning was provided. For example, older adults increased their preparatory TA and MG EMG amplitudes, whereas the young adults increased their TA amplitude and demonstrated either a decrease or no change in MG amplitude. This suggests that older adults rely on a stiffening, co-contraction stabilizing strategy in preparation of an upcoming perturbation (Kang & Lipitz, 2010; Melzer et al., 2001; Mixco, Reynolds, Tracy & Reiser II, 2011). However, despite older adults demonstrating greater preparatory EMG amplitude when a perturbation warning was given, this did not lead to any changes in their balance-recovery EMG amplitude.

5.4 Conclusion

Based on the study's findings**,** it is concluded that perturbation warning does not facilitate earlier attention switching following a perturbation in young and older adults. The lack of improvement in attention switching following the perturbation onset suggests the presence of a bottleneck during the response selection phase, causing a brief interference between tracking and balance. Although the warning enabled participants to increase their preparatory muscle activity prior to the perturbation, the warning had minimal and no benefits for balance recovery for the young and older adults, respectively. Therefore, future studies should focus on how to optimize perturbation warning so that attention shifting and balance preparation strategies are more effective in improving the balance recovery response.

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