The impact of auditory and visual cognitive tasks on postural control in young adults

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ABSTRACT

The purpose of the present thesis was two-fold. First, to evaluate the impact of cognitive demand on postural control in young adults and second, to examine the responsiveness of postural control to cognitive tasks presented in varying modalities. Seventeen young adults stood on a force platform while simultaneously performing cognitive tasks of varying difficulty (easy, moderate and difficult), each presented auditorily and visually. Performing the moderate and difficult tasks precipitated a greater reduction in area of 95% confidence ellipse and medio-lateral (ML) sway variability compared to the easy tasks. Presenting the tasks visually produced lower ML sway variability than presenting the tasks auditorily. Of secondary interest of this thesis was to determine if the duration of inter-stimulus intervals could modify the effectiveness of a cognitive task on postural control. Participants stood on a force platform while simultaneously performing cognitive tasks with five-second inter-stimulus intervals (i.e. discrete) and two-second inter-stimulus intervals (i.e. continuous), each presented auditorily and visually. Results revealed higher anterior-posterior (AP) mean power frequency (MPF) when performing the continuous tasks. In addition, presented the tasks visually resulted in a greater reduction in area of 95% confidence ellipse, AP and ML sway variability.

Key words: postural control, cognitive demand, sensory modality, dual-task

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CHAPTER 1: REVIEW OF LITERATURE

1.1. Postural control:

Postural control is a complex process that integrates sensory inputs from the somatosensory, vestibular and visual systems, along with higher-level systems, to maintain the body's position in space for the purpose of orientation and balance (Horak, 2006; Winter, 1995). Postural orientation is the active control of the body's alignment with respect to gravity, support surface, visual environment and internal references (Horak, 2006). Postural balance involves the coordination of sensorimotor strategies to stabilize the center of mass (COM) over the base of support during periods of instability, either self-initiated or externally provoked.

Postural control has been modeled as an inverted pendulum (Gage, Winter, Frank & Adkin, 2004, Winter 1995; Winter, Prince, Frank, Powell & Zabjek, 1996; Winter, Patla, Prince, Ishac & Gielo-Perczak, 1998) suggesting that the body behaves as a rigid structure that rotates about the ankles (Gage et al., 2004; Massion, 1998). The model predicts that the difference between center of pressure (COP) (i.e. controlling variable) and COM (i.e. controlled variable) is proportional to the horizontal acceleration of the COM in both the sagittal and frontal planes (Gage et al., 2004; Winter et al., 1998). Essentially, if the COP is ahead of the COM, then the COM is being accelerated backwards and vise versa (Winter, 1995; Winter et al., 1998). Similarly, if the COP is to the right of the COM, then the COM is being accelerated to the left and vise versa. The oscillation of the COP on either side of the COM ensures that the COM remains within the base of support and a stable body position is maintained (Horak, 2006; Winter et al., 2003). Otherwise, if the COM exceeds the bounds of the base of support, an adjustment to the movement strategy is required to prevent destabilization. Moreover, the movement of COP in both sagittal and frontal planes was previous suggested to be exclusively controlled by ankle musculature (Winter, 1995). However, studies have demonstrated that sagittal plane COP movement is controlled using plantarflexor/dorsiflexor ankle musculature, while frontal plane COP movement is controlled using hip abductor and adductor musculature, produced by a load/unload mechanism between the lower limbs (Gage et al., 2004; Winter et al., 1998). The ankle strategy is most appropriate for small amounts of postural sway such as when standing on a firm surface (Horak, 2006). While the hip strategy is favoured when standing on narrow or compliant surfaces, situations when the COM is at the extremes of the base of support (Karlsson and Lanshammar, 1997).

Postural control strategies may either be compensatory (i.e. reactive) or anticipatory (i.e. predictive), or a combination of both (Pollock, Durward, Rowe, & Paul, 2000). A compensatory postural adjustment involves a movement response following an unpredictable perturbation while an anticipatory postural adjustment compensates for destabilization associated with the movement of a limb in a feedforward manner (Aruin, Forrest, & Latash, 1998). Moreover, the magnitude and timing of postural adjustment is paramount and highly dependent on the physical parameters of the movement and the behaviour context in which the movement is executed (Adkin, Frank, Carpenter, & Peysar, 2002; Massion, 1994).

1.2. Working memory

Baddeley and Hitch (1974) proposed a multi-component model of working memory that functions to temporarily store and manipulate information for the execution of a wide variety of complex cognitive tasks. As Fig. 1 demonstrates, the model is comprised of a control system with a limited attentional capacity, termed the central executive, which is aided by two subsidiary systems: the phonological loop and the visuospatial sketchpad (Baddeley, 2003a).

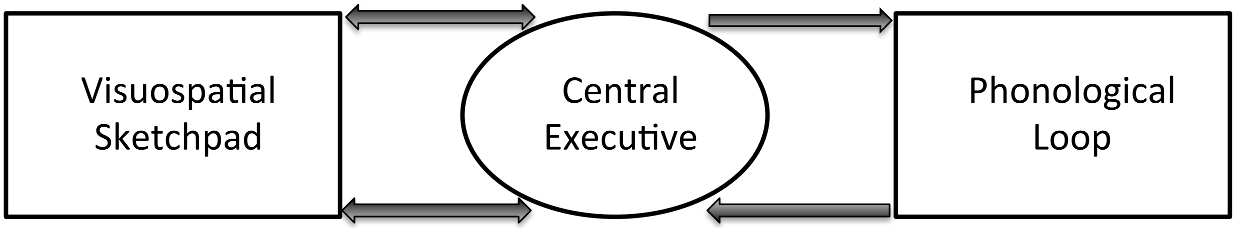

Fig. 1 The three-component model of working memory proposed by Baddeley and Hitch (1974).

The phonological loop is responsible for the storage and maintenance of acoustic and verbal information, while the visuospatial sketchpad is responsible for the storage and maintenance of visual and spatial information (Baddeley, 2002; Repovs & Baddeley, 2003).

1.2.1. The phonological loop

The phonological loop is comprised of two components, a phonological store, which maintains memory traces in acoustic or phonological form, and an articulatory rehearsal process, which is analogous to subvocalization (Repovs & Baddeley, 2003). The articulatory rehearsal process retrieves and re-articulates information held in the phonological store to prevent the memory traces from fading. Since articulation operates in real time, the phonological store capacity is limited to the number of items that can be articulated before the primary memory trace fades (Baddeley, 2003b; Repovs & Baddeley, 2003). Additionally, while speech input enters the phonological store directly, input from other modalities must be recoded into phonological form by articulatory rehearsal before entering the phonological store (Repovs &

Baddeley, 2003). Therefore, retention is contingent on an individual's acoustic or phonological characteristics (Baddeley, 2003a). Moreover, research has shown that similarity of sound affects the number of items recalled, whereas similarity of meaning has little to no effect (Baddeley, 1966). For instance, letters that sounded fairly different (e.g., F, K, Y, W, M, R) were more readily recalled than a sequence of similar sounding letters (e.g., B, V, G, T, C, D) (Conrad & Hull, 1964).

1.2.2. The visuospatial sketchpad

While the phonological loop is responsible for maintaining verbal information, the visuospatial sketchpad is concerned with maintaining and manipulating visual and spatial information (Repovs & Baddeley, 2003). According to empirical evidence, visual and spatial information are said to be distinct subcomponents of non-verbal working memory (Della Sala, Gray, Baddeley, Allamono, & Wilson, 1999; Logie, Zucco, & Baddeley, 1990). Della Sala et al. (1999) implemented the Corsi Blocking Tapping and Pattern Span tasks to assess spatial and visual short-term memory, respectively. The Corsi Block task involves reproducing a sequence of tapping movements of small blocks of wood fixed to a board at varying distances. Sequence length progressively increases until the participants can no longer replicate the correct order. In the Pattern Span task, participants are briefly presented with a partial filled matrix. The participants are then required to reproduce the pattern of filled squares by marking squares in a blank matrix of identical dimensions. The size of the matrix progressively increases until the participants can no longer replicate the correct pattern. Della Sala et al. (1999) found spatial interference (i.e. follow the sequence of blocks haptically, without looking at the board) to only disrupt the performance of the Corsi Block task and visual interference (i.e. keep the abstract painting in view, but try to ignore it as much as possible) to only disrupt the performance of the Pattern Span task. Della Sala et al. (1999) concluded that the visuospatial sketchpad is not a unitary system, but rather a structure with several subsystems.

Similarly, Logie (1995) proposed a fractionation of the visuospatial sketchpad analogous to the phonological loop. The components consist of a visual store component, termed the visual cache, tasked with retaining basic features (e.g., colour, shape, orientation) and a dynamic retrieval and rehearsal process, termed the inner scribe. Similar to the phonological loop, the rehearsal process refreshes the contents and reduces decay. The inner scribe is also responsible for maintaining spatial and movement related information.

1.2.3. Central executive

Initially, the central executive was envisioned as a pool of general processing resources with a limited capacity (Baddeley, 2003a). However after a decade, the model of attentional control proposed by Norman and Shallice (1986), was adopted to serve as a basis for better conceptualizing the central executive. According to the model, control is divided between two processes (Baddeley, 2003a). The first process involves the control of behaviour by habit patterns or schemas that are guided by cues from the environment. The second process involves an attentionally limited controller, termed the Supervisory Activating System (SAS), which intervenes when routine control is insufficient. Relying heavily on the SAS, four basic processes of the central executive were postulated: the ability to focus, divide and switch attention, and the ability to associate contents of working memory to long-term memory (LTM) (Baddeley, 1996a). Each process was investigated and a brief summary of the literature follows.

The ability to focus attention was examined using a random digit generation task, which is suggested to place strain on the central executive (Repovs & Baddeley, 2003; Robbins et al., 1996). Robbins et al. (1999) investigated the role of working memory in the performance of chess. In Experiment 1, participants were briefly presented chess pieces in various positions and were instructed to recall their position, following the execution of distractor tasks, each designed to affect a component of working memory. Suppression of the articulatory loop (i.e. repeating the word "the") resulted in no deficits in recall, whereas blocking the visuospatial sketchpad (i.e. manipulation of a keypad) and central executive (i.e. random letter generation) significantly disrupted recall. Robbins et al. (1999) concluded that impeding the central executive with an irrelevant task, such as random letter generation, significantly affects the analysis of chess positions, consequently impairing performance.

Baddeley, Bressi, Della Sala, Logie, & Spinnler (1991) assessed the ability to dual-task in Alzheimer's patients, who Baddeley believed suffered from central executive impairment due to their long-term memory and attentional deficits (Repovs & Baddeley, 2003). Participants were instructed to perform a tracking task, while repeatedly counting from one to five. The tracking task targeted the visuospatial sketchpad, while the counting task targeted the articulatory loop. Dual-task performance was significantly impaired compared to single-task performance. Baddeley et al. (1991) concluded that the interference was a result of the central executive, providing support for its role in the dividing of attention.

In a series of experiments, Baddeley, Chincotta and Adlam (2001) examined the ability to switch attention as a central executive process. Participants were instructed to perform an arithmetic-switching task under dual-task conditions employing various articulatory loop suppressions and central executive tasks. The arithmetic-switching task consisted of 40 operations requiring “1” to be either added or subtracted from single digits. The blocked condition involved performing the same operation, whereas the alternating condition involved switching between addition and subtraction. Tasks targeting the central executive (e.g. verbal trail and random letter generation) increased the cost of switching, while simultaneously impairing performance in the blocked conditions. Interestingly, the articulatory loop suppression task in Experiment 2 and 3, significantly increased completion time in the switching condition, while no effect was observed in the blocked conditions. Baddeley et al. (2001) concluded that attention switching requires the use of multiple processes rather than a single executive process, as initially proposed.

The ability to relate the contents of working memory to LTM, as proposed by Baddeley (1996b), subsequently led to the formation of a new component of working memory, termed the Episodic Buffer (Repovs & Baddely, 2003). The episodic buffer integrates information from the two subsidiary systems and LTM (Baddeley et al., 2001). It has a limited capacity and is episodic for its ability to hold coherent chunks of information in a multidimensional code. It is a buffer for its ability to provide an interface between a number of different codes (e.g., visual, verbal, perceptual) and LTM (Baddeley, 2007). Finally, it is assumed to rely heavily on the central executive and be accessible through conscious awareness (Baddeley et al., 2001; Baddeley, 2003b).

As demonstrated by the literature above, working memory is an essential part of the cognitive system by maintaining and manipulating information for the execution of a variety of complex activities (Repovs & Baddeley, 2003). It provides an interface between perception, attention, memory and action (Baddeley, 1996b). Moreover, since each component of working memory is distinct in terms of mechanisms and resource demand, its interaction with postural control may be different. Therefore, implementing working memory tasks into a postural dual-task paradigm may provide further information on how the processes involved in postural control and cognition are intertwined (Ramenzoni et al., 2007).

1.3. Dual-task paradigm:

Dual-task paradigms are employed to evaluate the role of attentional demand on motor control in healthy and special populations (Woollacott & Shumway-Cook, 2002). It is the process of comparing the performance of two tasks when executed simultaneously (e.g., walking and talking) (Remaud, Boyas, Lajoie, & Bilodeau, 2013). There are a number of assumptions that underlie the paradigm; they include: 1) the central information-processing capacity is limited, 2) executing a task demands a portion of said capacity, and 3) if two concurrent tasks exceed the total capacity, performance on one or both tasks will diminish (Kahneman, 1973; Lajoie, Teasdale, Bard & Fleury, 1996). Two theoretical frameworks, derived from cognitive psychology, have been suggested to elucidate differences in performance in a dual-task context: the capacity theory and the “bottleneck” theory (Fraizer & Mitra, 2008).

According to the capacity theory, dual-task interference is thought to arise from the sharing of a finite number of resources (Fraizer & Mitra, 2008). It stipulates that if the attentional demand of two concurrent tasks exceeds the processing capacity than performance on one or both tasks is expected to deteriorate (Kahneman, 1973; Reilly, Van Donkelaar, Saavedra & Woollacott, 2008; Remaud et al., 2013). Some theorists suggest that a single pool of resources (Kahneman, 1973) can account for the deterioration in performance, while others have argued for multiple pools of resources (Huang & Mercer, 2001; Pashler, 1994; Remaud et al., 2013). According to multi-resource theories, costs in dual-task performance should occur only if two tasks utilize the same resources (Guttentag, 1989; Huang & Mercer, 2001); in other words, if the two tasks compete for the same input or output processes (Weeks, Forget, Mouchnino, Gravel & Bourbonnais, 2003). This is what's commonly referred to as structural interference (Huang & Mercer, 2001; Kahneman, 1973). For example, Treisman and Davies (1972) simultaneously presented two lists of words and instructed participants to monitor the lists for the occurrence of the target words (i.e. words contained the letters "END" or the sound "end"). The lists were presented in either the same modality or different (i.e. visual and auditory). The results revealed that less target words were observed when the lists were presented in the same modality, suggesting that attention cannot be divided between two inputs when presented in the same modality.

An alternative perspective is that parallel processing may be difficult for certain cognitive tasks (Pashler, 1994) as they may simply require a single mechanism to be committed to them for a period of time (Pashler, 1994). Therefore, when two tasks performed concurrently require the same cognitive processing operation, a bottleneck arises, where each task can only be carried out sequentially (Granacher et al., 2011; Pashler, 1994). This framework refers to Broadbent's original filter theory, which emphasizes the serial nature of dual-tasking (Kahneman, 1973;

Fraizer & Mitra, 2008). As interference arises, the nervous system is suggested to temporarily delay performance of one task in favour of the prioritized task, resulting in performance decrements of the non-prioritized task (Fraizer & Mitra, 2008). However, it is important to emphasize that dual-task paradigms only provide limited means of discriminating between the capacity theory and the bottleneck theory.

1.4. Attentional demand of postural control

Initially, postural control was regarded as an automatic task with minimal attentional demand (Woollacott & Shumway-Cook, 2002). However, empirical evidence has shown that a considerable amount of information-processing resources are required for maintaining and recovering postural stability (Kerr, Condon & McDonald, 1985; Lajoie, Teasdale, Bard, & Fleury, 1993; Woollacott & Shumway-Cook, 2002).

Kerr et al. (1985) were the first to demonstrate that postural control and cognition are not independent functions in young adults. Twenty-four young adults stood blindfolded in a tandem Romberg position while simultaneously performing the spatial and non-spatial versions of the Brooks memory task. The spatial task involved placing numbers in imagined 4 x 4 matrices and remembering their position. The task relies on visual imagery and is susceptible to visual interference, which was proposed to occur as a result of the postural task necessitating similar visual/spatial processes. The non-spatial task involved recalling similar sentences. Maintaining the complex postural task was found to affect the recall scores for the spatial task but not for the non-spatial task. No significant difference in postural sway was observed between the two memory tasks. Kerr et al. (1985) concluded that the spatial task relies on the same information-processing resources that are necessary for the regulation of stability, suggesting that postural control is in fact attentionally demanding in young adults.

Lajoie et al. (1993) examined the interaction between postural task complexity and attentional demand in young adults. The experimental protocol required participants to perform four tasks: sitting, standing upright with a wide base of support, standing upright with a narrow base of support and walking, while concurrently responding "top" to an auditory stimulus. Reaction times (RT) were fastest for the sitting task, and progressively slowed for the standing and walking tasks, respectively. Lajoie et al. (1993) concluded that attentional demands increase with the complexity of the postural task. However, the limitation of this study was the use of a simple, relatively low cognitive demand task (Woollacott & Shumway-Cook, 2002). A task with greater cognitive demand might have elicited interference with the balance and gait tasks.

Remaud, Boyas, Caron, & Bilodeau (2012) investigated differences in attentional demand as a function of postural task complexity and vision. Twenty participants performed 12 combinations of three postural stances: feet together (FT), tandem (TD), and single leg (SL); two visual conditions: eyes open (EO) and eyes closed (EC); in the presence or absence of a RT task. RT decreased with the reduction in base of support but only in the absence of vision. Interestingly, the presence of vision resulted in no significant difference in reaction time, contrary to the findings of Lajoie et al. (1993). Remaud et al. (2012) concluded that vision could effectively negate the increase in attentional demand precipitated by the reduction of the base of support.

The aforementioned studies effectively demonstrate that postural control is attentionally demanding in young adults. However, these effects appear to be relatively small until the postural control system undergoes stress and participants are required to perform cognitive tasks with greater loads (Woollacott & Shumway-Cook, 2002). Therefore, it can be concluded that maintaining stability requires attentional resources and is modulated by postural complexity, age and sensory input.

1.5 Postural control and concomitant cognitive tasks

Although the relation between postural control and cognition is well documented in the literature, the results remain equivocal. Some researchers have observed postural stability to improve during the performance of a concomitant cognitive task (Huxhold, Li, Schmiedek, & Lindenberger, 2006; Riley, Baker, & Schmit, 2003; Swan, Otani, & Loubert, 2007), while others have found stability to attenuate (Pellecchia, 2003). The diverse data may be due, in part, to the features of the cognitive tasks employed.

1.5.1 Cognitive demand

A number of studies have manipulated task difficulty in an attempt to evaluate how cognitive demand modifies the relationship between cognition and postural control. However, the inconsistent findings have made it rather difficult to ascertain the exact impact of demand on postural control.

Pellecchia (2003) examined if postural sway varied with the difficulty of a concurrent cognitive task. Participants were instructed to stand on a compliant surface while performing a series of information reduction tasks of increasing demand (i.e., digit reversal, 2-bit classification and counting backwards by 3s, respectively). Sway path and AP sway variability was greatest in the counting backwards by 3s condition than all other cognitive conditions. Pellecchia (2003) concluded that from an action-oriented perspective, increasing cognitive demand might make integrating tasks into a combined action plan more difficult. However, standing on a compliant surface may have contributed to the increase in postural sway by augmenting the complexity of the postural task.

Riley et al. (2003) examined postural stability while performing a digit rehearsal task of varying difficulty. The difficulty of the cognitive task was tailored to participants' short-term memory capacity by measuring their maximum digit span. Three levels of difficulty were established. As opposed to Pellecchia (2003), postural sway was reduced when performing the difficult version of the digit rehearsal task. The effect was limited to anterior-postural sway variability, though a trend of decreasing sway across increasing cognitive demand was observed for medial-lateral sway variability. Riley et al. (2003) concluded that the results contradict the limited capacity theory, which suggests that in a dual-task context, if task demands exceed resource capacity, performance of one or both tasks deteriorates. In particular, the theory fails to account for the observed improvement in stability during dual-task conditions. However, quiet standing is relatively automatized in young adults that increasing the cognitive demand to one's maximum digit span may not have been enough to tax their resource capacity (Huxhold et al., 2006).

Huxhold et al. (2006) examined the impact of cognitive tasks with differing levels of demand on postural control. Participants were instructed to stand with feet shoulder-width apart, while concurrently performing an array of verbal-based cognitive tasks (i.e. digit choice reaction time, digit 2-back working memory and spatial 2-back working memory). Similar to Riley et al. (2003), postural stability progressively improved with increasing cognitive demand, as evidenced by a reduction in area. Huxhold et al. (2006) concluded that cognitive tasks improve stability by shifting attention away from monitoring a largely automatic skill, such as postural stability. The absence of a resource competition was also attributed to the young adults' relatively high attentional capacity.

Swan et al. (2007) investigated whether a decrease in postural sway is based on the demand of the cognitive task, the complexity of the postural task, or a combination of both. Participants were required to stand feet together (easy), stand feet together with a concurrent stimulus to the gastrocnemius muscle (moderate), and stand in a tandem position (difficult), while concurrently performing the easy and difficult Brooks' spatial and nonsense memory tasks. Performing the difficult version of the cognitive tasks resulted in a significant decrease in postural sway that was not observed with the easy version. The decrease in postural sway was not affected by the complexity of the postural task. Swan et al. (2007) concluded that the difficulty level of a cognitive task has a primary influence on stability in young adults. Similar to the conclusions drawn by Huxhold et al. (2006), Swan et al. (2007) also suggested that cognitive tasks could effectively withdraw attention from postural control, allowing the system to operate in an automatic mode.

Dault, Geurts, Mulder, and Duysens (2001a) examined to what extent postural control can be influenced by cognitive tasks of varying difficulty when balancing on different support-surface configurations. Participants were required to stand in three different configurations: shoulder-width stance, shoulder-width stance on seesaws, and tandem stance on seesaws, while concurrently performing three modified versions of the Stroop task. Contrary to the aforementioned studies, the cognitive tasks provoked no change in postural stability in the shoulder-width stance position. As opposed to Swan et al. (2007), increasing postural and cognitive complexity resulted in decreased stability in the frontal plane. Dault et al. (2001a) concluded that a shoulder-width stance requires minimal attention, whereas the observed instability in the complex postural conditions is a result of a capacity interference effect.

