Postural control and ankle muscle stiffness during continuous cognitive tasks and external focus of attention

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ABSTRACT

The objective of the present study was to; 1) determine if the use of a continuous cognitive task demonstrates distinct characteristics of a more automatic control of posture, compared to an external focus (EF) and feet together (FT) postural task, and to 2) examine which condition, if any, exhibits the characteristics of increased ankle stiffness proposed by Winter et al. (1998), as well as displaying increased ankle muscular co-contractions, which are a suggested neuromuscular mechanism that stiffens posture. Fifteen young adults stood on a force platform and performed 4 separate conditions: FT, EF, single number sequence (SNS), and double number sequence (DNS). Throughout the session, surface electromyography (EMG) signals were collected from the tibialis anterior (TA) and medial gastrocnemius (MG) of each leg. Each testing session consisted of 24 trials, with 6 per condition. Results displayed decreased sway area for SNS and DNS compared to FT. Sway variability in the anterior/posterior (AP) direction SNS and DNS were smaller compared to EF and FT. As well sway variability in the medial/lateral (ML) direction was smaller for SNS and DNS compared to FT. ML Mean velocity (MV) did not differ across conditions, though in the AP direction it was larger for SNS and DNS compared to EF and FT. AP Mean power frequency (MPF) was larger for SNS compared to FT. In the ML direction MPF was larger for SNS and DNS compared to FT. Co-Contraction indices revealed no differences across conditions. Conversely the left TA for DNS revealed increased EMG activation compared to EF and SNS.

Key words: dual-task, cognitive task, postural control, ankle stiffening, attentional focus

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CHAPTER ONE: REVIEW OF LITERATURE

1.1 Postural Control

Posture is a term used to describe the position of any body segment relative to the gravitational vector (Winter, 1995). Postural control is the control of the body's position in space for the purposes of balance and orientation (Shumway-Cook & Woollacott, 2000). There are three systems involved in the control of posture, the visual, vestibular and somatosensory systems. These three systems help to control posture and stability and they adapt depending on the task and environment (Woollacott, Shumway-Cook & Nashner, 1986; Shumway-Cook & Horak, 1986). The visual system is mainly involved with planning as well as aiding in avoiding obstacles. The vestibular system is involved with sensing linear and angular accelerations. The somatosensory system is a multitude of different sensors that can detect the velocity and position of our body segments. It also senses their contact (impact) with external objects like the ground or other objects (Winter, 1995).

No one stands completely still and therefore the human body is constantly swaying in small amounts in all directions. The directions that the body sways are broken down into anterior/posterior (forwards and backwards) and medial/lateral (side to side) sway. Measurements of quiet stance are often taken from determining the centre of mass (COM), and the centre of pressure (COP) of an individual. The COM is the point where the entire mass of the body is concentrated. The COM is a passive variable, which the postural control system maintains (Winter, 1995). The COP is comprised of two separate components, the first being the gravitational projection of the COM. It is also comprised of torques that are generated at the ankle and hip joints. The COP is controlled by ankle plantar flexors/dorsi flexors torque in the sagittal place and hip abductor/adductor torque in the frontal plane (Winter, Patla, Prince, Ishac & Gielo-Perczak, 1998). The COP is a representation of a weighted average of all the pressures that are in contact with the ground. If both feet are in contact with the ground the COP lies somewhere between the feet. If only one foot remains in contact with the ground then the COP lies underneath that foot. There is an expanse amount of literature supporting that the central nervous system has a goal to maintain the equilibrium of the COM around a specific set point (Winter, Prince, Frank, Powell & Zabjek, 1996). This goal is constantly being challenged because of perturbations that the body has to withstand on a constant basis. These perturbations are mainly internal and consist of muscle activity, breathing and heart rate (Soames & Atha, 1981, 1982; Jeong, 1991; Carpenter, Murnaghan & Inglis, 2010). Postural sway has been suggested to be the result of the interplay between COM and COP, where the COP controls or corrects the deviations of the COM from a desired position or point of equilibrium (Horak & MacPherson, 1996).