1.5.2. Cognitive tasks requiring articulation

Changes in the posture-cognition dynamic is generally attributed to dual-task interference between the postural and cognitive tasks (Yardley, Gardner, Leadbetter, & Lavie, 1999). However, musculature involved in the control of respiration is also involved in postural control. Therefore, postural control can be impaired by the need to coordinate respiration and articulation (Dault, Yardley, & Frank, 2003).

Yardley et al., (1999) examined whether the effect of a spoken mental arithmetic task (backward counting) on postural control is due to capacity interference, perturbation by articulation, or a combination of both. Participants completed four conditions of either low or high attentional demand, with and without articulation: repeat a number aloud (articulation); count backwards by multiples of seven aloud (articulation and attention); count backwards silently (attention) and no mental task (no articulation or attention). The conditions were performed on a stable and unstable surface. Counting backwards silently had no observable effect on postural sway, whereas repeating a number and counting aloud similarly increased postural sway. Additionally, no interaction between the effects of articulation and instability produced by the unstable surface were observed. Yardley et al. (1999) concluded that instability is a result of the perturbing effect of articulation, rather than the result of resource competition.

Similarly, Dault et al. (2003) examined the influence of articulation on postural control. Participants were required to maintain three postural stances: seated, standing on a stable surface and standing on an unstable surface, while concurrently performing a series of cognitive tasks. The cognitive tasks included no task, a silent task (listening to letters), a combination task (repeating a letter immediately after hearing it), an articulation task (repeating letters) and a motor task (opening and closing the jaw). Similar to the findings of Yardley et al. (1999), increased sway path and frequency was observed when the articulation and combination tasks were performed. Dault et al. (2003) concluded that the changes in sway path and frequency were probably the result of changes in respiration rate provoked by articulation, although respiration was never directly measured.

1.5.3 Spatial and non-spatial cognitive tasks

Kerr et al. (1985) argued that since visual information is necessary for postural control, maintaining a complex postural task would disrupt performance on a visual spatial task, since it involves the visual system as well. As hypothesized, the tandem Romberg position diminished recall scores for the spatial task but not for the non-spatial task. However, subsequent studies have demonstrated interference from both spatial and non-spatial cognitive tasks, leading to the conclusion that interference is more likely a result of competition for limited attentional resources (Shumway-cook, Woollacott, Kerns, & Baldwin, 1997; Maylor, Allison, & Wing, 2001; Woollacott & Vander Velde, 2008).

Shumway-Cook et al. (1997) examined the effects of a spatial and non-spatial cognitive task on postural control in young adults and older adults with and without a history of falls. Participants were required to stand on a firm and compliant foam surface, while concurrently performing a visual spatial line orientation task (JOLO) and a sentence completion task. As opposed to Kerr et al. (1985), greater interference was observed between the sentence completion task and standing on a compliant foam surface for all three participant groups. Shumway-Cook et al. (1997) concluded that the JOLO task might require stability for successful completion; therefore, to ensure accurate results, greater stability was maintained.

Maylor et al. (2001) examined the impact of the Brooks' spatial and non-spatial memory tasks on postural control. Participants were instructed to perform the two versions of the Brooks memory task in both a seated and standing position. The spatial task involved listening to a set of instructions for placing consecutive numbers in a 4 x 4 matrix. The instructions for the non-spatial task were similar to that of the spatial task, however, the words right, left, up, and down, were replaced with the words quick, slow, good and bad, respectively. Subsequently, participants were required to use the adjectives to fill a series of incomplete sentences. Sway variability and sway velocity was assessed during both the encoding and maintenance phases of the memory tasks. In comparison to the no task condition, stability was improved during the encoding phase of the spatial task but significantly reduced during the maintenance phase of the non-spatial task. Maylor et al. (2001) concluded that components of cognitive activity could be more disruptive than others on postural control.

Similarly, Swan, Otani, Loubert, Sheffert, and Dunbar (2004) examined the effect of the encoding phase of the Brooks' spatial and non-spatial memory task on postural control. Postural complexity was additionally manipulated by sway-referenced motion of the force platform and varying visual input. Postural sway was reduced however, contrary to Maylor et al. (2001) no significant difference was observed between the spatial and non-spatial memory tasks for the young adults. Swan et al. (2004) concluded that the balance task might not have been challenging enough to elicit an interference effect.

Woollacott & Vander Velde (2008) investigated the influence of modality and spatial coding resources on dual-task interference. Participants performed an auditory-spatial, an auditory-object and a visual-object n-back task at three levels of difficulty in two postural conditions (seated and tandem Romberg). The level of difficulty was manipulated by altering the number of load items needed to be contrasted with a subsequent probe. The 2-and 3-back auditory-spatial tasks significantly increased postural sway compared to auditory- and visual-object tasks. No significant difference in postural sway was observed across the easy, 1-back cognitive tasks. Woollacott & Vander Velde (2008) concluded that postural stability appears to be more vulnerable to cognitive tasks requiring spatial processing than visual or auditory processing.

1.5.4. Cognitive tasks targeting working memory

Performing a cognitive task in a dual-task paradigm can involve one or more components of working memory (WM) (Dault, Frank, & Allard, 2001b). Several studies have employed cognitive tasks that target specific components of WM to assess their impact on postural control (Dault et al., 2001b; Ramenzoni, Riley, Shockley, & Chiu, 2007; Vander Velde, Woollacott, & Shumway-Cook, 2005).

The aim of Dault et al. (2001b) study was three-fold. First, to examine the effects of different WM tasks on postural control; second, to examine the effect of varying the level of difficulty of the WM tasks on postural control and third, to examine the effect of postural complexity on the performance of the WM tasks. The cognitive tasks consisted of the Manikin test (uses the visuo-spatial sketchpad), word categories (uses the articulatory loop subsystem of the phonological loop) and random number generation (places demands on the central executive system). Each cognitive task was performed in a seated position, standing with feet shoulder-width apart, and standing in a tandem position. An increase in mean power frequency and a decrease in amplitude in postural sway were observed with the WM tasks. However, no significant differences in postural sway were found between the WM tasks. Secondly, manipulating the difficulty level of the WM tasks resulted in no changes in postural sway. Finally, cognitive performance remained constant across the three postural stances. Dault et al. (2001b) concluded that regardless of type or level of difficulty, WM tasks prompt tighter control of postural sway.

Vander Velde et al. (2005) examined the impact of two visual WM tasks on postural control in young adults. The visual object WM task involved indicating if the load and probe objects were the same or different. The visual spatial WM was similar, with the exception of the load-probe pairings being spatial rather than object based. Additionally, the level of difficulty was manipulated by varying the number of load items to be contrasted with a subsequent probe. The cognitive tasks were performed in three postural positions: seated, standing in a tandem Romberg position on a firm and compliant surface. Dual-task effects were restricted to cognitive performance as no significant difference in postural sway was observed across the WM tasks. Standing in a tandem Romberg position on a firm and compliant surface significantly diminished performance on the visual spatial WM task. Vander Velde et al. (2005) concluded that interference between postural control and cognition is limited to the spatial domain, similar to the findings of Woollacott & Vander Velde (2008), who observed diminished stability during the performance of the 2-back and 3-back spatial cognitive task.

Ramenzoni et al. (2007) examined how cognitive tasks targeting different components of WM affect postural control in young adults. The cognitive tasks consisted of a verbal (string of letters and numbers) and a visual (Japanese anagrams) task. The tasks targeted the phonological loop and visuo-spatial sketchpad, respectively. Participants were required to rehearse the presented material and subsequently, identify the position of a randomly selected item in the string. Additionally, verbal and visual interference was employed to activate the central executive system and disrupt the phonological loop and visuo-spatial sketchpad. Analysis of postural sway was divided into two processing phases: encoding and rehearsal. Contrary to Maylor et al. (2001), sway variability increased during the encoding phase and differed between the visual and verbal tasks. Specifically, AP sway variability significantly increased for the verbal task compared to the visual and control conditions. Whereas, ML sway variability significantly increased for the visual task compared to the control condition. Sway variability was also reduced during the rehearsal process, though no significant difference was observed between the cognitive tasks, similar to Dault et al. (2001b) and Vander Velde et al. (2005). Ramenzoni et al. (2007) concluded that during rehearsal, postural control is sensitive to cognitive load rather than cognitive tasks utilizing different components of working memory.

1.5.5. Visual and auditory cognitive tasks

Since processing visual and auditory stimuli is thought to require distinct mechanisms (Riley, Baker, Schmit, & Weaver, 2005), several studies have manipulated the modality of the cognitive task to assess if the sensitivity of postural control differs (Jamet, Deviterne, Gauchard, Vancon, & Perrin, 2007; Prado, Stoffregen, & Duart, 2007; Riley et al., 2005).

Riley et al. (2005) examined the impact of a visual and auditory digit-rehearsal task on postural control in young adults. In Experiment 1, participants were required to stand on a firm and compliant surface with their eyes open and closed, while performing the easy and difficult, visual digit-rehearsal tasks. The experimental protocol in Experiment 2 was identical to Experiment 1 with the exception of the cognitive task, which was presented auditorily. Under increased cognitive load, both the visual and auditory tasks reduced ML sway variability. However, the auditory task was associated with greater changes in the spatiotemporal profile of postural sway. Specifically, increased randomness and decreased complexity of postural sway in both AP and ML was observed. Additionally, the observed effects were independent of the surface and vision manipulations. Riley et al. (2005) concluded that the interaction between cognition and postural control might be sensitive to the modality of the cognitive task.

Jamet et al. (2007) examined the impact of a mental task and two tasks requiring external information on postural control. The mental task consisted of counting backwards by seven. The tasks requiring external information consisted of a visual-verbal task, corresponding to the Stroop test, and an auditory-verbal task, requiring participants to indicate whether the words “right” or “left” were congruent or incongruent with the side the words were presented on. The cognitive tasks were performed while standing with feet 30 degrees apart. Similar to Riley et al. (2005), the auditory-verbal task significantly reduced area and AP and ML sway variability. There was a trend for reduced area and AP sway variability in the visual-verbal condition. Additionally, no significant difference was observed between the control and mental task condition. Jamet et al. (2005) concluded that the improved stability was a result of greater attentional focus placed on the auditory stimuli.

Prado et al. (2007) examined the impact of visual cognitive tasks presented at varying distances on postural control. Participants were required to stand while concurrently performing a visual inspection and a visual search task at a near and far distance. The inspection task involved maintaining gaze within the borders of the target. While the search task involved silently counting the number of times a designated target was presented in a block of Portuguese text. Contrary to Jamet et al. (2007), postural sway was significantly reducing during the visual search task compared to the visual inspection task. Additionally, postural sway was reduced when viewing the tasks at a near distance compared to a far distance. Prado et al. (2007)

concluded that certain visual cognitive tasks may be more disruptive than others; suggesting that changes in postural stability are task specific.

1.6. Theoretical models

Three models have been proposed to elucidate the conflicting findings in the posture-cognition literature: the cross-domain competition model, the U-shaped non-linear interaction model and the task prioritization model (Huxhold et al., 2006; Lacour, Bernard-Demanze, & Dumitrescu, 2008).

According to the cross-domain competition model, posture and cognition compete for attentional resources in a dual-task paradigm (Lacour et al., 2008). Consequently, postural control becomes more vulnerable to destabilization and/or cognitive performance diminishes compared to single-task performance (Remaud et al., 2012). Moreover, the model suggests that fewer resources would be available for postural control, thereby propagating a decline in postural performance (Lacour et al., 2008). Support for the model can be found in several studies examining age-related differences in postural control. For instance, both Maylor and Wing (1996) and Maylor et al. (2001) observed declines in postural stability with increasing age when concurrently performing an array of cognitive tasks (e.g. Brooks' spatial and non-spatial memory tasks, and backward digit recall). In addition, manipulating cognitive demand in older adults has produced similar findings (Huxhold et al., 2006). However, the cross-domain competition model fails to account for numerous findings in the literature. Specifically, the studies on young adults where improvements (Dault et al., 2001b; Huxhold et al., 2006; Jamet et al., 2007; Maylor et al., 2001; Riley et al., 2003; Riley et al., 2005; Swan et al., 2004) as well as no change (Dault et al., 2001a) in postural stability have been observed. The inability to address these findings highlights serious limitations to the cross-domain competition model.

The U-shape non-linear interaction model suggests there are limits to the effectiveness of a cognitive task on postural control (Huxhold et al., 2006; Lacour et al., 2008). It stipulates that postural stability either improves or attenuates depending on whether the cognitive demand of the secondary task is lower or higher, respectively. However, studies manipulating cognitive demand in young adults have reported findings that do not follow the predicted U-shape function (Huxhold et al., 2006; Riley et al., 2003; Swan et al., 2007). In particular, Huxhold et al. (2006) observed no disruptions to stability as the difficulty of the cognitive task increased. Instead, postural sway was found to improve with increasing demand. Typically, the U-shape relationship is evident in older adults (Huxhold et al., 2006), who have a reduced attentional capacity as a result of diminished sensorimotor function (Borel & Alescio-Lautier, 2013). Collectively, this suggests that individual differences in attentional capacity modify the point at which a given level of cognitive demand transitions from being beneficial to adverse (Huxhold et al., 2006).

The task prioritization model suggests that in certain divided attention situations, postural control is prioritized over cognitive task performance (Huxhold et al., 2006; Lacour et al., 2008). This ‘posture-first’ principle suggests the existence of a hierarchy in the allocation of attentional resources with postural control being the first priority (Shumway et al., 1997). However, this does not appear to be the case for young adults, as the literature demonstrates otherwise. Barra, Bray, Sahni, Golding and Gretsy (2006) instructed participants to stand in tandem on beams of 2, 3, 6, and 8 cm widths, while concurrently performing the verbal and spatial Stroop tasks. Verbal task performance was not sacrificed, even under the hardest postural condition. Stable cognitive performance has also been observed across different postural tasks (Andersson, Hagman, Talianzadeh, Svedberg, & Larsen, 2002; Dault et al., 2001a; Swan et al., 2004). Furthermore, this model may not be suitable to explain the findings on young adults, seeing as cognitive performance is rarely sacrificed for postural stability.

1.7. Task prioritization

As outlined in the sections above, there are considerable differences in methodology, postural and cognitive tasks across studies, thereby making it extremely difficult to discern a clear pattern to the observed findings (Mitra & Fraizer, 2004). An additional contributor to the variable findings may be the instructions provided regarding the allocation of attention (Fraizer & Mitra, 2008). Numerous studies have observed an individual's focus of attention to affect motor control processes involved in the execution of motor skills including postural control (Shea & Wulf, 1999; Wulf, Hob, & Prinz, 1998; Wulf, McNevin, & Shea, 2001; for a review, see Wulf, 2007). Specifically, the effects of focusing on the movement itself (internal focus) were compared to focusing on the effects of the movement on an apparatus or implement (external focus). The results consistently demonstrated that maintaining an external focus produced more effective performance than an internal focus. It is suggested that utilizing an internal focus interferes in the coordination of automatic processes responsible for regulating the movement. While, an external focus enables the automatic processes to function unconstrained, thereby enhancing the performance of the movement (Shea & Wulf, 1999; Wulf et al., 1998; Wulf et al., 2001). Following this line of thinking, instructions provided in a dual-task context may impact the allocation of attention resources, and in doing so, alter postural performance.

More over, prioritizing cognition over postural control may effectively modify resource allocation by shifting attention from a fairly automatized task, similar to an external focus, consequently improving postural performance and promoting a more automatic mode of control (Huxhold et al., 2006).

Although there are ample studies examining the posture-cognition relationship, few have disclosed the instructions provided and more importantly, few studies have addressed the impact of task prioritization on both, posture and cognitive performance (Burcal, Drabik, & Wikstrom, 2014; Mitra & Fraizer, 2004; Remaud et al., 2013; Siu & Woollacott, 2007; Stins, Roerdink, & Beek, 2011). These studies may help explain the conflicting findings in the current literature.

Siu and Woollacott (2007) examined the ability to shift attention between a postural task and a visual spatial memory task. Participants were instructed to stand with their feet together while simultaneously performing a visual spatial memory task under three instructional conditions: focus equally on the two tasks, focus primarily on the postural task and focus primarily on the cognitive task. No significant difference in postural sway was observed between the posture and cognitive task instructions. However, compared to the single-task condition, postural sway was improved with the addition of a cognitive task. Additionally, verbal reaction time was faster when participants were instructed to focus on the cognitive task. Siu and Woollacott (2007) concluded that young adults can flexibly allocate attentional resources without negatively affecting stability.

Burcal et al. (2014) examined the impact of instructions on postural control across multiple domains of working memory. Participants were required to stand in a single-leg stance while performing three working memory tasks: counting backwards by threes, manikin test and random number generation. In addition, each dual-task was performed under three instructional conditions: no instructions, focus on the postural task and focus on the cognitive task. Similar to Sui and Woollacott (2007), both postural and cognitive instructions comparably improved postural stability compared to the no instructions conditions, however, AP sway was further improved with the cognitive focus instruction. The effects in stability were similar across the three working memory tasks. Prioritizing cognition also resulted in improved cognitive scores compared to the no instruction condition. Burcal et al. (2014) concluded that instructions can influence the posture-cognition interaction, especially instructions that withdraw attention away from postural control.

Remaud et al. (2013) examined the effects of instructions on dual-task performance during postural tasks of varying difficulty. Participants were required to stand in a feet together, tandem and single-leg stance, with eyes open and closed. All the postural conditions were performed with and without an auditory reaction time task. In addition, each dual-task condition was performed under two instructional conditions: focus on balance and minimizing sway as much as possible and focus on the reaction time task and respond as quickly as possible. Contrary to Burcal et al. (2014), AP sway velocity decreased in the most complex postural condition (i.e. tandem stance, eyes closed and single-leg stance, eyes closed) when participants were instructed to focus on the postural task than the reaction time task. No significant difference was observed between the instructions for sway area and ML sway variability. Additionally, faster reaction times were reported when participants were instructed to focus on the cognitive task. Remaud et al. (2013) concluded that allocation of attentional resources influences stability only under challenging postural conditions.

Mitra and Fraizer (2004) examined the effect of instructions on dual-task performance. Participants were instructed to maintain two postural stances, feet together and feet apart, while simultaneously performing a visual search task of varying difficultly under two instructional conditions: focus on the postural task (i.e. minimize sway) and focus on the cognitive task. Regardless of instructions, postural sway increased when performing the difficult version of the visual search task. Postural sway was also reduced when participants were instructed to do so. Mitra and Fraizer (2004) concluded that the results contradict the facilitatory control view, which stipulates that postural control is primarily a facilitator of cognitive performance, and rather suggest that increasing the search load causes attentional resources to be withdrawn from maintaining stability. In terms of cognitive performance, search speed tended to be faster under cognitive instructions while in a feet together position. The opposite pattern was observed when participants were instructed to focus on minimizing their sway.

Stins et al. (2011) examined the effect of manipulating attention on postural control. Participants were required to perform two single-task conditions: stand with no secondary task and stand on a platform, 1 m off the ground and two dual-task conditions: stand while concurrently performing a cognitive and motor task. The cognitive task involved silently counting backwards by seven, while the motor task involved holding a cup close to the body and trying to not spill the liquid. Prioritizing either the cognitive or motor task resulted in reduced

COP amplitudes and increased sway frequencies compared to baseline, although the findings were stronger for the cognitive dual-task condition, similar to Burcal et al. (2014). No significant difference was observed between the baseline and height conditions. However, lower sample entropy (i.e. marker of attentional involvement) was found in the height condition compared to the dual-task conditions. Stins et al. (2011) concluded that shifting attention from maintaining stability by prioritizing a secondary task may enhance postural performance.

CHAPTER TWO: INTRODUCTION

2.1. Introduction

By integrating sensory inputs from the somatosensory, vestibular, and visual systems, postural control synergies maintain the body's position in space for the purpose of orientation and balance (Horak, 2006; Winter, 1995). Initially, it was regarded as an autonomous system; however, empirical evidence has shown that postural control is in fact, responsive to cognitive manipulations (Burcal et al., 2014; Dault et al., 2001a; Dault et al., 2001b; Dault et al., 2003; Huxhold et al., 2006; Jamet et al., 2007; Kerr et al., 1985; Lajoie et al., 1993; Maylor et al., 2001; Pellecchia, 2003; Prado et al., 2007; Ramenzoni et al., 2007; Remaud et al., 2012; Riley et al., 2003; Riley et al., 2005; Shumway-Cook et al., 1997; Swan et al., 2004; Swan et al., 2007; Vander Velde et al., 2005; Woollacott & Verde, 2008; Yardley et al., 1999). The association between postural control and cognition was revealed through the use of dual-task paradigms, which compares the performance of two tasks when performed concurrently (Woollacott & Shumway-Cook, 2002). There are a number of assumptions that underlie the paradigm: 1) the central information-processing capacity is limited, 2) executing a task necessitates a portion of said capacity, and 3) if two concurrent tasks exceed the total capacity, performance on one or both tasks will diminish (Kahneman, 1973).

However, the variation in experimental protocols and consequently, the diverse findings, make it extremely difficulty to discern a clear pattern in the literature (Fraizer & Mitra, 2007). In particular, researchers have observed improved (Dault et al., 2001b; Huxhold et al., 2006; Jamet et al., 2007; Kerr et al., 1985; Maylor et al., 2001; Prado et al., 2007; Ramenzoni et al., 2007; Riley et al., 2003; Riley et al., 2005; Swan et al., 2004; Swan et al., 2007), attenuated (Dault et al., 2003; Maylor et al., 2001; Pellecchia, 2003; Ramenzoni et al., 2007; Vander Velde et al., 2005; Woollacott & Vander Velde, 2008; Yardley et al., 1999) and unaltered (Dault et al., 2001a) postural stability during the concurrent performance of a cognitive task, attributing the findings to factors such as postural complexity and individual differences (Huxhold et al., 2006). While these are valid and supported explanations, an alternative contributor to the conflicting results, may be the features of the cognitive task.

The aforementioned studies reveal a wide variety of cognitive tasks such as digit rehearsal (Riley et al., 2003), Brooks' spatial and non-spatial memory task (Maylor et al., 2001; Swan et al., 2007), n-back tasks (Huxhold et al., 2006; Woollacott & Vander Velde, 2008), counting backwards (Pellecchia, 2003) and working memory tasks (Dault et al., 2001b; Vander Velde et al., 2005) to name a few. Seeing as the tasks have produced variable findings, it is therefore, reasonable to suggest that certain features of a cognitive task could have more disruptive than facilitating influences on postural control and vise versa.

Considering few studies have systematically varied cognitive complexity, its influence on postural control remains unknown (Dault et al., 2001a; Huxhold et al., 2006; Pellecchia, 2003; Riley et al., 2003; Swan et al., 2007). For example, Huxhold et al. (2006) found stability to improve with increasing cognitive demand, while the complete opposite was observed by Pellecchia (2003). Findings have been attributed to both, a parallel sharing of a limited set of attentional resources (Dault et al., 2001a; Fraizer & Mitra, 2008; Kahneman, 1973) and a shift in attentional focus from a highly automatized activity (i.e. postural control) (Huxhold et al., 2006; Swan et al., 2007). The former suggests that if the demand of two concurrent tasks exceeds the processing capacity, performance on one or both tasks will suffer (Kahneman, 1973; Reilly et al., 2008). While, the latter suggests that cognitive tasks modify resource allocation by shifting attention from an automatized task, thereby allowing postural control to operate in a more automatic manner (Riley et al., 2003). This explanation is substantiated by findings that demonstrate improved postural stability when an external focus of attention is adopted relative to an internal focus of attention (Shea & Wulf, 1999; Wulf et al., 1998; Wulf et al., 2001; for a review, see Wulf, 2007). Nevertheless, until further studies are performed on the topic, the interaction between cognitive demand and postural control will remain speculative.

Cognitive tasks have also been presented both, visually and auditorily and, yet what modality is most effective in promoting postural stability remains undetermined (Jamet et al., 2007; Prado et al., 2007; Riley et al., 2005; Stoffregen et al., 2000). According to Baddeley and Hitch's (1974) multi-component model of working memory, visual and auditory processes and their underlying mechanisms are thought to be distinct. The model suggests that auditory input enters the phonological store directly, while visual input must be recoded into phonological form by articulatory rehearsal before entering the phonological store (Repovs & Baddelely, 2003). Therefore, the differences in processing may have an effect in modifying the interaction between cognition and postural control, suggesting that postural control is sensitive to the modality of the stimulus presentation (Riley et al., 2005). However, few studies have directly addressed this point (Jamet et al., 2007; Prado et al., 2007; Riley et al., 2005), which is why additional research is required.

Additionally, the literature on posture-cognition has yet to considered the role of inter-stimulus intervals within a cognitive task on postural control. In keeping with the notions of resource allocation (Shea & Wulf, 1999; Wulf et al., 1998; Wulf et al., 2001; for a review, see Wulf, 2007), the time between stimuli, when participants are not actively performing the task, may provide brief opportunities for attention to shift from the cognitive task to postural control. Whereas, a task with shorter intervals (e.g. three seconds or less) may not afford the same opportunities and therefore, enhance stability by allowing postural control to function in a more automatized manner. Therefore, the time between stimuli may be a possible contributor to the contradictory results. Studies have employed reaction time tasks (Lajoie et al., 1993; Remaud et al., 2012), which contain numerous inter-stimulus intervals, however, the two aforementioned tasks have never been directly compared. The secondary interest of this thesis was to make this comparison.

Therefore, examining how specific features of a cognitive task interact with postural control is required, to not only achieve a better understanding of postural control but to also be able to elucidate the current state of findings. It is the suggestion of this thesis that to decipher the variability in findings, understanding the role of cognitive demand is critical. It may be the cause for why certain types of cognitive tasks promote postural stability, while others attenuate it. If the implications of cognitive demand are not properly understood, it may be a serious confounding variable when trying to examine the impact of specific cognitive tasks (e.g., working memory, spatial and non-spatial, visual or auditory, etc.) on postural control..

2.2. Purpose

The purpose of this thesis was two-fold. First, to examine the impact of cognitive demand on postural control in young adults and second, to determine how the modality (auditory vs. visual) of the cognitive task impacts the postural control system. Of secondary interest, was to compare the effects of a discrete and continuous cognitive task on postural control, to determine if the time between stimuli presentation would modify postural stability.

2.3. Hypotheses

Manuscript #1:

1. Irrespective of modality, the cognitive tasks with the highest level of difficulty would produce the greatest improvements in postural stability (i.e. reduction in postural sway) (Huxhold et al., 2006; Riley et al., 2003; Swan et al., 2007). This will transpire by a shift in attentional focus from consciously monitoring stability to executing the cognitive task, thereby promoting a more automatic mode of control.
2. Irrespective of cognitive demand, the visual cognitive tasks would generate greater improvements to postural stability compared to the auditory cognitive tasks (Prado et al., 2007) by establishing a visual anchor, ultimately reducing ocular movement (Hunter & Hoffman, 2001; Vander Velde et al., 2005).

Manuscript #2:

1. Compared to the single-task condition (quiet standing), the addition of the cognitive tasks would reduce postural sway (Kerr et al., 1985; Huxhold et al., 2006; Maylor et al., 2001). Performing a challenging or complex concurrent cognitive task will promote a more automatic mode of postural control by allocating attention to cognition (Huxhold et al., 2006)

2. Irrespective of modality, the continuous cognitive tasks would generate greater postural stability compared to the discrete cognitive tasks by limiting or eliminating opportunities for attentional focus to shift away from the cognitive task.
3. Irrespective of stimuli presentation, the visual cognitive tasks would produce greater postural stability compared to the auditory cognitive tasks (Prado et al., 2007) by establishing a visual anchor, ultimately reducing ocular movement (Hunter & Hoffman, 2001; Vander Velde et al., 2005).

CHAPTER THREE: MANUSCRIPT #1

Reducing postural sway by concurrently performing challenging cognitive tasks

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Submitted

Reducing postural sway by concurrently performing challenging cognitive tasks

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Abstract:

The present experiment varied cognitive complexity and modality to assess the responsiveness of postural control in young adults. Seventeen participants (23.71 ± 1.99 years) were instructed to stand feet together on a force platform while concurrently performing cognitive tasks of varying degrees of difficulty (easy, moderate and difficult). The cognitive tasks were presented both, auditorily and visually. Auditory tasks consisted of counting the occurrence of one or two letters and repeating a string of words. Visual tasks consisted of counting the occurrence of one or two numbers. With increasing cognitive demand, area of 95% confidence ellipse and ML sway variability was significantly reduced. Additionally, presenting the cognitive tasks visually reduced ML sway variability. Collectively, the posturographic findings suggest that performing tasks that are of high cognitive demand and visually presented can be beneficial to promoting postural stability.

Key words: postural control, cognitive demand, dual-task, sensory modality

Word count: 137

1. **Introduction**

Postural control was commonly regarded as an automatic task, suggesting that the need for resources was minimal (Woollacott & Shumway-Cook, 2002). However, with the use of dual-task paradigms, maintaining and recovering stability was revealed to require a considerable amount of information-processing resources (Kerr, Condon, & McDonald, 1985; Lajoie, Teasdale, Bard, & Fleury, 1993; for a review, see Woollacott & Shumway-Cook, 2002). Kerr et al. (1985) were one of the first to demonstrate the resource requirements of postural control. In their experiment, Kerr et al. (1985) found maintaining a tandem Romberg stance to negatively affect the spatial recall scores. Similarly, Lajoie et al. (1993) observed that increasing postural complexity, from sitting to standing, precipitated a rise in attentional costs as evidenced by longer reaction times.

In addition, the responsiveness of postural control to cognitive influences has been extensively investigated using a wide variety of cognitive tasks such as Brooks' spatial and non-spatial memory tasks (Maylor, Allison, & Wing, 2001; Swan, Otani, & Loubert, 2007), n-back tasks (Huxhold, Li, Schmiedek, & Lindenberger, 2006; Woollacoot & Vander Velde, 2008), digit rehearsal (Riley, Baker, & Schmit, 2003) and counting backwards (Maylor & Wing, 2006) to name a few. However, despite the broad range of tasks, few studies have actively manipulated cognitive load (Dault, Guerts, Mulder, & Duysens, 2001a; Huxhold et al., 2006; Riley et al., 2003; Swan et al., 2007). For example, Riley et al. (2003) reported a decrease in postural sway when performing the difficult version of a digit rehearsal task, while Pellecchia (2003) implemented information reduction task of varying difficulty and observed an increase in postural sway. Deficits in postural stability are commonly explained in terms of limited capacity

(Kahneman, 1973), which stipulates that if two concurrent tasks exceed total resource capacity, performance on one or both tasks will suffer. However, there are limitations to the theory due to its inability to account for the cases of improved postural stability (Huxhold et al., 2006; Riley et al., 2003; Swan et al., 2007).

Alternatively, the reported fluctuation in postural sway may be more associated with interference with the motor control processes than a competition for resources. Directing attention towards postural control constrains the motor control processes, whereas, directing attention towards the cognitive task limits interference and promotes a more automatic mode of control (Huxhold et al., 2006; Shea & Wulf, 1999; Wulf, Hob, & Prinz, 1998: Wulf, McNevin, & Shea, 2001). This is consistent with the findings that demonstrate improved stability when utilizing an external focus relative to an internal focus (Shea & Wulf, 1999; Wulf et al., 1998; Wulf et al., 2001). Furthermore,, the cognitive load findings only provide limited insight into the relationship between postural control and cognitive activity. Additional research is required to gain a better understanding of the interaction and attain some form of consensus.

Features of a cognitive task may also contribute to the current state of findings. Modality, for one, has been found to modulate the effectiveness of cognition on postural control (Jamet, Deviterne, Gauchard, Vancon, & Perrin, 2007; Prado, Stoffregen, & Duart, 2007; Riley, Baker, Schmit, & Weaver, 2005; Stoffregen, Pagulayan, Bardy, Hettinger, 2000). Riley et al. (2005) observed greater changes to the spatiotemporal profile (i.e. increased randomness and decreased complexity in both, anterior-posterior (AP) and medial-lateral (ML) directions) of postural sway when presenting the digit rehearsal task auditorily than visually. Likewise, Jamet et al. (2007)

found reduced sway, AP and ML sway variability when participants performed the auditory-verbal task compared to the visual-verbal task. These results have been explained in terms of structural interference (Kerr et al., 1985). Specifically, presenting cognitive tasks visually may interfere with the visual processing needed for the control of posture (Kerr et al., 1985; Hunter & Hoffman, 2001) precipitating declines in postural stability. However, Stoffregen et al. (2000) reported reduced postural sway when concurrently performing a visually presented search task. The variation in results suggests that postural stability may have greater sensitivity to the type of cognitive task performed, granted this assertion still merits further scrutiny.

To address the variability with regards to cognitive demand and modality, the purpose of present experiment was to examine the modulating effects of cognitive demand on postural control in young adults and secondly, to determine how presenting cognitive tasks in differing modalities would modify postural stability. Based on several previous studies, we hypothesized that postural stability would have the greatest improvement when concurrently performing the cognitive task with the highest level of difficulty (Huxhold et al., 2006; Riley et al., 2003; Swan et al., 2007). We also hypothesized that presenting the tasks visually would promote greater enhancements to postural stability than auditorily presenting the tasks (Prado et al., 2007; Stoffregen et al., 2000; Stoffregen & Duart, 2007) by providing participants with a visual anchor (Vander Velde, Woollacott, & Shumway-Cook, 2005).

2. **Methods**

2.1 Participants

Seventeen healthy University of Ottawa students (Nine females, eight males; 23.71 ± 1.99 years) participated in the experimental protocol. A health questionnaire was administered to ensure participants had no injuries or disorders that could impede their balance ability. None of the participants had prior experience with the tasks. The study was approved by the Research Board at the University of Ottawa in accordance with the principles of the Declaration of Helsinki. Prior to testing, each participant signed an informed consent form.

2.2. Apparatus

To evaluate postural control, an AMTI force platform (ORG-6-1000, Don Mills, ON, Canada) was used to record the body's projection of ground-reaction forces at a sampling rate of 500 Hz. For the auditory cognitive tasks, a media player was used to present the recordings. Speakers were placed on either side of the participant. For the visual cognitive tasks, a 19'' computer monitor placed at eye-level, 1.5 meters from the force platform, was used to present the PowerPoint slides.

2.3. Postural task

The postural task involved standing as still as possible on the force platform with feet together and arms alongside the body, while looking at a fixation cross (i.e. during auditory cognitive tasks) or a sequence of 3-digit or 5-digit numbers displayed in the middle of the computer screen 1.5 meters from the force platform. The placement of the participant's feet was traced to ensure the same position was maintained throughout the entire experimental protocol.

2.4. Cognitive tasks

A pilot study consisting of eight participants was performed to determine the level of difficulty for each auditory and visual cognitive task. In the experimental protocol, task parameters such as stimulus presentation and acceptable error scores varied across condition, whereas time of response was kept constant. In all cognitive dual-task conditions, participants communicated their answer only upon completion of the trial. All tasks were designed to be performed silently to eliminate articulation. Additionally, during cognitive tasks requiring keeping count, participants were prohibited from using their fingers as a counting aid in order to maximize cognitive effort. The acceptable error score limits were designed to match the difficulty of the cognitive task and were not modeled after previous literature.

2.4.1 Auditory cognitive tasks

Three different auditory tasks were performed that differed with respect to their level of cognitive demand.

2.4.1.1 Easy auditory cognitive task

A string of letters was auditorily presented and participants were instructed to silently count the total number of times a pre-selected letter was verbalized in the given string. Each letter was presented every two seconds for a total of 30 letters. Each easy trial used a different recording to eliminate the possibility of memorization. If participants' error score was greater than three, the trial was redone at the end of the experimental protocol.

2.4.1.2.Moderate auditory cognitive task

The moderate task was adapted from a cognitive task performed in a study by Dault et al. (2003). A string of words separated by the phrase ‘next word’ were broken down into individual letters and participants were instructed to repeat the words in the order presented upon completion of the trial. For example, “p-a-n-t-s/next word/m-y/next word/g-r-e-e-n/next word/a-t-e/next word/s-i-s-t-e-r/next word/m-y.” Each letter and ‘next word’ were presented every two seconds. The words ranged from two to eight letters. Each moderate trial used a different recording and contained between five and six words. If participants’ failed to mention three or more words in the correct order, the trial was redone at the end of the experimental protocol.

2.4.1.3.Difficult auditory cognitive task

In the difficult task, a string of three-letter words was auditorily presented and participants were instructed to count the total number of times two pre-selected letters (e.g. a vowel and a consonant) were present in the given string. The task required participants to simultaneously search for the specified letters in each three-letter word and keep two running totals. Each three-letter word was presented every three seconds for a total of 20 words. Each difficult trial used a different recording to eliminate the possibility of memorization. If participants’ combined error score was greater than six, the trial was redone at the end of the experimental protocol.

2.4.2 Visual cognitive tasks

Three different visual tasks were performed that differed with respect to their level of cognitive demand.

2.4.2.1.Easy visual cognitive task

A sequence of 30 3-digit numbers was presented on the computer screen and participants were instructed to count the total number of times a pre-selected digit appeared in the given sequence. The task required participants to simultaneously search for the specified digit in each 3-digit number and keep a running total. Each 3-digit number was presented every two seconds. Each easy trial used a different sequence to eliminate the possibility of memorization. If participants' error score was greater than three, the trial was redone at the end of the experimental protocol.

2.4.2.2.Moderate visual cognitive task

A sequence of 30 3-digit numbers was presented on the computer screen and participants were instructed to count the total number of times two pre-selected digits appeared in the given sequence. The task required participants to simultaneously search for the specified digits in each 3-digit number and keep two running totals. Each 3-digit number was presented every two seconds. Each moderate trial used a different sequence to eliminate the possibility of memorization. If participants' combined error score was greater than four, the trial was redone at the end of the experimental protocol.

2.4.2.3.Difficult visual cognitive task

A sequence of 20 5-digit numbers was presented on the computer screen and participants were instructed to count the total number of times two pre-selected digits appeared in the given sequence. The task required participants to simultaneously search for the specified digits in each 5-digit number and keep two running totals. Each 5-digit number was presented every three seconds. Each difficult trial used a different sequence to eliminate the possibility of memorization. If participants' combined error score was greater than six, the trial was redone at the end of the experimental protocol.

2.5. Procedure

The experimental protocol consisted of six dual-task conditions. The dual-task conditions involved combinations of one postural task (feet together) and three cognitive tasks (easy, moderate, and difficult), each presented in two modalities (auditory and visual). At the beginning of the experimental protocol, participants performed each of the cognitive tasks while seated. Instructions concerning the postural task were only provided once at the beginning of testing to prevent participants from prioritizing posture over cognition during the dual-task conditions. The dual-task conditions were comprised of five, 60-second trials. All trials were counterbalanced to eliminate an order effect. In addition, if errors were outside the appropriate error limits, the trials were redone at the end of the experimental protocol. Participants were not informed if mistakes were made.

2.6. Data Analysis

Center of pressure (COP) was acquired from the ground-reaction forces collected by the force platform. Subsequently, MatLab software (MathWorks Inc., MA, USA) was used to attain outcome measures such as area of 95% confidence ellipse, standard deviation (SD) of COP in the anterior-posterior (AP) and medial-lateral (ML) direction and mean velocity in the AP and ML direction. Additionally, a Fast Fourier Transform (FFT) analysis was performed on the COP data using BioProc3 Software (D.G.E. Robertson, Ottawa, Canada). This allowed for mean power frequency (MPF) to be computed. This analysis discerns subtle differences in frequency adjustments between experimental conditions (Wulf et al., 2001).

2.7. Statistical analysis

Cognitive demand (easy, moderate, and difficult) x modality (auditory and visual) analysis of variance (ANOVA) with repeated measures was performed on each of the aforementioned outcome measures. Additionally, cognitive demand x modality ANOVA with repeated measures was performed on percentage of trials with errors within the appropriate error limits. If Mauchly's Test of Sphericity was violated, a Greenhouse-Geisser correction was performed. If the data failed normality, a log transformation was performed. Statistical significant was set at $p < 0.05$. When necessary, Tukey HSD post-hoc analysis was performed to ascertain the location of significance.

3. Results

Means and standard deviations for the following outcome measures are presented in Table 1.

3.1. Area of 95% confidence ellipse

A logarithmic transformation was applied to area of 95% confidence ellipse.

The main effect of cognitive demand, $F\ (2,32) = 37.66, p < 0.0001,\ \eta_p^2 = 0.701$, on sway area was statistically significant (Fig 1.). Post-hoc analysis indicated that the moderate and difficult tasks generated significantly smaller sway areas compared to the easy cognitive tasks ($p < 0.001$ and $p < 0.001$, respectively). No statistically significant difference was observed between the moderate and difficult cognitive tasks ($p > 0.05$). The main effect of modality, $F\ (1, 16) = 3.28, p > 0.05,\ \eta_p^2 = 0.170$, on sway area was not statistically significant. The cognitive demand x modality interaction, F (2,32) = 1.67, $p > 0.05$, $\eta_p^2 = 0.098$, was not statistically significant.

3.2. *SD of COP*

The main effects of cognitive demand and modality on sway variability of COP in the AP direction were superseded by a cognitive demand x modality interaction, F (2, 32) = 3.61, $p < 0.05$, $\eta_p^2 = 0.184$ (Fig 2.). Post-hoc analysis indicated that for the visual cognitive tasks, the increase in demand from moderate to difficult significantly reduced sway variability ($p < 0.05$). However, for the auditory cognitive tasks, a similar increase in demand did not yield a significant difference ($p > 0.05$).

The main effect of cognitive demand, F (2, 32) = 38.77, $p < 0.0001$, $\eta_p^2 = 0.708$, on sway variability of COP in the ML direction was statistically significant (Fig 3.). Post-hoc analysis indicated that sway variability was significantly lower in the moderate and difficult cognitive task conditions compared to the easy cognitive task conditions ($p < 0.001$ and $p < 0.001$, respectively). No statistically significant difference was observed between the moderate and difficult cognitive tasks ($p > 0.05$). The main effect of modality, F (1,16) = 10.46, $p < 0.01$, $\eta_p^2 = 0.395$, on sway variability of COP in ML direction was statistically significant with visual generating lower sway variability compared to auditory. The cognitive demand x modality interaction, F (2, 32) = 2. 45, $p > 0.05$, $\eta_p^2 = 0.133$, was not statistically significant.

3.3. *Mean velocity*

The main effects of cognitive demand and modality on mean velocity in the AP direction were superseded by a cognitive demand x modality interaction, F (2, 32) = 3.64, $p < 0.05$, η_p^2 = 0.185 (Fig 4.). Post-hoc analysis indicated that for the auditory cognitive tasks, the increase in demand from moderate to difficult significantly lowered AP mean velocity ($p < 0.05$). However, for the visual cognitive tasks, a similar increase in demand did not yield a significant difference ($p > 0.05$).

The main effects of cognitive demand and modality on mean velocity in the ML direction were superseded by a cognitive demand x modality interaction, F (2, 32) = 8.50, $p < 0.01$, η_p^2 = 0.346 (Fig 4.). Post-hoc analysis indicated that compared to easy auditory cognitive task increasing the demand significantly lowered AP mean velocity ($p < 0.05$ and $p < 0.001$, respectively). However, increasing the cognitive demand of the visual cognitive tasks did not yield significant differences ($p > 0.05$).

3.4. Mean Power Frequency (MPF)

The main effect of cognitive demand, F (2, 32) = 0.496, $p > 0.05$, η_p^2 = 0.030, on MPF in the AP direction was not statistically significant (Fig 5.). The main effect of modality, F (1, 16) = 0.267, $p > 0.05$, η_p^2 = 0.016, on MPF in the AP direction was not statistically significant. The cognitive demand x modality interaction, F (2, 32) = 0.612, $p > 0.05$, η_p^2 = 0.037, was not statistically significant.

The main effect of cognitive demand, F (2, 32) = 3.319, $p < 0.05$, η_p^2 = 0.172, on MPF in the ML direction was statistically significant (Fig 5.). Post-hoc analysis indicated that the difficult cognitive tasks increased MPF compared to the easy cognitive tasks ($p < 0.05$). The main effect of modality, F (1, 16) = 0.64, $p > 0.05$, $\eta_p^2 = 0.038$, on MPF in the ML direction was not statistically significant. The cognitive demand x modality interaction, F (2, 32) = 0.985, $p > 0.05$, $\eta_p^2 = 0.058$, was not statistically significant.