1.2 Models Associated with Postural Control

The control of posture requires cognitive resources and is not an entirely automatic and reflex controlled process as once believed (Woollacott & Shumway-Cook, 2002). There has been extensive research that has outlined that attention is involved in postural control and depends on a variety of factors. These factors consist of postural task, age and balance abilities (Woollacott & Shumway-Cook, 2002). There are a variety of dual task performance models that propose explanations for the interaction between the control of posture and cognitive demand. These models all assess postural control and cognitive load together, because controlling posture is rarely performed by itself, whether it is static (standing/sitting), or dynamic (walking/running).

This means that in the real world, individuals do not normally purely control posture. They are often performing a secondary task that requires cognitive resources. In a lab setting, in order to determine the attentional resources required for the postural task, it is performed as a single postural task (baseline comparison), and then paired with a cognitive or motor task. This pairing then makes it a dual-task scenario. The differences viewed between the single and dual task scenarios provide understanding as to where attentional resources are being allocated. Declines in the dual-task performance compared to the single-task have been explained as a competition for cognitive resources (Li, Krampe & Bondar, 2005). There have been explanations put forth to explain where these performance declines arise. There are extrinsic factors such as the primary task being used, whether there is postural threat or not and the nature of the secondary task. As already mentioned the primary task can be static or dynamic. Dynamic tasks have been shown to require more attentional resources than a static task (Lajoie, Teasdale, Bard & Fleury, 1993).

There are a number of factors than can affect performance while using the dual-task paradigm, one of these being the level of difficulty of the secondary task. Whether it is spatial, visual, visuospatial or a mental arithmetic task, it has been shown to play a role (Woollacott & Shumway-Cook, 2002). The environmental constraints behind why the task is being performed can also have an affect on the performance, meaning whether there is a postural threat or not (Lacour, Bernard-Demanze & Dumitrescu, 2008). There are also intrinsic factors that affect the dual-task performance, such as aging declines as well as sensorimotor expertise. As one ages, there are declines viewed in many components of the body such as neurological, proprioception, vestibular, visual, somatosensory and muscular (Maylor, Allison & Wing, 2001; Manchester, Woollacott, Zederbauer-Hylton & Marin, 1989). There are models that have been put forth to explain the interaction between cognitive tasks and postural control. Some models are dependent on intrinsic and extrinsic properties and some are dependent on the focus of an individual's attention.

The task prioritization model proposes the use of different sensorimotor strategies amongst different individuals. There are two major strategies adapted by individuals experiencing a threat to postural control, one being an ankle strategy and the other a hip strategy. The ankle strategy is a bottom-up initiation, which involves the gastrocnemius, hamstrings and paraspinal muscles. The hip strategy is top down initiation involving the abdominal and quadriceps femoris muscles (Nashner, 1985; Nashner & McCollum, 1985). Depending on the support surface (wide surface or narrow) and the task difficulty, this will dictate which strategy is used. Older adults have been reported to use the hip strategy more predominantly than young adults. Older adults use the hip strategy because it is the safer of the two and helps them avoid falls (Lacour et al., 2008). The hip strategy serves as a higher cost of energy compared with the ankle strategy. Literature has shown that older adults more often than young adults will prioritize postural control over the secondary task in dual-task scenario. Older adults have been shown to stop walking when starting a conversation in order to preserve the control of posture (Lindenberger & Baltes, 1997). The task prioritization model is one that is better suited for explaining dual-task performance in older adults compared to young adults who do not normally prioritize postural control over the secondary task (Brown, Sleik, Polych & Gage, 2002).