3.5. Cognitive performance

The main effect of cognitive demand, F (2, 32) = 66.85, $p < 0.0001$, $\eta_p^2 = 0.807$, on percentage of trials with error scores within the established limits was statistically significant (Fig 6.). Post-hoc analysis indicated that the difficult cognitive tasks increased the percentage of trials compared to the easy cognitive tasks ($p < 0.001$). The main effect of modality, F (1, 16) = 0.10, $p > 0.05$, $\eta_p^2 = 0.006$, on percentage of trials with error scores within the established limits was not statistically significant. The cognitive demand x modality interaction, F (2, 32) = 1.17, $p > 0.05$, $\eta_p^2 = 0.068$, was not statistically significant.

4. **Discussion**

The objective of this experiment was two-fold. First, to evaluate the effect of cognitive demand on postural control in young adults and second, to determine if presenting cognitive tasks in contrasting modalities would modify postural stability differently. According to the objectives, the following hypotheses were proposed: first, irrespective of modality, the difficult cognitive task would yield greater improvements to postural stability. Second, irrespective of demand, presenting the cognitive tasks visually would yield greater improvements to postural stability than presenting the tasks auditorily. The present results revealed: (1) the moderate and difficult cognitive tasks reduced sway area and ML sway variability compared to the easy cognitive task; (2) the moderate and difficult cognitive tasks were not statistically different; and (3) presenting the tasks visually yielded lower ML sway variability compared to auditorily presenting the tasks. A detailed discussion of the aforementioned findings follows.

4.1. Modifications to postural stability as a function of cognitive demand

Previous research has shown increasing cognitive demand to precipitate contrasting effects on postural stability in young adults (Dault et al., 2001a; Huxhold et al., 2006; Pellecchia, 2003; Riley et al., 2003; Swan et al., 2007). As a result, determining an optimal level of difficulty has proven to be rather challenging. One of the main purposes of this experiment was to discern the impact of cognitive demand on postural control in an attempt to establish some form of consensus. With regards to the present findings, increasing cognitive demand resulted in a minimization of postural sway as evidenced by a reduction in 95% confidence area ellipse (i.e. sway area) and ML sway variability, similar to the findings of Huxhold et al. (2006), Riley et al. (2003), and Swan et al. (2007). A statistically significant difference was expected between the moderate and difficult level tasks, however, it was not observed. Although participants perceived a difference in difficulty between the two tasks, it is possible that both tasks were actually not markedly different in terms of demand, consequently, eliciting the comparable effects. Alternatively, the lack of significance may demonstrate that increasing the demand past a moderate level may not precipitate further improvements to postural stability, in other words, producing a ceiling effect.

Previous research has demonstrated that shifting attention from a motor skill to an implement or apparatus ensures a more effective execution of the movement by restricting opportunities for conscious monitoring of the skill (Shea & Wulf, 1999; Wulf et al., 1998; Wulf et al., 2001). Whereas, directing the focus towards the movement (i.e. internal focus), interferes with the motor control processes, triggering a decline in performance. Therefore, the current cognitive tasks may have improved stability by directing participants' attention away from engaging in conscious control. This in turn, minimized interference with the motor control processes and enabled postural control to function in a more automatic manner (Huxhold et al., 2006; Shea & Wulf, 1999; Wulf et al., 1998; Wulf et al., 2001). Huxhold et al. (2006) observed comparable improvements in stability with increasing cognitive demand, drawing similar conclusions as the current experiment. Additionally, the moderate and difficult cognitive tasks may have been more effective in retaining focus, as a result of their greater cognitive demand. As a result, opportunities to internalize focus were either eliminated or extremely limited relative to the easy cognitive tasks. This may explain why a greater reduction in sway area and ML sway variability was observed with both the moderate and difficult tasks. Moreover, greater improvements to postural stability have been reported when participants were instructed to place their focus on the cognitive task (Burcal, Drabik, & Wikstorm, 2014).

Researchers have postulated that cognitive demand and postural control interact in a U-shape formation, suggesting that there are limits to the effectiveness of a cognitive task on postural control (Huxhold et al., 2006; Lacour, Bernard-Demanze, & Dumitrescu, 2008). Particularly, the model stipulates that postural stability improves or attenuates depending on whether the cognitive demand is lower or higher, respectively. However, since a destabilization in postural control was not observed with increasing cognitive demand, the present findings fail to substantiate the predicted U-shape function. Alternatively, the findings may suggest that both tasks (i.e. postural control and cognition) had enough resources to prevent a resource competition from arising (Lacour et al., 2008). Moreover, with postural control operating on a more automatic level as a result of a shift in attention allows the cognitive task to have the adequate resources necessarily for its execution.

Additionally, directing attentional focus towards the effects of a movement on apparatus or implement (i.e. external focus) has repeatedly been shown to augment MPF (McNevin, Shea, & Wulf, 2003; Wulf, McNevin, & Shea, 2001; Wulf, Shea, & Park, 2001). This increase in MPF is suggested to reflect a more automatic mode of control. Presently, the variation in cognitive demand only had a pronounced effect on the ML MPF. Consistent with previous research (Dault et al., 2001a), the difficult cognitive tasks yielded a higher ML MPF than the easy cognitive task. The observed rise in ML MPF may suggest that cognitive tasks with a high degree of difficulty promote a more automatic mode of control. Moreover, the simultaneous reduction in sway area and ML sway variability may further substantiate this claim.

However, improvements in postural stability have been attributed to the use of an ankle stiffening strategy (McNevin & Wulf, 2002). Specifically, an increase in MPF and a simultaneous reduction of sway variability has been suggested to be an indicator of ankle stiffness (Carpenter, Frank, & Silcher, 1999; Carpenter, Frank, Silcher, & Peysar, 2001; Dault et al., 2001a). The combination of posturographic findings was derived from experimental protocols, where participants are instructed to stand on an elevated platform, subsequently experiencing a high level of perceived postural threat (Carpenter et al., 1999; Carpenter et al., 2001) or have a reduced base of support (i.e. shoulder-seesaw and tandem-seesaw) (Dault et al., 2001a). Therefore, ankle stiffness may not be a suitable explanation for the current set of results as the aforementioned and present protocols are markedly different (Stins, Roerdink, & Beeks, 2011). Stins et al. (2011) examined affective, motor and cognitive manipulations on postural control and, observed higher muscle activity in the affective condition than either the motor or cognitive dual-task conditions, suggesting that ankle stiffness may not account for improved stability in a cognitive dual-task context. If an ankle stiffening strategy is utilized, a corresponding increase in mean velocity should be observed. Presently, increasing the cognitive demand for the auditory cognitive tasks actually precipitated a reduction in AP and ML mean velocity. Further suggesting that ankle stiffening may not be a suitable strategy to elucidate the current state of dual-task findings.

In terms of cognitive performance, the difficult cognitive tasks yielded a higher percentage of trials with error scores within the established limits compared to the easy cognitive tasks. While deficits in cognitive scores may suggest that cognitive performance was sacrificed to ensure postural stability (Riley et al., 2003), we are inclined to suggest an alternative explanation. The errors committed reflect more the level of difficulty of the given task than the utilization of a “posture-first” strategy, which is the reason an error score criterion was implemented into the experimental protocol. As previously stated, shifting attention towards the cognitive task promotes the emergence of an automatic mode of control, which in turn ensures that postural control does not require attentional resources that could otherwise by used for the performance of a cognitive task (Riley et al., 2003). Therefore, we suggest that in addition to their larger attentional capacity, participants had ample resources to execute both tasks without having to sacrifice one task over the other. Moreover, trials that exceeded the accepted error scores that could potentially suggest that cognitive performance was sacrificed were excluded from analysis and the trials were redone.

4.2. Modifications to postural stability as a function of modality

Few studies have addressed how the modality of a concurrent cognitive task affects postural stability in young adults (Jamet et al., 2007; Prado et al., 2007; Riley et al., 2005; Stoffregen et al., 2000). Collectively, the results have been far from analogous. Presently, the visual cognitive tasks significantly reduced ML sway variability compared to the auditory cognitive tasks. However, a main effect was not found on sway area, AP and ML MPF.

Cognitive tasks presented visually were postulated to cause structural interference, since visual processing is a vital component of the postural control system (Kerr et al., 1985). However, previous literature has demonstrated improved postural stability when cognitive tasks are presented visually (Prado et al., 2007; Stoffregen et al., 2000). The improvement in stability may be credited to the establishment of a visual anchor, which promotes ocular stability. Hunter and Hoffman (2001) manipulated eye movement and, observed elevated ML sway variability in the eye movement condition relative to the no movement condition. The minimization of eye movement may explain why greater improvements were observed with the visual cognitive tasks. To successfully complete the visual tasks, participants' needed to maintain visual contact with the computer screen. If participants' vision deviated from the monitor, numbers in the sequence could potentially be missed, consequently altering the total number count (s). The auditory tasks also required participant to maintain fixation (i.e. on the cross), however, it was not a vital component to the execution of the task. Moreover, on several occasions, participants reported deviating from the fixation cross. Furthermore, the added eye movement may explain why ML sway variability was elevated relative to the visual cognitive tasks.

Additionally, according to the three-component working memory model proposed by Baddeley and Hitch (1974), auditory and visual stimuli require distinct mechanisms. In particular, auditory input enters the phonological loop directly, while stimuli presented visually must first be recoded into phonological form before entering the phonological store (Repovs & Baddeley, 2003). The extra layer processing and its corresponding demand did not appear to negatively impact postural stability or cognitive performance. Presenting the tasks visually actually significantly reduced ML sway variability compared to tasks presented auditorily. Additionally, a main effect of modality on cognitive performance was not observed. While the current study targeted only one component of working memory (i.e. the phonological loop), Dault et al. (2001b) found no significant difference in both postural stability and cognitive performance across tasks targeting different components of working memory (i.e. articulatory loop, visuo-spatial sketchpad and central executive). Perhaps, the changes observed in postural stability across studies are more so related to the cognitive demand of the tasks and the formation of an anchor, if the tasks are presented visually.

4.3. Cognitive demand by modality interaction

The current results revealed a cognitive demand x modality interaction for AP sway variability, AP and ML mean velocity. Notably, increasing cognitive demand from a moderate to difficult level prompted a significant reduction in AP sway variability when the tasks were presented visually. However, this effect was not observed when the tasks were presented auditorily. No further improvement in AP sway variability was observed once the moderate level was surpassed. This may suggest that there are limits to the effectiveness of cognitive manipulation when tasks are presented auditorily.

Conversely, increasing cognitive demand from a moderate to difficult level resulted in a significant reduction in AP mean velocity when the tasks were presented auditorily. However, this effect was not found when the tasks were presented visually. In fact, AP mean velocity was comparable across the three levels of difficulty. The same pattern of results was found for ML mean velocity. However, the difficult auditory task significantly reduced AP mean velocity compared to the easy auditory task. It is possible that mean velocity may be more sensitive to the combined effects of cognitive demand and modality than other posturographic measures. However, this claim necessitates further scrutiny.

5. **Conclusion**

In summary, the results of the present experiment suggest that increasing cognitive demand facilitates postural stability, corroborating previous research (Huxhold et al., 2006; Riley et al., 2003; Swan et al., 2007). Additionally, presenting cognitive tasks visually promotes greater improvements to stability than tasks presented auditorily. Collectively, this experiment suggests that both cognitive demand and modality contribute to the effectiveness of a cognitive task on postural control. However, both areas have not been extensively explored and necessitate further research to achieve a better understanding of the responsiveness of postural control to cognitive manipulations.

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Table 1. Mean and standard deviation (SD) of each cognitive task across all outcome measures

	Easy Auditory		Moderate Auditory		Difficulty Auditory		Easy Visual		Moderate Visual		Difficult Visual	
Outcome Measure	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Area of 95% confidence ellipse (cm^2)	0.580	0.163	0.453	0.150	0.456	0.123	0.541	0.164	0.458	0.141	0.395	0.165
SD of COP in AP (cm)	0.497	0.129	0.419	0.101	0.418	0.084	0.477	0.138	0.446	0.127	0.395	0.100
SD of COP in ML (cm)	0.456	0.081	0.384	0.065	0.398	0.071	0.422	0.085	0.382	0.060	0.356	0.069
Mean velocity in AP (cm/s)	3.219	0.542	3.217	0.551	3.129	0.504	3.005	0.485	3.034	0.511	3.015	0.497
Mean velocity in ML (cm/s)	2.727	0.553	2.666	0.479	2.617	0.456	2.490	0.371	2.505	0.385	2.492	0.373
MPF in AP (Hz)	0.242	0.064	0.237	0.086	0.244	0.05	0.233	0.057	0.251	0.081	0.264	0.077
MPF in ML (Hz)	0.243	0.049	0.260	0.041	0.255	0.055	0.238	0.057	0.260	0.050	0.280	0.064

Figure Captions

Fig 1. Area of 95% confidence ellipse (cm^2) across the three levels of difficulty
$^{\phi}$ significantly different from the easy level of difficulty ($p < 0.001$)

Fig 2. AP sway variability (cm) across the three levels of difficulty
$^{\phi}$ significantly different from the easy auditory task ($p < 0.05$)
$^{\lambda}$ significantly different from the easy visual task ($p < 0.01$)
$^{\alpha}$ significantly different from the moderate visual task ($p < 0.05$)

Fig 3. ML sway variability (cm) across the three levels of difficulty
$^{\phi}$ significantly different from the easy level of difficulty

Fig 4. AP and ML mean velocity (cm.s-1) across the three levels of difficulty
$^{\Phi}$ significantly different from the easy auditory task in the AP direction ($p < 0.05$)
$^{\lambda}$ significantly different from the moderate auditory task in the AP direction ($p < 0.001$)
$^{\alpha}$ significantly different from the difficult auditory task in the AP direction ($p < 0.001$)
$^{\delta}$ significantly different from the easy auditory task in the ML direction ($p < 0.05$)
$^{\Delta}$ significantly different from the moderate auditory task in the ML direction ($p < 0.05$)
$^{\Theta}$ significantly different from the difficult auditory task in the ML direction ($p < 0.05$)

Fig 5. ML MPF (Hz) across the three levels of difficulty
ϕ significantly different from the easy level of difficulty ($p < 0.05$)

Fig 6. Percentage of trials with errors within the established error limits across the three levels of difficulty
$^{\phi}$ significantly different from the easy level of difficulty ($p < 0.001$)
$^{\lambda}$ significantly different from the moderate level of difficulty ($p < 0.01$)

Fig 1.

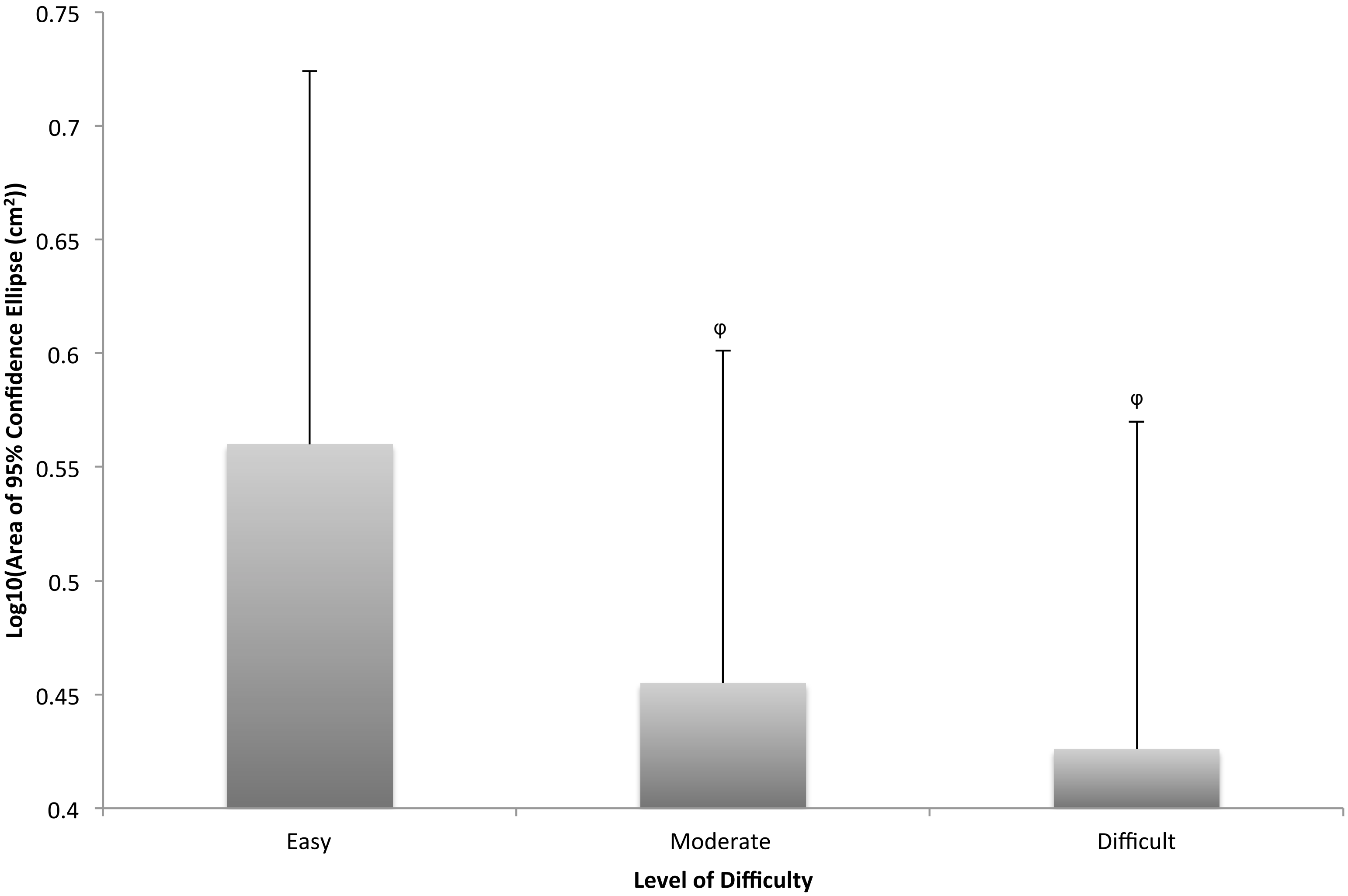

0.75
0.7
0.65
0.6
0.55
0.5
0.45
0.4
Log10(Area of 95% Confidence Ellipse (cm²))
φ
φ
Easy
Moderate
Difficult
Level of Difficulty

Fig 2.

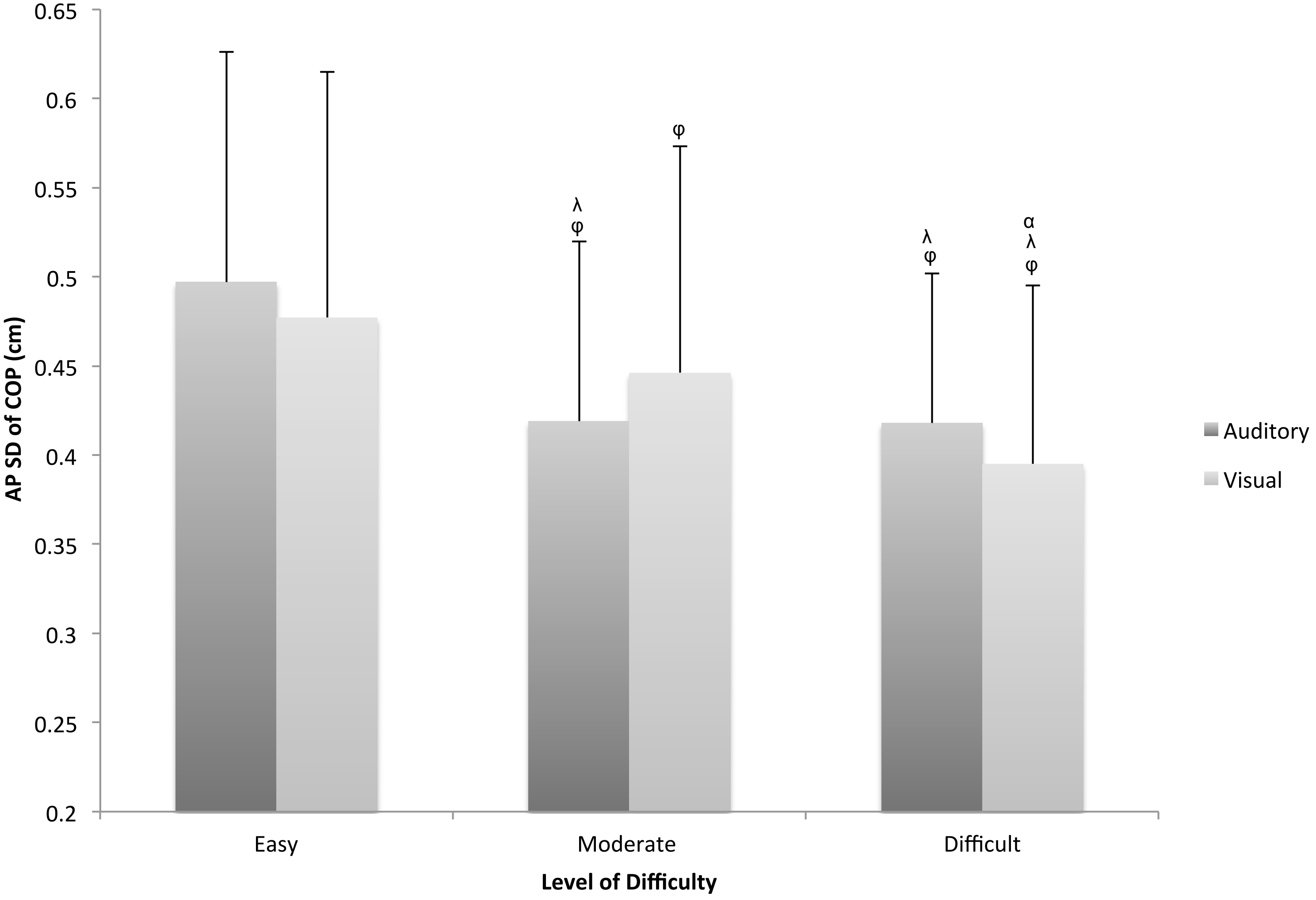

0.65
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0.2
AP SD of COP (cm)
λ
φ
φ
λ
φ
α
λ
φ
Easy
Moderate
Difficult
Level of Difficulty
Auditory
Visual

Fig 3.

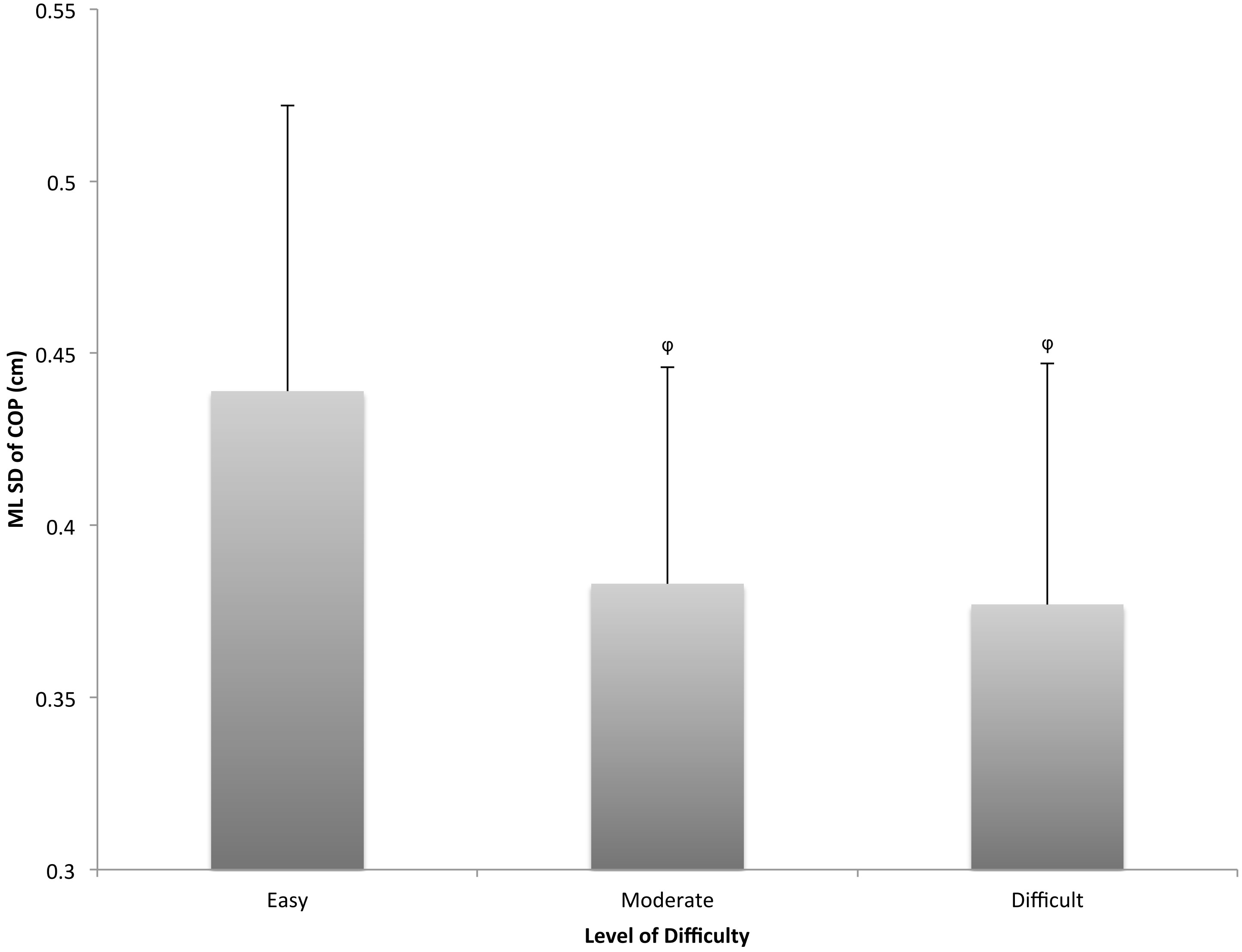
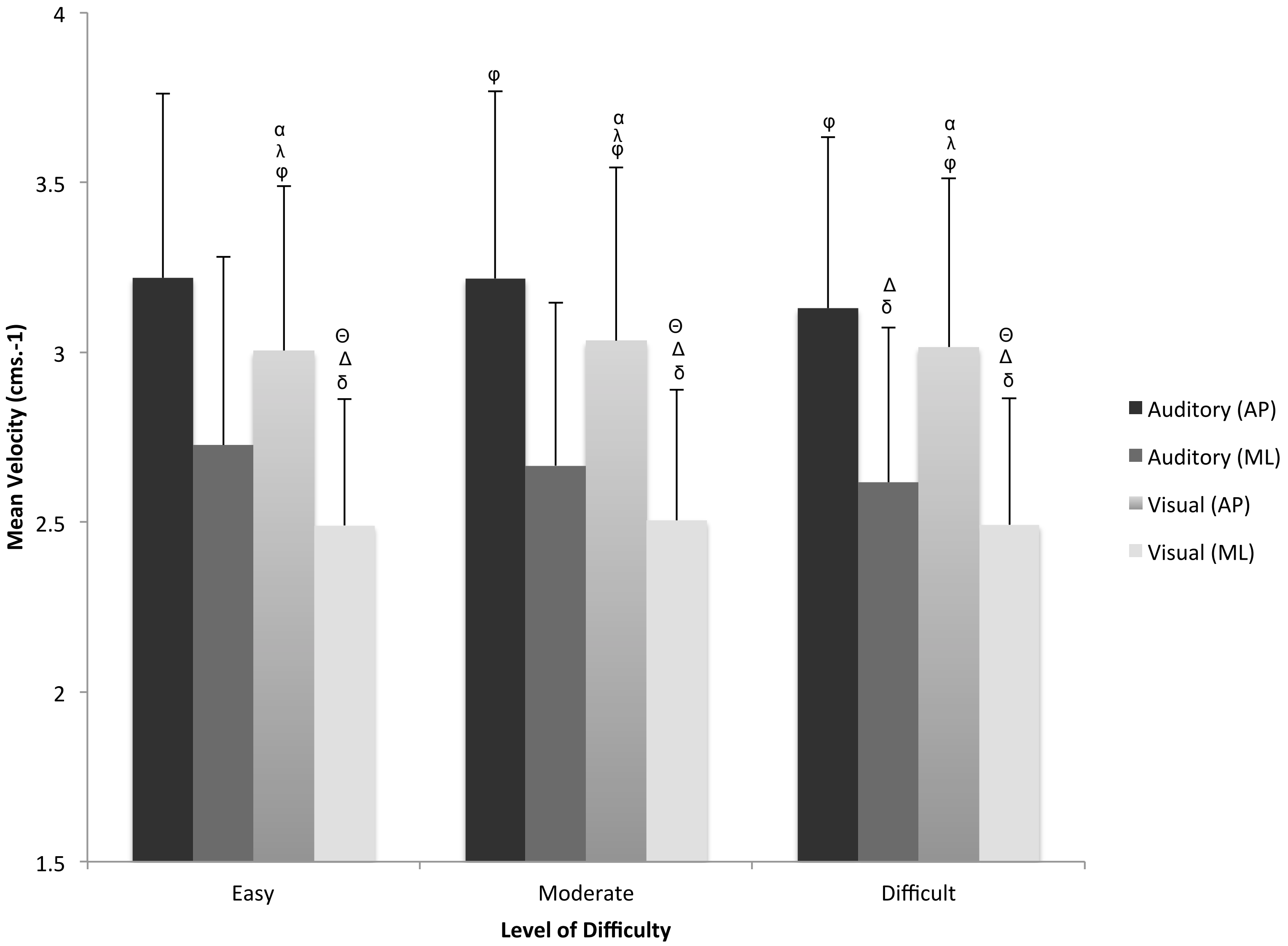
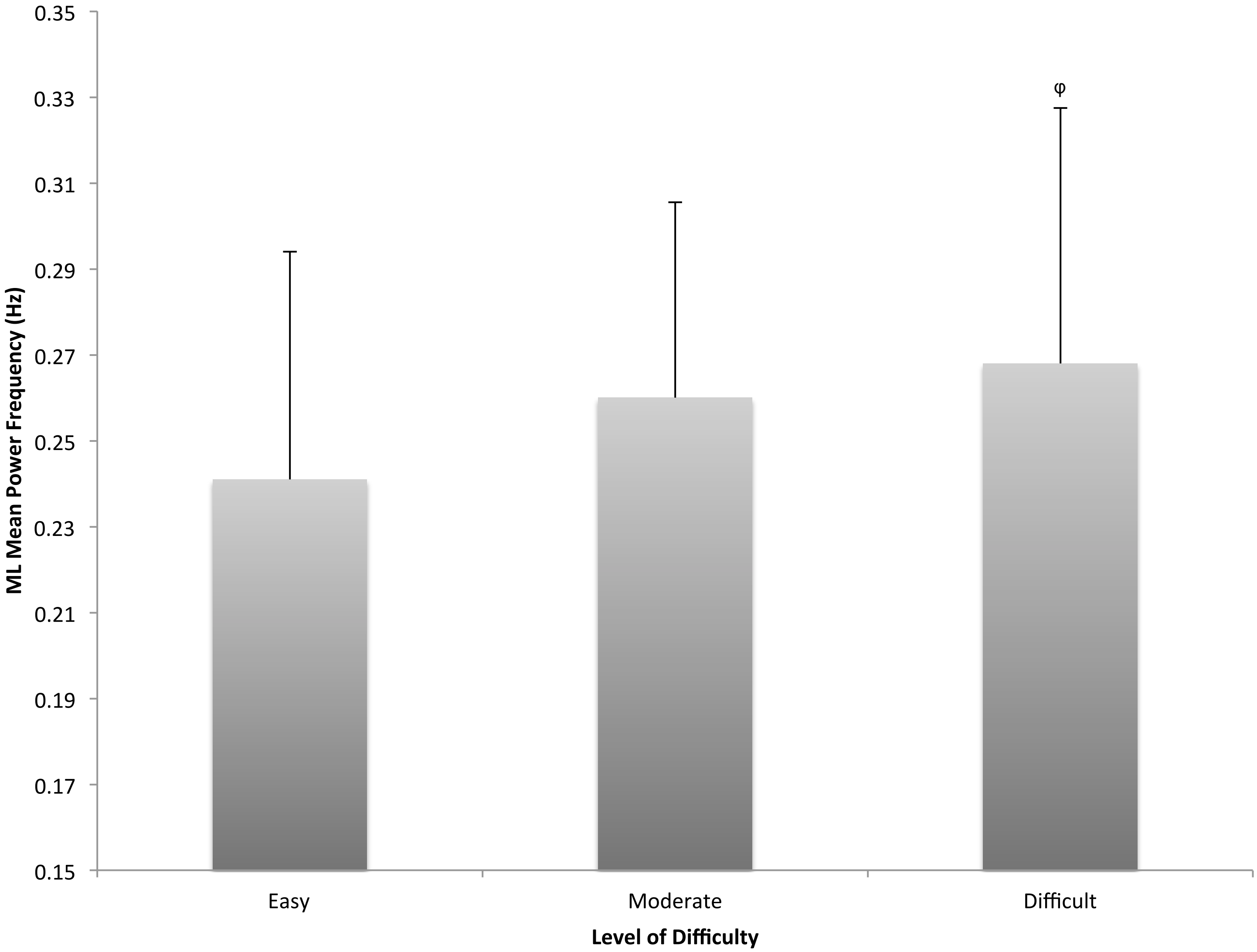

0.55
0.5
0.45
0.4
0.35
0.3
ML SD of COP (cm)
φ
φ
Easy
Moderate
Difficult
Level of Difficulty

Fig 4.



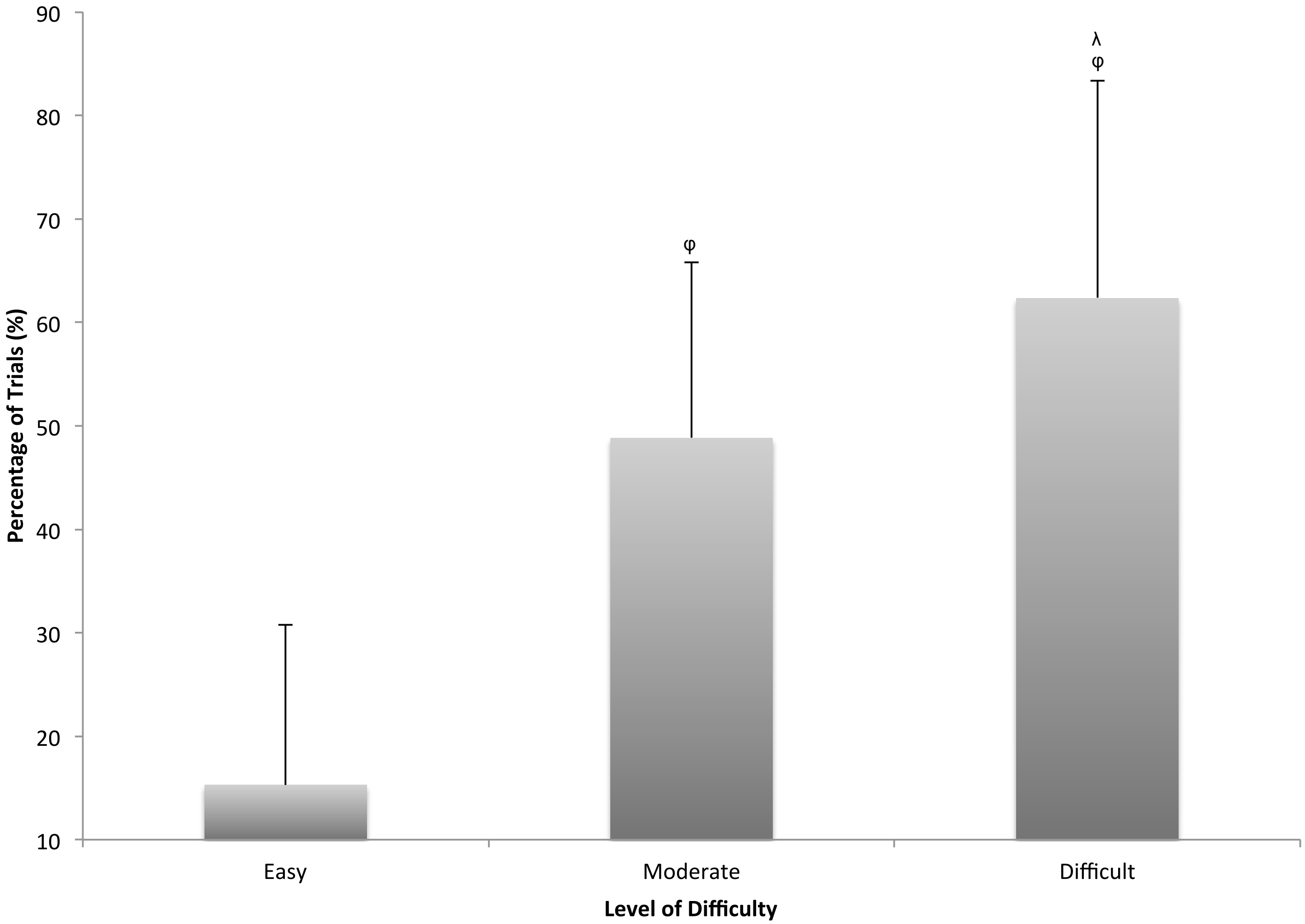
4
3.5
3
2.5
2
1.5
Mean Velocity (cms.-1)
α
λ
φ
Θ
Δ
δ
φ
α
λ
φ
Θ
Δ
δ
φ
Δ
δ
α
λ
φ
Θ
Δ
δ
Easy
Moderate
Difficult
Level of Difficulty
Auditory (AP)
Auditory (ML)
Visual (AP)
Visual (ML)

Fig 5.



0.35
0.33
0.31
0.29
0.27
0.25
0.23
0.21
0.19
0.17
0.15
ML Mean Power Frequency (Hz)
φ
Easy
Moderate
Difficult
Level of Difficulty

Fig 6.


90
80
70
60
50
40
30
20
10
Percentage of Trials (%)
λ
φ
φ
Easy
Moderate
Difficult
Level of Difficulty

CHAPTER FOUR: MANUSCRIPT #2

Inter-stimulus intervals and sensory modality can modulate the effectiveness of a cognitive task on postural control

Journal of Human Movement Science

In preparation for submission

Inter-stimulus intervals and sensory modality can modulate the effectiveness of a cognitive task on postural control

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Abstract

The current literature not only reveals the use of a wide variety of cognitive tasks but variability in their interaction with postural control. The question then arises, as to, whether postural control is sensitive to specific features of a cognitive task. The present experiment assessed the impact of cognitive tasks with inter-stimulus intervals of varied duration on postural control in young adults. Seventeen participants (23.71 ± 1.99 years) were instructed to stand on a force platform while concurrently performing cognitive tasks with inter-stimulus intervals of two and five seconds. The tasks were presented both, auditorily and visually. The visual tasks consisted of counting the total occurrence of a single-digit in a sequence of three-digit numbers. The auditory tasks consisted of counting the total occurrence of a single letter in a sequence of letters. Performing the cognitive tasks with an inter-stimulus interval of two seconds resulted in only an increase in the anterior-posterior (AP) mean power frequency (MPF). Presenting the tasks visually also significantly reduced area of 95% confidence ellipse and AP and medial-lateral (ML) sway variability. These results suggest that inter-stimulus intervals that are of short duration may contribute to promoting postural stability in young adults. Additionally, presenting tasks visually enhances its ability to minimize postural sway.

Key words: postural control, dual-task, sensory modality, cognitive tasks

Word count: 207

1. Introduction

Dual-task paradigms are commonly implemented to evaluate the role of attentional demand on postural control (Woollacott & Shumway-Cook, 2002). Under such conditions, postural sway has been observed to either increase (Pellecchia, 2003) or decrease (Huxhold, Li, Schmiedek, & Lindenberger, 2006; Siu & Woollacott, 2007). A potential contributor to the variable findings reported could be the use of a wide variety of cognitive tasks. For instance, tasks that necessitate articulation such as arithmetic and repeating a number aloud, have been shown to increase postural sway (Dault, Yardley, & Frank, 2003; Yardley, Gardner, Leadbetter, & Lavie, 1999), suggesting that instability is more a result of perturbation than a competition for attention resources. Similarly, Woollacott and VanderVelde (2008) implemented tasks with both, spatial and modality components, and observed an increase in postural sway with the spatial n-back tasks suggesting that postural stability is also sensitive to tasks requiring spatial processing than modality processing.

Even studies employing tasks with similar processing requirements as the aforementioned studies have produced varying results. For example, Swan, Otani, Loubert, & Dunbar (2004) implemented Brooks' spatial and non-spatial memory tasks and found no significant difference between the two. Additionally, while Woollacott and VanderVelde (2008) observed no sensitivity to modality, several studies manipulating modality have reported improvement in stability with tasks presented auditorily (Jamet, Deviterne, Gauchard, Vancon, & Perrin, 2007; Riley, Baker, Schmit, & Weaver, 2005). Therefore, the interaction between postural control and cognition in young adults may reflect the cognitive task used than a competition for resources (Ramenzoni, Riley, Shockley, & Chiu, 2007).

Additionally, maintaining an upright stance is suggested to require minimal resource since it is largely a well-learned task (Dault, Geurts, Mulder, & Duysens, 2001a). Therefore, postural instability may be attributed to attentional interference brought on by the cognitive tasks than a competition for attentional resources. Studies have found an individual's focus of attention to impact the execution of motor skills such as postural control (Shea & Wulf, 1999; Wulf, Hob, & Prinz, 1998; Wulf, McNevin, & Shea, 2001; for a review, see Wulf, 2007). In particular, directing focus to the movement itself (i.e. internal focus) has been found to be detrimental to postural performance than directing focus to the effect of a movement on an apparatus or implement (i.e. external focus). It is suggested that an internal focus interferes with the coordination of motor control processes responsible for regulating the movement. Whereas, an external focus enables the motor control process to function unconstrained, promoting the emergence of a more automatic mode of control. Although it has never been examined, inter-stimulus intervals within a cognitive task may alter a participant's allocation of attention in a dual-task context. Specifically, long duration intervals may allow focus to shift from the cognitive task to the postural task, interfering with the motor control process, consequently causing a decline in stability. On the other hand, short intervals may limit such deviations and ensure that focus is maintained on the cognitive task, allowing postural control to operate in an automatic mode. A study by Burcal, Drabik, and Wikstrom (2014) found focusing on the cognitive task to precipitate a greater reduction in anterior-posterior sway than focusing on the postural task. Thus, understanding how a cognitive task influences the allocation of attention may be vital in breaking down the interaction between postural control and cognition.

Therefore, the objective of the present experiment was first, to examine if the duration of an inter-stimulus interval can alter the effectiveness of a cognitive task on postural control and second, to determine if postural control is sensitive to the modality of the cognitive task. It was hypothesized that: (1) irrespective of modality, cognitive task with short inter-stimulus intervals would produce the greatest improvement in postural stability and (2) irrespective of inter-stimulus interval, presenting the cognitive tasks visually would yield greater improvements in postural stability than presenting the tasks auditorily.

2. **Methods**

2.1. Participants

Seventeen healthy University of Ottawa students (Nine females, eight males; 23.71 ± 1.99 years) participated in the experimental protocol. A health questionnaire was administered to ensure participants had no injuries or disorders that could impede their balance ability. Participants had no prior experience with the tasks. The study was approved by the Research Board at the University of Ottawa in accordance with the principle of the Declaration of Helsinki. Prior to testing, each participant signed an informed consent form.

2.2. Apparatus

To assess postural control, an AMTI force platform (ORG-6-1000, Don Mills, ON, Canada) was used to record the body's projection of ground-reaction forces at a sampling frequency of 500 Hz. For the auditory cognitive tasks, a media player was used to present the recording. Speakers were placed on either side of the participant. For the visual cognitive tasks, a

19” computer monitor placed at eye-level, 1.5 meters from the force platform, was used to display the PowerPoint slides.

2.3. Postural task

The postural task consisted of standing as still as possible on the force platform with feet together and arms alongside the body, while looking at a fixation cross or a 3-digit sequence displayed in the middle of the computer screen, 1.5 meters from the force platform. The placement of the participant’s feet was traced to ensure the same position was maintained throughout the entire experimental protocol.

2.4. Cognitive tasks

Task parameters such as an acceptable error score and stimulus presentation varied across conditions. Error score limits were designed to match the cognitive demand of the task and were not modeled after previous literature. In all cognitive conditions, participants provided their answer only upon completion of the trial. To eliminate articulation, all cognitive tasks were executed silently. Participants were prohibited from using their fingers as a counting aid in order to maximize cognitive effort.

2.4.1. Discrete and continuous auditory cognitive tasks

For both tasks, a string of letters was auditorily presented and participants were instructed to count the total number of times a pre-selected letter was verbalized in the given string. For the discrete task, each letter was presented every five seconds for a total of 12 letters. If participants’ error score was greater than two, the trial was redone at the end of the experimental protocol. For the continuous task, each letter was presented every two seconds for a total of 30 letters. If participants' error score was greater than three, the trial was redone at the end of the experimental protocol. Each discrete and continuous trial used a different recording to eliminate the possibility of memorization.

2.4.2. Discrete and continuous visual cognitive tasks

For both tasks, a sequence of 3-digit numbers was presented on the computer screen and participants were instructed to count the total number of times a pre-selected digit appeared in the given sequence. The tasks required participants to simultaneously search for the specified digit in each 3-digit number and keep a running total. For the discrete task, each 3-digit number was presented every five seconds for a total of 12 3-digit numbers. If participants' error score was greater than two, the trial was redone at the end of the experimental protocol. For the continuous task, each 3-digit number was presented every two seconds for a total of 30 3-digit numbers. If participants' error score was greater than three, the trial was redone at the end of the experimental protocol. Each discrete and continuous trial used a different sequence to eliminate the possibility of memorization.

2.5. Procedure

The experimental protocol was comprised of one single-task condition and four dual-task conditions. The single-task condition consisted of standing as still as possible on a force platform with feet together and arms alongside the body with no concurrent cognitive task. The dual-task conditions consisted of one postural task (feet together) and two cognitive tasks (discrete and continuous), each presented in two modalities (auditory and visual). At the beginning of the experimental protocol, participants performed each cognitive task in a seated position. Instructions regarding the postural task were provided only at the beginning of testing to prevent participants from prioritizing posture over cognition during the dual-task conditions. The single- and dual-task conditions were comprised of five, 60-second trials. All trials were counterbalanced to eliminate an order effect. In addition, if errors were outside the established error limits, trials were redone at the end of the experimental protocol. Participants were not informed if mistakes were made.

2.6. Data analysis

Center of pressure (COP) was acquired from the ground-reaction forces collected by the force platform. Subsequently, MatLab software (MathWorks Inc., MA, USA) was used to attain outcome measures such as area of 95% confidence ellipse, standard deviation (SD) of COP in the anterior-posterior (AP) and medial-lateral (ML) directions and mean velocity in the AP and ML directions. Additionally, a Fast Fourier Transform (FFT) analysis was performed on the COP data using BioProc3 Software (D.G.E. Robertson, Ottawa, Canada). This allowed for mean power frequency (MPF) to be computed. This analysis discerns subtle differences in frequency adjustments between experimental conditions (Wulf et al., 2001).

2.7. Statistical analysis

Task type (discrete and continuous) x modality (auditory and visual) analysis of variance (ANOVA) with repeated measures was performed on each of the outcome measures. One-way ANOVAs with repeated measure on task type (no cognitive task, discrete, continuous) for each modality were performed on each of the outcome measure. Additionally, task type x modality

ANOVA with repeated measures was performed on percentage of trials with errors within the established error limits. If Mauchly's Test of Sphericity was violated, a Greenhouse- Geisser correction was performed. If the data failed normality, a log transformation was applied. Statistical significance was set at $p < 0.05$. When necessary, Tukey HSD post-hoc analysis was performed to determine the location of significance.

3. Results

Means and standard deviations (SD) for the following outcome measures are presented in Table 1.

3.1. Area of 95% confidence ellipse

A logarithmic transformation was applied to the area of 95% confidence ellipse.

The main effect of task type, $F\ (1, 16) = 0.04$, $p = 0.84$, $\eta_p^2 = 0.002$, on sway area was not statistically significant. The main effect of modality, $F\ (1, 16) = 11.49$, $p = 0.004$, $\eta_p^2 = 0.408$, on sway area was statistically significant (Fig 1.). The results indicated that the visual cognitive tasks produced significantly smaller sway areas compared to the auditory cognitive tasks ($p = 0.004$). The task type x modality interaction, $F\ (1, 16) = 3.78$, $p = 0.07$, $\eta_p^2 = 0.192$, was not statistically significant.

The main effect of auditory task type, $F\ (2, 32) = 1.19$, $p = 0.32$, $\eta_p^2 = 0.069$, on sway area was not statistically significant. The main effect of visual task type, $F\ (2, 32) = 13.58$, $p = 0.00004$, $\eta_p^2 = 0.459$, on sway area was statistically significant. Post-hoc analysis revealed that the discrete visual and the continuous visual cognitive tasks generated significantly smaller sway areas compared to the no cognitive task condition ($M = 0.623$, $SD = 0.186$) ($p = 0.00015$ and $p =$

0.004 respectively). No statistically significant difference was observed between the discrete and continuous cognitive tasks (p = 0.22).

3.2. SD of COP

3.2.1. AP SD of COP

The main effect of task type, F (1, 16) = 0.02, p = 0.89, η_p^2 = 0.001, on sway variability in the AP direction was not statistically significant. The main effect of modality, F (1, 16) = 7.21, p = 0.02, η_p^2 = 0.311, on sway variability in the AP direction was statistically significant (Fig 2.). The results indicated that the visual cognitive tasks reduced sway variability compared to the auditory cognitive tasks (p = 0.02). The task type x modality interaction, F (1, 16) = 1.32, p = 0.27, η_p^2 = 0.076, was not statistically significant.

The main effect of auditory task type, F (2, 32) = 0. 78, p = 0.47, η_p^2 = 0.047, on sway variability of COP in the AP direction was not statistically significant. The main effect of visual task type, F (2, 32) = 4.21, p = 0.02, η_p^2 = 0.208, on sway variability of COP in the AP direction was statistically significant. Post-hoc analysis indicated that the discrete visual cognitive task reduced sway variability compared to the no cognitive task condition (p = 0.02).

3.2.2. ML SD of COP

The main effect of task type, F (1,16) = 0.48, p = 0.50, η_p^2 = 0.029, on sway variability of COP in the ML direction was not statistically significant. The main effect of modality, F (1,16) = 12.42, p = 0.003, η_p^2 = 0.437, on sway variability in the ML direction was statistically significant (Fig 2.). The results indicated that the visual cognitive tasks significantly reduced sway variability compared to the auditory cognitive tasks (p = 0.003). The task type x modality interaction, F (1, 16) = 0.89, p = 0.36, η_p^2 = 0.053, was not statistically significant.

The main effect of auditory task type, F (2, 32) = 0.10, p = 0.91, η_p^2 = 0.06, on sway variability of COP in the ML direction was not statistically significant. The main effect of visual task type, F (2, 32) = 8.30, p = 0.0012, η_p^2 = 0.341, on sway variability of COP in the ML direction was statistically significant. Post-hoc analysis indicated that the discrete visual and continuous visual cognitive tasks significantly reduced sway variability compared to the no cognitive task condition (p = 0.0013 and p = 0.02, respectively). No statistically significant difference was found between the discrete and continuous cognitive tasks (p = 0.55).

3.3. Mean velocity

3.3.1. AP Mean velocity

The main effects of task type and modality on mean velocity in the AP direction were superseded by a task type x modality interaction, F (1, 16) = 14.99, p = 0.001, η_p^2 = 0.484 (Fig 3.). Post-hoc analysis indicated that the continuous visual cognitive task yielded a significantly lower mean velocity compared to the discrete and continuous auditory cognitive tasks (p = 0.0006 and p = 0.0002, respectively).

The main effect of auditory task type, F (2, 32) = 21.77, p = 0.0012, η_p^2 = 0.576, on mean velocity in the AP direction was statistically significant. Post-hoc analysis indicated that the continuous auditory cognitive task significantly increased mean velocity compared to the no cognitive task and discrete visual cognitive task conditions (p = 0.00012 and p = 0.007, respectively). The main effect of visual task type, F (2, 32) = 0.12, p = 0.73, η_p^2 = 0.008, on mean velocity in the AP direction was not statistically significant.

3.3.2. ML Mean velocity

The main effects of task type and modality on mean velocity in the ML direction were superseded by a task type x modality interaction, F (1, 16) = 5.95, p = 0.03 η_p^2 = 0.271 (Fig 3.). Post-hoc analysis indicated that the continuous visual cognitive task yielded a significantly lower mean velocity compared to the continuous auditory cognitive task (p = 0.0003).

The main effect of auditory task type, F (2, 32) = 5.92, p = 0.03, η_p^2 = 0.270, on mean velocity in the ML direction was statistically significant. Post-hoc analysis indicated that the continuous auditory cognitive task significantly increased mean velocity compared to the no task condition (p = 0.005). The main effect of visual task type, F (2, 32) = 2.45, p = 0.10, η_p^2 = 0.102, on mean velocity in the ML direction was not statistically significant.

3.4. MPF

3.4.1. AP MPF

The main effect of task type, F (1, 16) = 7.01, p = 0.02, η_p^2 = 0.305, on MPF in the AP direction was statistically significant (Fig 4.). The results indicated that the continuous cognitive tasks yielded higher MPFs compared to the discrete cognitive tasks (p = 0.02). The main effect of modality, F (1, 16) = 0.30, p = 0.59, η_p^2 = 0.019, on MPF in the AP direction was not statistically significant. The task type x modality interaction, F (1,16) = 3.68, p = 0.07, η_p^2 = 0.187, was not statistically significant.

The main effect of auditory task type, F (2, 32) = 3.564, p = 0.07, η_p^2 = 0.182, on MPF in the AP direction resulted in a trend towards statistical significance. The main effect of visual task type, F (2, 32) = 1.197, p = 0.28, η_p^2 = 0.070, was not statistically significant.

3.4.2. ML MPF

The main effect of task type, F (1,16) = 2.22, p = 0.16, η_p^2 = 0.122, on MPF in the ML direction was not statistically significant. The main effect of modality, F (1, 16) = 0.06, p = 0.81, η_p^2 = 0.004, on MPF in the ML direction was not statistically significant. The task type x modality interaction, F (1, 16) = 0.39, p = 0.55, η_p^2 = 0.023, was not statistically significant.

The main effect of auditory task type, F (2, 32) = 3.167, p = 0.056, η_p^2 = 0.165, on MPF in the ML direction resulted in a trend towards statistical significance. The main effect of visual task type, F (2, 32) = 4.225, p = 0.02, η_p^2 = 0.209, on MPF in the ML direction was statistically significant. Post-hoc analysis indicated the continuous visual cognitive task yielded a higher MPF compared to the no cognitive task condition (p = 0.03).

3.5. Cognitive performance

The main effect of task type, F (1,16) = 16.55, p = 0.0009, η_p^2 = 0.508, on percentage of trials with errors within the appropriate error limits was statistically significant (Fig. 5). . Post-hoc analysis indicated that the continuous cognitive tasks yielded a higher percentage of trials than the discrete cognitive task. The main effect of modality, F (1, 16) = 2.98, p = 0.10 η_p^2 = 0.157, on percentage of trials with errors within the appropriate error limits was not statistically significant. The task type x modality interaction, F (1, 16) = 0.00, p = 1.00, η_p^2 = 0.00, was not statistically significant.

4. **Discussion**

The aim of the present experiment was two-fold. First, to examine if the duration of an inter-stimulus interval can modify the effectiveness of a cognitive task on postural stability and second, to determine if postural stability is responsive to the modality of a cognitive task. Based on the aforementioned objectives, a set of hypotheses was proposed: first, irrespective of modality, the continuous tasks (i.e. brief inter-stimulus intervals) would yield greater postural stability than the discrete tasks (i.e. longer inter-stimulus intervals). Second, irrespective of task type, visual cognitive tasks would facilitate greater postural stability than auditory cognitive tasks. To our knowledge, this is the first experiment to evaluate stimuli presentation and its potential implications. The results indicated: (1) the continuous task generated a significantly higher AP MPF compared to the discrete task; (2) presenting the tasks visually generated a smaller sway area and reduced AP and ML sway variability compared to presenting the tasks auditorily. A detailed discussion of the findings follows.

4.1. Modifications to postural stability as a function of task type

Inter-stimulus intervals of five seconds were postulated to afford participants with the opportunity to shift overt attention away from the cognitive task. Moreover, the long inter-stimulus intervals would make maintaining focus challenging, consequently precipitating postural deficits if the available attention is then directed towards postural control. This prediction was derived from extensive attentional focus literature suggesting that utilizing an internal focus (i.e. concentrating on the movement itself) interferes with the automatic control processes responsible for regulating the movement (Shea & Wulf, 1999; Wulf et al., 1998; Wulf et al., 2001; for a review see Wulf, 2007). Alternatively, inter-stimulus intervals of two seconds were postulated to necessitate greater focus, thereby minimizing or even eliminating opportunities for attention to deviate. As a result, the automatic control processes would remain unconstrained and postural stability would be promoted (Shea & Wulf, 1999; Wulf et al., 1998; Wulf et al., 2001). Moreover, postural control in young adults is relatively automatic and requires minimal resources unless challenged (e.g. unstable support surface, etc.) (Dault et al., 2001a), therefore, observations of postural deficits under normal circumstances (e.g. stable support surface, feet together, etc.) may be more a result of attentional interference with the motor control processes than a competition for attentional resources.

According to the findings, the continuous task yielded a significantly higher AP MPF compared to the discrete task. This may suggest that the continuous tasks encouraged a more automatic mode of control. Studies have reported increased MPF when attentional focus was shifted from the body by way of an external focus, suggesting that the rise in MPF reflects the presence of an automatic mode of control. (Wulf et al., 2001; Wulf, Shea & Park, 2001). Moreover, shorter inter-stimulus intervals may in fact have limited interference with the automatic processes by ensuring focus was constantly maintained on the cognitive task. However, since the present experiment observed no significant difference in sway area, AP and ML sway variability and ML MPF, the potential implications of inter-stimulus intervals remain exceedingly speculative. The lack of significance may also be attributed to the requirements of the cognitive task, specifically keeping count of a number or letter. This may have helped maintain focus on the cognitive task during the five-second delays; however, we are still inclined to suggest that participants had the opportunity to flexibly allocate their attention between the discrete and postural tasks due to the task's very low cognitive demands and the observed increase in AP MPF.

In a cohort of healthy young adults, we suggest that when executing a relatively simple postural task, a decline in cognitive performance does not necessarily demonstrate a prioritization of stability over cognition. Rather, it may simply reflect the complexity of the given cognitive task. This was apparent in the present findings, as the task with a greater demand (i.e. continuous cognitive task) yielded a higher percentage of trials with errors within the error limits. Moreover, releasing postural control from any attentional influences aides in promoting a more automatic mode of control, which in turn provides resources to the cognitive task that could otherwise be utilized by the postural control system (Shea & Wulf, 1999, Wulf et al., 1998; Riley et al., 2003). Therefore, we suggest that even though participants committed errors, a resource competition did not arise and both tasks had ample resources at their disposal. Additionally, no trials were needed to be excluded from analysis seeing as the error limits were never surpassed by any of the participants. Moreover, several studies have observed stable cognitive performance across postural task of varying difficulty, when the resource demand was indeed higher (Dault et al., 2001a; Swan et al., 2004). Further demonstrating that even under greater postural demands, young adults do not have the tendency to sacrifice cognitive performance, as opposed to their older counterparts (Huxhold et al., 2006).

4.2. Modifications to postural stability as a function of modality

The discrete and continuous tasks were also presented both, auditorily and visually, to determine if the interaction between postural control and cognition is modality specific. The findings indicated a notable reduction in sway area, AP and ML sway variability when the cognitive tasks were presented visually, suggesting that postural control has a differential response to tasks presented in different modalities. The considerable reduction in postural sway may be related to the formation of a visual anchor (Vander Velde, Woollacott, & Shumway-Cook, 2005), which would have minimized any unnecessary eye movement. Hunter and Hoffman (2001) reported excessive eye movement to produce higher ML sway variability compared no eye movement as a result of elevated oculomotor demands. Reducing sway variability also aids in maintaining stable fixation of the presented stimuli (Stoffregen, Pagulayan, Bardy, & Hettinger, 2000). While both auditory and visual tasks necessitated constant fixation (fixation cross and 3-digit numbers, respectively), participants did report occasionally deviating during the auditory conditions. Moreover, although required, constant visual fixation was not necessary for accurately performing the auditory task, whereas, it was for the visual. If participants altered their fixation numbers in the sequence could potentially be overlooked, consequently compromising cognitive performance.

Processing visual stimuli into short-term memory, more specifically into the phonological loop, requires the information to be recoded into phonological form, while auditory stimuli enters directly (Repovs & Baddeley, 2003). The additional processing requirement did not appear to negatively interact with the postural control system in the present study. In fact, presenting the tasks visually yielded greater postural performance than presenting the tasks auditorily, which as previously mentioned is more related to the establishment of a visual anchor

(Vander Velde et al., 2005). While the current cognitive tasks utilized the same component of working memory, postural control may not have a selective response to cognitive tasks utilizing different components of working memory. Several studies have employed cognitive tasks that specifically target different components of working memory (e.g., phonological loop, visuo-spatial sketchpad and central executive) and collectively, observed no significance differences in postural or cognitive performance (Dault et al., 2001b; Ramenzoni et al., 2007; Vander Velde et al., 2005), ultimately drawing the same conclusion as the present experiment.

Additional analyses were performed to compare single- and dual-task performance. Compared to postural task alone, both visual cognitive tasks (discrete and continuous) reduced sway area, AP and ML sway variability, similar to previous literature (Kerr, Condon, & McDonald, 1985; Huxhold et al., 2006; Maylor, Allison, & Wing, 2001; Siu & Woollacott, 2007). However, no significant difference was observed for sway area, AP and ML sway variability when the tasks were presented auditorily, suggesting that cognitive tasks presented visually are more effective in minimizing postural sway than their auditory counterparts. However, this contradicts several previous studies that have demonstrated greater postural stability when tasks are presented auditorily (Jamet et al., 2007; Riley et al., 2005). Possibly, the aforementioned tasks may have been more cognitively demanding than the present auditory tasks.

With regards to MPF, no significant difference was found between the two modalities. However, when compared to single-task, both types of visual cognitive tasks yielded higher ML MPF. This suggests that the cognitive tasks withdrew attention from postural control and in doing so limited interference with the motor control processes (Shea & Wulf, 1999; Wulf et al., 1998; Wulf et al., 2001). McNevin and Wulf (2002) reported no significant difference in MPF between the baseline and internal focus conditions, suggesting that participants may adopt an internal focus when performing only the postural task. Participants internalizing focus and consequently, constraining the motor control processes may explain why baseline generated a low ML MPF. With respect to the auditory cognitive tasks, a trend for significance was observed for both AP and ML MPF.

4.3. Task type by modality interaction

The current results revealed a task type by modality for AP and ML mean velocity. The continuous cognitive task increased AP and ML mean velocity when presented auditorily. The effect was not observed when the task was presented visually. Additionally, the continuous auditory cognitive task produced AP and ML mean velocities that were significantly higher than baseline. The discrete and continuous auditory cognitive tasks may not require a reduction in mean velocity (i.e. minimization of postural sway) to accurately perform the tasks. In terms of cognitive performance, only 7% of all discrete trials and 11% of all continuous trials contained errors within the established error limits; the remaining trials were performed accurately.

5. Conclusion

In summary, the present experiment suggests that inter-stimulus intervals may contribute to the effectiveness of a cognitive task on postural control. Although significance was only observed in ML MPF, performing cognitive tasks with shorter inter-stimulus intervals may aid in maintaining focus on the cognitive task and limit opportunities for attention to shift from the cognitive task to postural control. This experiment highlights the need for future research to determine if specific features of a cognitive task generate differential effects on postural control. Finally, based on the findings, presenting tasks visually appears to be a more effective medium for promoting postural stability than presenting tasks auditorily due to the establishment of visual anchor and the consequent reduction in ocular movement.

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Table 1. Mean and standard deviation (SD) of baseline and each cognitive task across all outcome measures

	Baseline		Discrete Auditory		Continuous Auditory		Discrete Visual		Continuous Visual	
Outcome Measure	M	SD	M	SD	M	SD	M	SD	M	SD
Area of 95% confidence ellipse (cm^2)	0.623	0.186	0.612	0.182	0.580	0.163	0.502	0.170	0.541	0.164
SD of COP in AP (cm)	0.300	0.167	0.521	0.172	0.497	0.129	0.458	0.109	0.477	0.138
SD of COP in ML (cm)	0.464	0.087	0.459	0.089	0.456	0.081	0.406	0.073	0.422	0.085
Mean velocity in AP (cm/s)	3.004	0.503	3.112	0.519	3.219	0.542	3.011	0.485	3.015	0.485
Mean velocity in ML (cm/s)	2.513	0.363	2.588	0.405	2.727	0.553	2.495	0.362	2.490	0.371
MPF in AP (Hz)	0.203	0.078	0.191	0.042	0.242	0.064	0.215	0.038	0.233	0.057
MPF in ML (Hz)	0.206	0.040	0.222	0.051	0.243	0.049	0.231	0.041	0.238	0.057

Figure Captions

Fig 1. Area of 95% confidence ellipse (cm^2) across modality
ϕ significantly different from the auditory modality ($p = 0.004$)

Fig 2. AP and ML sway variability (cm) across modality
ϕ significantly different from the auditory modality in the AP direction ($p = 0.02$)
λ significantly different from the auditory modality in the ML direction ($p = 0.002$)

Fig 3. AP and ML mean velocity (cm.s^{-1}) across task type
ϕ significantly different from the discrete auditory cognitive task in the AP direction ($p < 0.01$)
λ significantly different from the continuous auditory cognitive task in the AP direction ($p < 0.001$)
α significantly different from the continuous auditory cognitive task in the ML direction ($p < 0.05$)

Fig 4. AP MPF (Hz) across task type
ϕ significantly different from the discrete cognitive tasks ($p = 0.02$)

Fig 5. Percentage of trials with errors within the established error limits across task type
ϕ significantly different from the discrete cognitive tasks ($p = 0.0009$)

Fig 1.

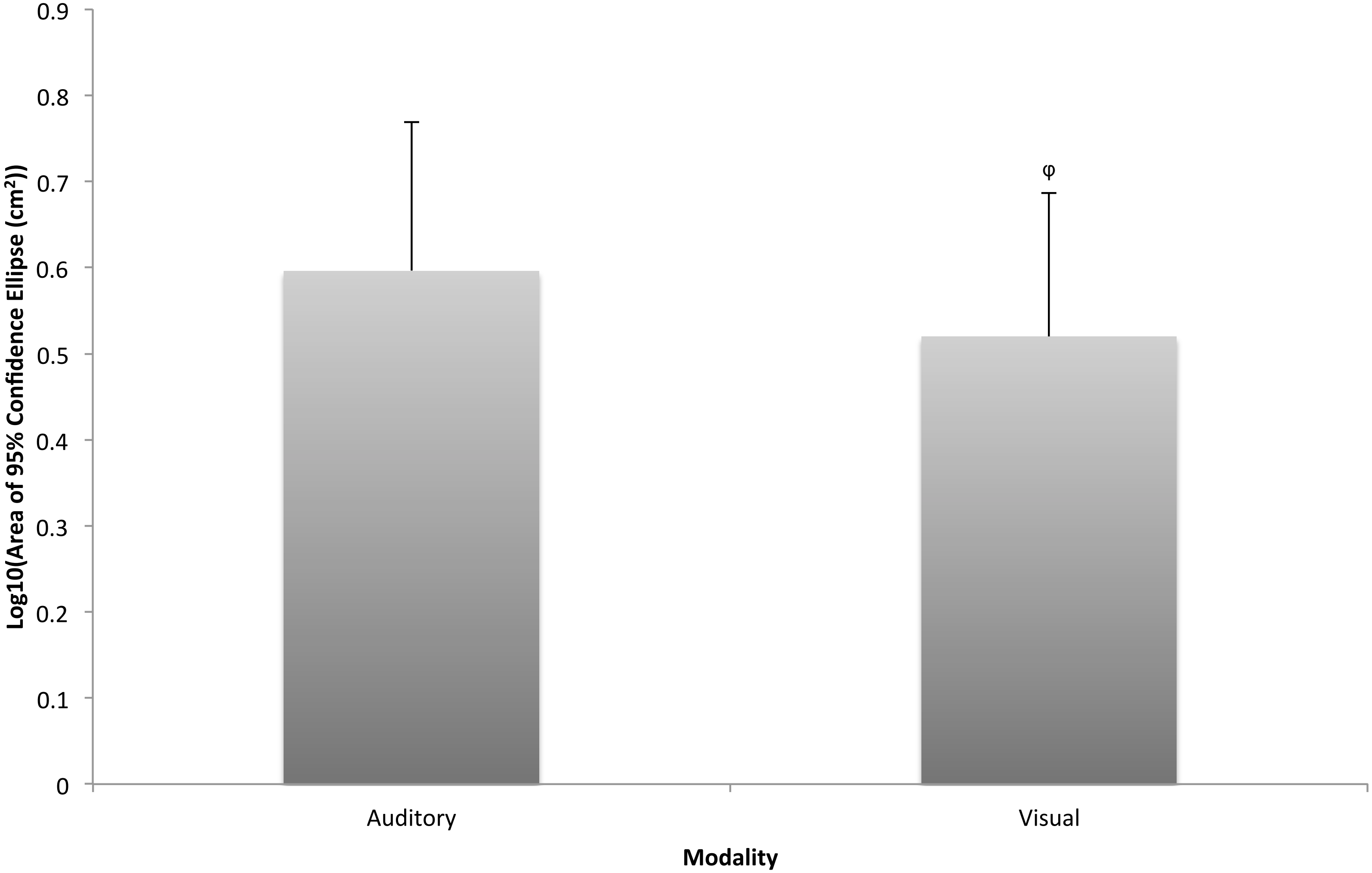

0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Log10(Area of 95% Confidence Ellipse (cm²))
φ
Auditory
Visual
Modality

Fig 2.

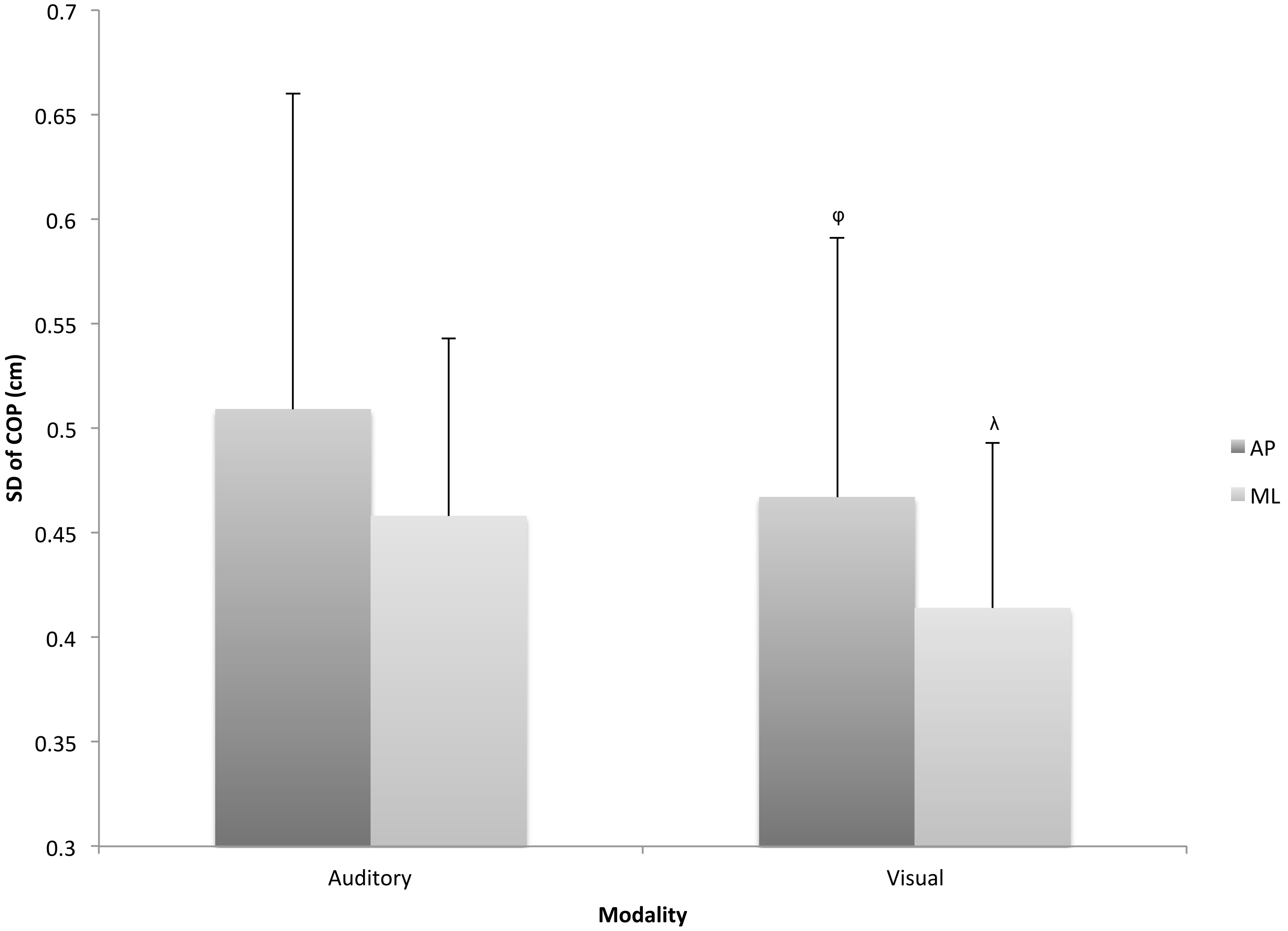
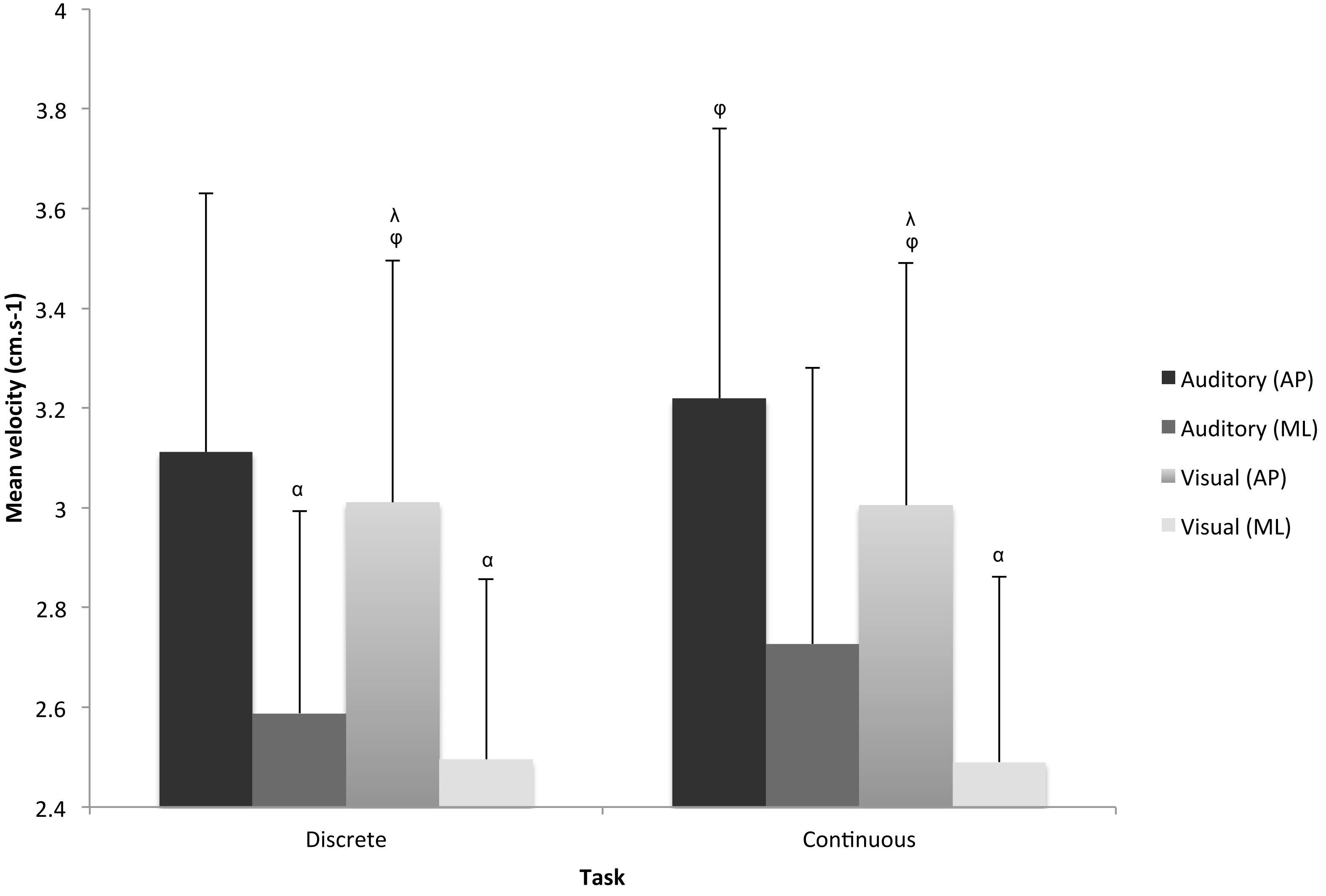

0.7
0.65
0.6
0.55
0.5
0.45
0.4
0.35
0.3
SD of COP (cm)
φ
λ
AP
ML
Auditory
Visual
Modality

Fig 3.



Mean velocity (cm.s-1)
4
3.8
3.6
3.4
3.2
3
2.8
2.6
2.4
φ
λ
φ
λ
φ
α
α
α
Discrete
Continuous
Task
Auditory (AP)
Auditory (ML)
Visual (AP)
Visual (ML)

Fig 4.

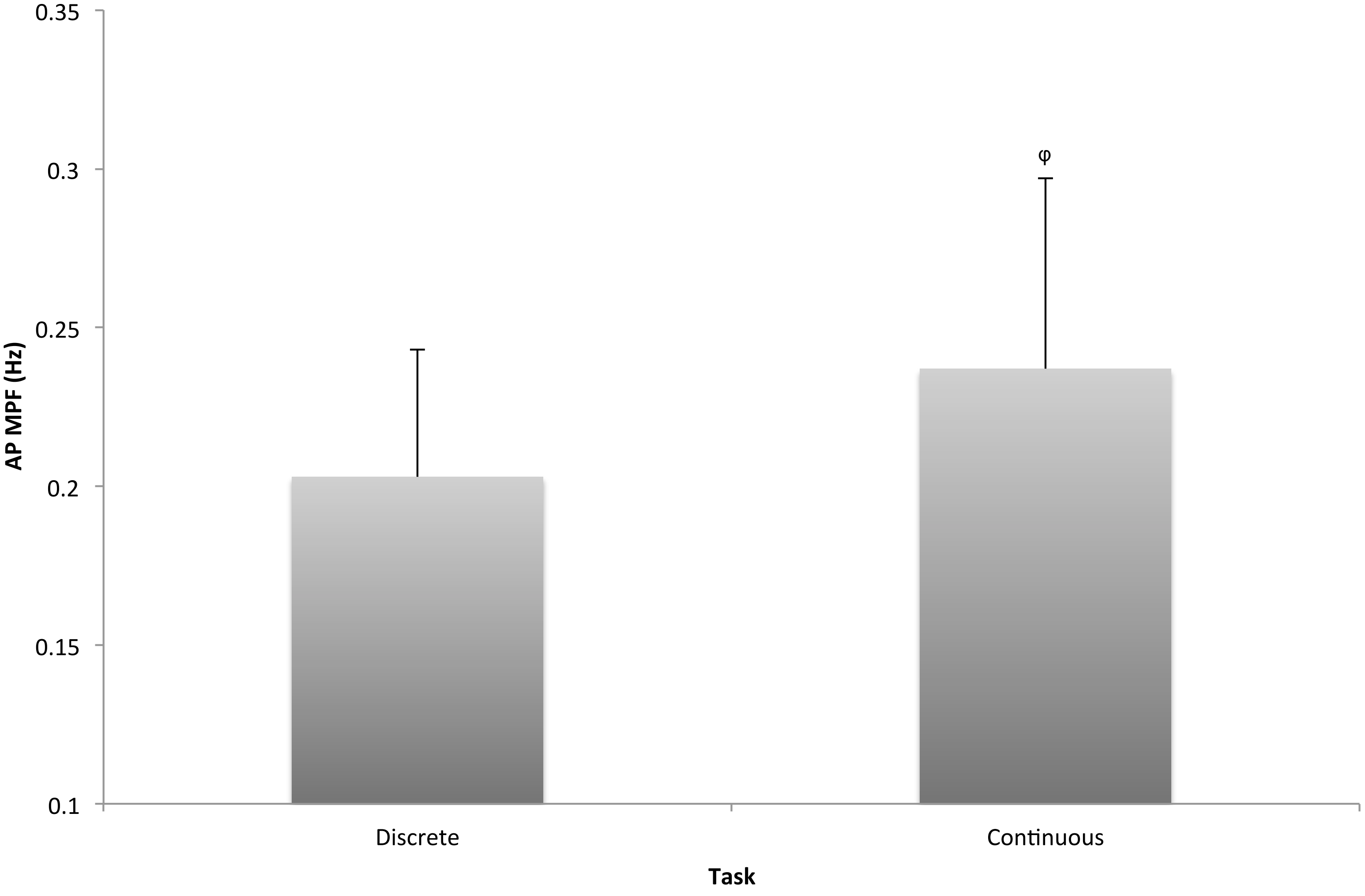
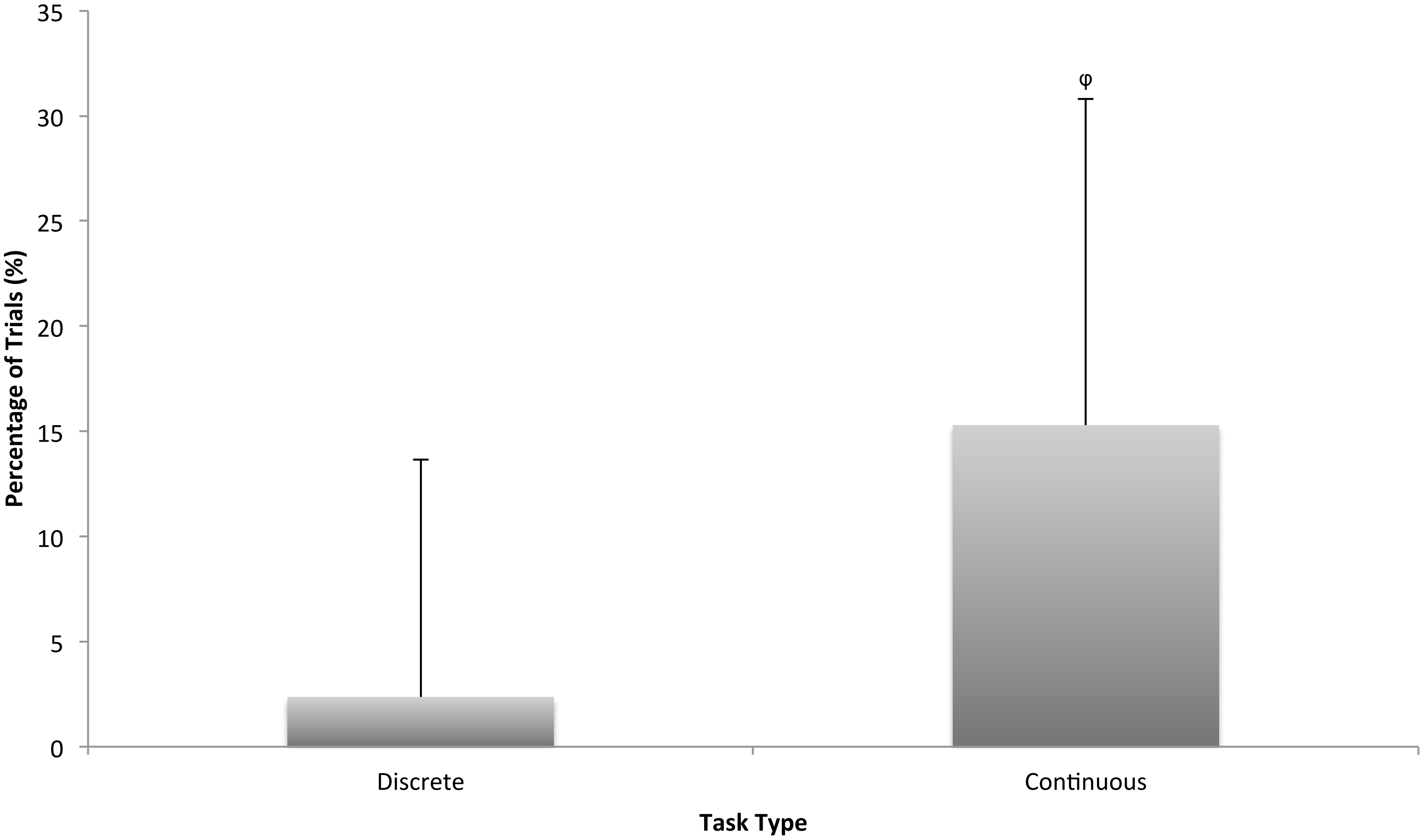


Fig 5.


35
30
25
20
15
10
5
0
Percentage of Trials (%)
φ
Discrete
Continuous
Task Type

CHAPTER FIVE: GENERAL DISCUSSION

The objective of this thesis was two-fold. First, to examine the effects of cognitive demand on postural control and second, to determine how the modality (auditory vs. visual) of the cognitive task impacts postural control. Of secondary interest, was to compare the effects of a discrete and continuous cognitive task on postural control, to ascertain if inter-stimulus intervals of varying duration could modify postural stability differently. According to the aforementioned objectives, the following hypotheses were proposed: first, irrespective of modality, the cognitive tasks with the highest level of difficulty would generate the greatest improvements in postural stability (Huxhold et al., 2006; Riley et al., 2003; Swan et al., 2007). Second, irrespective of cognitive demand, the visual cognitive tasks would generate greater improvements in postural stability compared to the auditory cognitive tasks (Prado et al., 2007). Third, compared to quiet standing, the addition of the cognitive tasks would minimize postural sway (Kerr et al., 1985: Huxhold et al., 2006; Maylor et al., 2001). Fourth, irrespective of modality, the cognitive task with two-second inter-stimulus intervals (i.e. continuous) would generate greater postural stability compared to the cognitive task with five-second inter-stimulus intervals (i.e. discrete task). Lastly, it was hypothesized that irrespective of inter-stimulus duration, the visual cognitive tasks would generate greater postural stability than the auditory cognitive tasks (Prado et al., 2007).

The findings of the present study, specifically relating to cognitive demand, did not fully support the first proposed hypothesis, as significance was not observed in all outcome measures. A reduction in area of 95% confidence ellipse (i.e. sway area) and ML sway variability was observed as the demand increased, however, no statistically significant difference was found between the moderate and difficult cognitive tasks. The visual cognitive tasks were superior to the auditory cognitive tasks in reducing ML sway variability, however, the effect was not evident across all outcome measures. As a result, the second hypothesis was once again not fully supported. Compared to quiet standing, a reduction in sway area, AP and ML sway variability was observed with the addition of only visually presented cognitive tasks, nevertheless supporting the third proposed hypothesis. A statistically significant difference was not observed between the discrete and continuous cognitive tasks in most outcome measures (i.e.,, sway area, AP and ML sway variability), with the exception AP MPF. As a result, the fourth hypothesis was not fully supported. The final hypothesis was supported seeing as a reduction in sway area and AP and ML sway variability was observed during the concurrent performance of the visual cognitive tasks. Interactions between cognitive demand and modality and task type and modality were observed in AP sway variability, AP and ML mean velocity and AP and ML mean velocity, respectively.

5.1. Modifications to postural control as a function of cognitive demand (M1)

Manipulation of cognitive task difficulty and its subsequent effect on postural control is not well documented in the literature. Of the studies that have examined this issue, the results reported have been far from unequivocal (Dault et al., 2001a; Huxhold et al., 2006; Pellecchia, 2003; Riley et al., 2003; Swan et al., 2007). One of the main purposes of this thesis was to ascertain the impact of cognitive demand on postural control in an attempt to establish consensus on the topic. Based on several studies (Huxhold et al., 2006; Riley et al., 2003; Swan et al., 2007), it was hypothesized that the difficult cognitive task would produce the greatest improvement in postural stability compared to its lower cognitive demand counterparts. Consistent with the aforementioned literature, increasing the cognitive demand resulted in a minimization of postural sway as evidenced by a reduction in sway area and ML sway variability. A statistically significant difference was expected between the moderate and difficult cognitive tasks, however, it did not transpire in the present results. A possible explanation for this is that the moderate and difficult cognitive tasks were not distinctly different from one another in terms of cognitive demand and as a result, elicited similar effects. Interestingly, the difficult cognitive tasks yielded a higher ML MPF suggesting that cognitive demand may contribute in promoting a more automatic mode of control compared to the easy cognitive tasks (Wulf et al., 2001). This will be further discussed in a later section.

The observed improvement in postural stability may be explained by a shift in attentional focus. According to previous research, withdrawing attention from a fairly automatized motor skill such as postural control, minimizes opportunities for conscious monitoring of stability and as a result, enhances performance (Shea & Wulf, 1999; Wulf et al., 1998; Wulf et al., 2001). Therefore, in keeping with this line of thinking, the present cognitive tasks may have improved stability (i.e. reduction of sway area and ML sway variability) by directing participants' attention away from postural control; thereby limiting opportunities to interfere with the motor control processes, promoting a more automatic mode of control (Huxhold et al., 2006). This parallels previous research, where similar improvements in stability were observed with the addition of a concurrent cognitive task (Dault et al., 2001b; Huxhold et al., 2006; Jamet et al., 2007; Kerr et al., 1985; Maylor et al., 2001; Prado et al., 2007; Ramenzoni et al., 2007; Riley et al., 2003; Riley et al., 2005; Swan et al., 2004; Swan et al., 2007). The moderate and difficult cognitive tasks may have retained more focus, consequently eliminating any opportunities for attention to be withdrawn from the cognitive task.

According to the U-shape function, there are limits to the effectiveness of a cognitive task on postural control (Huxhold et al., 2006; Lacour et al., 2008). The model stipulates that postural stability improves or attenuates depending on whether the cognitive demand of the concurrent task is lower or higher, respectively. However, the current findings do not lend support since a decline in stability was not observed with increasing cognitive load. The U-shape function is most apparent in older adults (Huxhold et al., 2006), who have a reduced attentional capacity as a result of aging (Borel & Alescio-Lautier, 2013). Prompting a more automatic mode of postural control by shifting attention ensures that resources that could be utilized by the postural task are now available to the cognitive task. Additionally, the decline in postural stability observed in several studies (Pellecchia, 2003) may be more related to attentional interference with the motor control processes than a competition for resources. In particular, maintaining an upright stance is largely a well-learned and automatic skill for young adults requiring minimal resources, unless challenged (e.g. unstable surface, small base of support, etc.); therefore, attentional interference (i.e. internal focus) may be the cause of the observed deficits in postural performance under normal circumstances as opposed to a resource competition. (Ramenzoni et al., 2007).

The manipulation of cognitive complexity only had a pronounced effect on ML MPF. Compared to the easy cognitive tasks, the difficult cognitive tasks yielded a significantly higher ML MPF. A main effect of cognitive demand on AP MPF was not observed across the three levels of difficulty. Wulf et al. (2001) found that utilizing an external focus of attention augmented the MPF. This finding has been replicated in several studies (McNevin, Shea, & Wulf, 2003; Wulf, Shea, & Park, 2001) and is suggested to reflect a more automatic mode of control. Therefore, based on the aforementioned studies, the present increase in ML MPF may further suggest that increasing cognitive demand promotes a more automatic mode of control, likely as a result of a shift in attentional focus. Similarly, Dault et al. (2001a) found frequency to increase with increasing cognitive demand in all three postural stances (i.e. shoulder-width, shoulder-seesaw and tandem-seesaw). However, Dault et al. (2001a) attributed the increase to the stiffness model, proposed by Winter et al. (1998).

The use of an ankle stiffening strategy has been postulated as an alternative explanation for the improvement in postural stability. In particular, the combined existence of a high MPF and low sway variability has been interpreted as an indicator of ankle stiffness (Carpenter, Frank, & Silcher, 1999; Carpenter, Frank, Silcher, & Peysar, 2001; Dault et al., 2001a). However, it is important to note that this assumption was derived from experimental protocols, where participants' experience either a high level of perceived postural threat (i.e. standing on the edge of a elevated platform) or have a severely reduced base of support (i.e. shoulder-seesaw and tandem-seesaw). Since the protocol of this thesis is exceedingly different from the aforementioned protocols, an argument can be made that ankle stiffness may not be a suitable strategy to elucidate the current findings (Stins et al., 2011). However, since muscle contraction was never directly examined, a level of uncertainty still exists.

Numerous studies have observed steady cognitive performance across postural tasks of varying degrees of difficulty (Maylor et al., 2001; Swan et al., 2004; Dault et al., 2001a). We suggest that errors committed demonstrate the cognitive demand of the task rather than prioritization. Unlike existing literature, we implemented a criterion for acceptable error scores, which was designed to match the difficulty of the cognitive task. The difficult cognitive task did in fact yield the highest percentage of trials with errors within the established limit. We suggest that since postural control was operating on a more automatic level, ample resources were available to both tasks. Moreover, errors committed may not necessarily be an indication that cognitive performance was sacrificed in young adults. In addition, participants used a 10-point likert scale to rank the difficulty of each cognitive task. We employed the scale to ensure that participants perceived the correct level of difficulty in relation to the other cognitive tasks. Participants' ranking can be found in Appendix B.

5.2. Modifications to postural control as a function of modality (M1)

The second purpose of this thesis was to ascertain if cognitive tasks presented in different modalities (e.g. auditory and visual) would modify postural stability differently. The few studies that have pursued this line of research (Jamet et al., 2007; Prado et al., 2007; Riley et al., 2005; Stoffregen, Pagulayan, Bardy, & Hettinger, 2000) have produced conflicting results. For the purpose of this thesis, it was hypothesized that cognitive tasks presented visually would promote greater postural stability than cognitive tasks presented auditorily. Presently, the visual cognitive tasks significantly reduced ML sway variability compared to the auditory cognitive tasks. However, a main effect of modality on sway area, AP and ML MPF was not found. Cognitive demands x modality interaction on AP sway variability, AP and ML mean velocity was observed.

Since visual processing is an integral component of the postural control system, researchers have suggested that cognitive tasks presented visually would give rise to structural interference (Kerr et al., 1985). However, studies have shown, present included, reduced postural sway during the concurrent performance of a visual cognitive task (Kerr et al., 1985; Prado et al., 2007; Stoffregen et al., 2000). These findings have been explained in terms of the facilitatory control view, which stipulates that postural control primarily functions to enable or facilitate the performance of other activities (Stoffregen et al., 2000). This view emphasizes that certain cognitive tasks necessitate a high degree of stability for successful execution, while others do not. Thus, to facilitate performance of the aforementioned visual cognitive tasks, postural sway was minimized.

Alternatively, the visual cognitive tasks of the present study may have served as visual anchors and as a result, aided postural stability (i.e. reduced ML sway variability) (Vander Velde et al., 2005). Hunter and Hoffman (2001) manipulated eye movement and observed greater ML sway variability in the eye movement condition than the no eye movement condition. Hunter and Hoffman (2001) suggest that excessive eye movement places additional demands on the postural control system, consequently diminishing stability. On several occasions a number of participants reported deviating from the fixation cross during the auditory cognitive tasks, which may explain why variability was higher. Therefore, the higher ML sway variability observed may be a consequence of the excessive eye movement.

Additionally, the extra layer of processing required for visual input to enter the phonological store (Repovs & Baddeley, 2003) did not appear to negatively impact postural stability or cognitive performance. Although the present cognitive tasks utilized the same component of WM (i.e. the phonological loop) and found no significant difference in sway area, AP and ML MPF, studies such as Dault et al. (2001b) observed no significant difference in postural stability and cognitive performance across cognitive tasks targeting different components of WM (i.e. articulatory loop, visuo-spatial sketchpad and central executive). Collectively, these findings suggest that postural control does improve with WM tasks, however, does not generate different degrees of improvement depending on the WM component targeted; a similar conclusion was drawn by Ramenzoni et al. (2007), who observed no significant difference in sway variability between the two WM tasks (i.e. verbal and visual).

As previously mentioned, a main effect of modality was not found on sway area, AP and ML MPF. Each of the variables had exceedingly low partial eta squares (0.170, 0.016, and 0.058, respectively), which suggests there may not have been enough statistical power to detect a significant difference. 17 participants were tested for the present experiment, which is not a negligible amount, however, greater statistical power may be required to detect a difference, if one does it fact exist.

5.3. Cognitive demand by modality interaction (M1)

The present findings revealed a cognitive demand x modality interaction for AP sway variability, AP and ML mean velocity. For the visual cognitive tasks, increasing the cognitive demand from a moderate to difficult level significantly reduced AP sway variability. However, the effect was not observed with the auditory cognitive tasks. This may suggest that there are limits to the effectiveness of cognitive demand when the tasks are presented auditorily. In particular, surpassing the moderate level of difficulty appeared to yield no further improvements to stability. Alternatively, the moderate and difficult tasks may not be markedly different from one another in terms of demand, though participants did state otherwise.

Conversely, for the auditory cognitive tasks, increasing the cognitive demand from a moderate to difficult level significantly lowered AP mean velocity, while the effect was not observed with the visual cognitive tasks. As a matter of fact, increasing cognitive demand from easy to difficult resulted in no significant difference in AP mean velocity. A similar pattern of results was observed for ML mean velocity. Compared to the easy auditory cognitive task, increasing the cognitive demand to the moderate and difficult level lowered ML mean velocity. Furthermore, the variability in results may suggest that certain outcome measures used to characterize postural control are more sensitive to the combined effect of cognitive demand and modality than others. However, this claim merits further scrutiny.

5.4. Modifications to postural control as a function of task type (M2)

Changes in postural stability have been accredited to factors such as cognitive demand (Dault et al., 2001a; Huxhold et al., 2006; Riley et al., 2003; Swan et al., 2007), postural complexity (Lajoie et al., 1993; Remaud et al., 2012) and individual differences (Huxhold et al., 2006). However, inter-stimulus intervals within a cognitive task have yet to be considered as a potential factor. To our knowledge, this was the first experiment to examine such implications. Moreover, it was of secondary interest to the thesis and it was hypothesized that the continuous cognitive tasks (i.e. inter-stimulus intervals of two-seconds) would produce greater improvements to postural stability than the discrete cognitive tasks (i.e. inter-stimulus intervals of five-seconds). According to the findings, performing the continuous task yielded a significantly higher AP MPF compared to the discrete task. However, no significant difference was found between the two tasks for sway area, AP and ML sway variability and ML MPF. Task type x modality interaction was observed for AP and ML mean velocity, which will be further discussed in a later section.

Cognitive tasks with inter-stimulus intervals, five seconds or greater, were postulated to afford participants' the opportunity to shift attention from the cognitive task to maintaining stability, thereby disrupting postural control. This was based on the studies that have consistently shown an internal focus (i.e. concentrating on the movement itself) to hinder postural performance by interfering with the automatic control processes responsible for regulating the movement (Shea & Wulf, 1999; Wulf et al., 1998; Wulf et al., 2001; for a review see Wulf, 2007). On the other hand, a continuous cognitive task with inter-stimulus intervals, two seconds or shorter, was postulated to limit such opportunities in attentional shifting. As a result, the automatic processes would remain unconstrained, performance would be executed more effectively, and a more automatic mode of control would be promoted (Shea & Wulf, 1999; Wulf et al., 1998; Wulf et al., 2001). Compared to the discrete cognitive task, the continuous cognitive task yielded a significantly higher AP MPF, which may suggest the emergence of a more automatic mode of control. Moreover, it may suggest that there was limited interference with the automatic processes as a result of greater attention directed towards the cognitive task. However, this may not be the case seeing as no significant difference was observed in sway area, AP and ML sway variability and ML MPF. Additionally, the requirements of the cognitive task may have contributed to the lack of significance. Specifically, keeping count of a number or letter may have helped retain focus on the cognitive task during the five-second inter-stimulus intervals. However, we are still inclined to suggest that participants could flexibly allocate their attention between the discrete and postural task due to the cognitive task's low demand.

Alternatively, sway area, AP and ML sway variability had extremely low partial eta squares (0.002, 0.001, and 0.029, respectively). This suggests that a significant difference between the two tasks may exist but this thesis did not have enough statistical power to detect it. In summary, inter-stimulus intervals may contribute to destabilization, however, it is a topic that has yet to be properly investigated. Further research is required to better ascertain, if in fact, it is a contributing factor. Possibly, inter-stimulus intervals of five-seconds were not enough to elicit significant differences in postural stability.

In addition, participants committed errors within the appropriate limits on a greater percentage of trials when executing the continuous cognitive task. As previously mentioned in section 5.1, we suggest that such scores demonstrate the difficulty of the cognitive task and not a competition for resources. Performing a fairly simple task such as feet together and the continuous cognitive task should not have exceeded the participants' capacity. Cognitive performance has been shown to remain stable under challenging postural conditions (Dault et al., 2001a; Maylor et al., 2001; Swan et al., 2004). Participants' ranking of each cognitive task using the 10-point likert scale can be found in Appendix B.

5.5. Modification to postural control as a function of modality (M2)

As previously stated in the introduction, few studies have addressed the topic of modality and its subsequent implications on postural stability (Jamet et al., 2007; Prado et al., 2005; Riley et al., 2005; Stoffregen et al., 2000). Therefore, to further contribute to the literature, the discrete and continuous tasks were presented both auditorily and visually, to ascertain if postural control is sensitive to modality. Similar to the second proposed hypothesis, it was postulated that cognitive tasks presented visually would generate greater improvements to postural stability than tasks presented auditorily. In the present experiment, presenting the tasks visually notably reduced sway area, AP and ML sway variability compared to presenting the tasks auditorily. However, no significant difference was found for AP and MP MPF. A task type x modality interaction was found for both AP and ML mean velocity, which will be further discussed in a later section.

Similar to the explanation provided in section 5.2 of the discussion, the visual tasks (i.e. discrete and continuous) may have improved stability by serving as visual anchors (Vander Velde et al., 2005), consequently limiting eye movement. Excessive eye movement has been found to increase ML sway variability by placing additional demands (i.e. greater oculomotor demands) on the postural control system (Hunter & Hoffman, 2001). While the auditory tasks necessitated constant fixation, participants did report occasionally deviating from the fixation cross similar to the auditory cognitive tasks of varying demand, which could explain why sway area, AP and ML sway variability was higher compared to visual.

Additionally, one-way RM ANOVAs on task type were performed to determine if the addition of a cognitive task would improve postural stability compared to quiet standing. The analysis was executed for both auditory and visual tasks. It was hypothesized that relative to quiet standing, postural performance would improve with the addition of a concurrent cognitive task. Compared to quiet standing, both the discrete and continuous visual tasks reduced sway area, AP and ML sway variability, paralleling previous literature (Kerr et al., 1985; Huxhold et al., 2006; Maylor et al., 2001) and confirming the third proposed hypothesis. However, no significant difference was observed for sway area, AP and ML sway variability when the tasks were presented auditorily. Collectively, this suggests that presenting cognitive tasks using a visual medium may be a more effective strategy to improving stability. However, this contradicts previous studies that have observed greater improvements to postural stability when concurrent cognitive tasks are presented auditorily (Jamet et al., 2007; Riley et al., 2005). For example, Jamet et al. (2007) observed a greater reduction in area and AP and ML sway variability with the auditory-verbal than visual-verbal task. Jamet et al. (2007) concluded that postural stability improved on account of greater attention focus placed on the auditory stimuli.

In terms of MPF, no significant difference was observed between auditory and visual, in both AP and ML directions. However, when compared to quiet standing, both the discrete and continuous visual cognitive tasks significantly increased ML MPF. This may suggest that both cognitive tasks withdrew attention from maintaining stability, limiting interference with the automatic control processes (Shea & Wulf, 1999; Wulf et al., 1998; Wulf et al., 2001). Whereas, quiet standing may not have afforded the same opportunities, and as a result, participants' were likely to internalize focus, ultimately constraining the control processes (McNevin & Wulf, 2002). With respect to the auditory tasks, a trend towards significance was observed for both AP and ML MPF, which may suggest that compared to quiet standing, auditory tasks promote a more automatic mode of control. However, further research is required to ascertain, if that is in fact the case, since a significant difference in sway area, AP and ML sway variability was not observed.

5.6. Task type by modality interaction (M2)

The present findings revealed a task type x modality interaction for AP and ML mean velocity. In comparison to the discrete task, performing the continuous task increased AP and ML mean velocity, when presented auditorily. The effect was not observed when the tasks were presented visually. Additionally, no significant difference was found between the discrete and continuous visual cognitive tasks for AP and ML mean velocity. Moreover, when compared to quiet standing, the continuous auditory cognitive task yielded the highest AP and ML velocity. However, when compared to the cognitive demand findings mentioned in section 5.3, a decline in AP and ML mean velocity was observed with increasing cognitive load. Specifically, the discrete and continuous auditory tasks may not have necessitated a reduction in postural sway to accurately perform the tasks (Stoffregen et al., 2000). Whereas, the moderate and difficult auditory tasks may have required a minimization of postural sway to properly perform the tasks. What's more is even under higher postural sway, participants' performed the discrete and continuous auditory task either accurately or within the acceptable limits.

5.7. Summary of findings

The results of the present experiment, specifically the reduced sway area and ML sway variability, suggest that cognitive tasks of higher difficulty (i.e. moderate and difficult) promote greater postural stability than tasks of lower demand (i.e. easy). This parallels previous literature examining the interaction between cognitive demand and postural control (Huxhold et al., 2006; Riley et al., 2003; Swan et al., 2007). Although the first hypothesis was not fully supported as no significant difference was observed between the moderate and difficult cognitive task, this thesis is still inclined to suggest that increasing cognitive demand is beneficial to enhancing postural stability in young adults. Additionally, it appears that cognitive tasks presented visually promote greater stability that tasks presented auditorily as evidenced by a reduction in ML sway variability. Moreover, difficult cognitive tasks presented visually significantly reduce AP sway variability compared their auditory counterparts. Although, no significance was found between the discrete and continuous cognitive tasks, presenting the tasks visually significantly reduced sway area, AP and ML sway variability compared to presenting the tasks auditorily. Lastly, consistent with previous literature (Kerr et al., 1985; Huxhold et al., 2006; Maylor et al., 2001), the addition of a concurrent cognitive task improved stability compared to standing alone.

CHAPTER SIX: CONCLUSION

6.1. Contribution to the literature

The present set of results contributes to our understanding of the interaction between postural control and cognition in several ways. First, increasing cognitive demand facilitates postural performance in young adults. Second, presenting tasks visually appears to be more effective in promoting greater postural stability than tasks presented auditorily. Third, cognitive tasks with long duration inter-stimulus intervals may not be optimal for maintaining postural stability. However, with limited significance, this suggestion is rather speculative and requires further research. Finally, the present findings reinforce the current literature that demonstrates that relative to single-task performance, stability is greatly improved when a cognitive task is concurrently performed (Kerr et al., 1985; Huxhold et al., 2006; Maylor et al., 2001).

6.2. Future studies

Based on the current set of results, future studies need to implement dual-task conditions of higher demand to assess the limitations of the postural control system in healthy young adults. Maintaining a feet together postural stance, while concurrently performing cognitive tasks of varying degrees of difficulty does not appear to provoke a resource competition. Perhaps, engaging in a simple postural task is a relatively automatic process for young adults and subsequently increasing cognitive demand may not be enough to exceed resource capacity (Huxhold et al., 2006). Therefore, increasing the demands of postural task by heavily reducing the base of support or introducing perturbations may demonstrate how attentional resources are allocated to postural or cognitive performance under such demanding conditions. It may also highlight the conditions necessary to provoke a resource competition in young adults. Lastly, future studies should continue investigating how specific features of a cognitive task effect postural stability in an attempt to determine if certain cognitive tasks are more effective than others.

6.3. Limitations

It is important to highlight the limitations of the present thesis. To our knowledge, no study has implemented a criterion for acceptable error scores and evaluated performance in such a manner. The limitation may lie in the fact that the error limits were generated subjectively and were not determined using any form of guide. Nevertheless, we suggest that committing errors within a certain range does not necessarily imply that cognitive performance was jeopardized. Therefore, it is still the recommendation of this thesis that future studies introduce a similar cognitive performance criterion into their experimental protocol when examining healthy young adults. Another possible limitation of this study could be the design of the discrete cognitive task. The goal of keeping count of a specific number or letter may have aided in maintaining focus on the cognitive task during the five-second inter-stimulus intervals. The task of future studies is to design a discrete task that does not require participants to actively keep count, similar to a reaction time task, while simultaneously eliminating articulation, as it has been shown to disrupt postural stability (Dault et al., 2003; Yardley et al., 1999).

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APPENDIX A

Health Questionnaire

Full Name: Sex: M/F

Age: Weight (kg/lbs): Height (cm/feet):
Dominant leg: left/right Hours of physical activity/week:
Type of activity/sport:

Previous injuries (last 6 months): yes/no
If yes, please describe (sprain, tendinitis, fracture, surgery, strain):

Current status of injury (solved, persistent):

Internal ear/vestibular problems (dizziness, vertigo, balance): yes/no
If yes, please describe:

Vision problems or corrections (colour blindness, glasses, contacts): yes/no
If yes, please describe:

APPENDIX B

Participants' Level of Difficulty Ranking Across Condition

	Auditory			Visual		
	Easy	Moderate	Difficult	Easy	Moderate	Difficult
Participant 1	1.75	2.25	1.8	1.8	2.4	2.5
Participant 2	2.8	4.8	5.4	1.5	3.8	3.4
Participant 3	3.4	6.2	6.4	2.8	7.2	8
Participant 4	2	5	5	3	5.2	5.4
Participant 5	1.6	5.2	5.8	1.4	6	5.6
Participant 6	1.2	6.8	4.4	1	4	4.2
Participant 7	4.4	6.2	7	3.4	7.2	7.4
Participant 8	3.4	6.8	7	3	6	6.4
Participant 9	2.4	7.8	7	3.8	6.5	6.6
Participant 10	2.6	5.2	5.6	2	4	4.6
Participant 11	1.4	7.6	8	1.4	8.2	7.2
Participant 12	2.4	5.6	6	1.4	4.2	5
Participant 13	2.8	6.8	6.2	3.4	6.6	7.2
Participant 14	1	4.6	5.2	1	3.4	3.5
Participant 15	2	6.25	6.6	2	5	5.4
Participant 16	3.8	5.6	7.4	4.2	7.4	7.4
Participant 17	2.8	5.4	5.8	2.4	3.4	3.6
TOTAL AVERAGE	**2.455882353**	**5.770588235**	**5.917647059**	**2.323529412**	**5.323529412**	**5.494117647**