The Cross-Domain Competition Model proposes that cognitive tasks and postural control will compete for attentional resources, so that the control of posture during the dual-task scenario will be affected compared to the single-task scenario. Andersson et al. (1998) demonstrated support for this theory in a study that used a task of increasing cognitive difficulty. The results displayed that with the increase in difficulty the participant's postural task performance decreased. A similar outcome was demonstrated in a study by Maylor & Wing (1996), which involved young and old adults. The study displayed age differences in the task being performed, as well as an increase in cognitive demands. Other studies display this decrease in postural control with an added cognitive load more so in older adults compared to young adults (Mitra, 2003; Nashner & McCollum, 1985). Along with declines viewed in the control of posture, there have also been studies that have reported no change or even improvements to postural control with the added cognitive load (Riley, Baker & Schmitt, 2003; Dault, Geurts, Mulder & Duysens, 2001). This leads to a limitation in this model that does not account for all the literature on the dual-task paradigm.

The constrained action hypothesis was suggested by McNevin et al. (2003) to explain the learning advantages behind an external focus (EF) of attention when learning a motor skill compared to that of an internal focus (IF) of attention. The hypothesis outlines that focusing on the movement itself (IF) and also partially a near body focus (near-external) interferes with the automatic motor control processes. Compared to when focusing on the effects of the movement (external focus), which does not interfere with those processes. McNevin et al. (2003) had participants perform a motor learning task (balancing on a stabilometer) using either an IF, and three separate (near, far-inside, and far-outside) EFs of attention tasks. They found that the farther the focus was from the body (external) the better the performance of the task.

When internally focusing attention, it is deduced that people actively interfere in the perpetuation of stable posture more than when individuals focus on remote effects, or an EF. It is suggested that there is an interference with the automaticity of postural/movement control that ends up with a degraded performance when internally focusing attention. In the study by McNevin et al. (2003) they found increased mean power frequency (MPF) for the external far conditions, compared to the external-near and IF condition. A higher MPF is one of the markers believed to represent an increased automatic control of posture.

1.3 Posture and Cognitive Tasks

As previously mentioned, the control of posture was originally believed to be almost entirely automatic and required a small amount of cognitive processing (Neumann, 1984). However, recent literature has provided evidence displaying that this is not actually the case. The literature has shown that posture does in fact require some degree of attention, and at times a large amount (Woollacott & Shumway-Cook, 2002). The amount of attention required for postural control appears to vary depending on the tasks (both postural and secondary) being performed as well as other factors. Specifically factors related to the age and the postural control abilities of the individual (Woollacott & Shumway-Cook, 2002). As humans age, there is deterioration that occurs to the postural control system (visual, vestibular and somatosensory systems). This deterioration then leads to a reduction in the ability to control posture. The deterioration that occurs is usually viewed in the vestibular and proprioceptive systems. This deterioration results in postural adjustments that originally were rapid and almost effortless that end up becoming diminished (Melzer, Benjuya & Kaplanski, 2001). It is believed that using a discrete cognitive task allows brief opportunities for the participant to slip from an automatic mode of postural control to a more conscious mode. When performing a continuous cognitive task, the task lasts for the whole trial and therefore limits chances for conscious involvement in the control of posture (Polskaia, Richer, Dionne & Lajoie, 2015). Attention in the context for this review is the information processing capacity of the individual (Woollacott & Shumway-Cook, 2002). As mentioned, attention is thought to posses a limited capacity due to declines viewed in a task or tasks when they are performed together (Kahneman, 1973; Reilly, van Donkelaar, Saavedra & Woollacott, 2008). This is due to the information processing capacity being reached or exceeded.

An increase in postural sway is commonly associated with a weakened postural control (Mitra, Knight & Munn, 2013). In a dual-task paradigm, there are discrepancies in the literature while performing cognitive tasks of altering cognitive load. The display of postural control has been shown to increase (Mitra et al., 2013; Mitra & Frazier, 2004), decrease (Andersson, Hagman, Talianzadeh, Svedberg & Larsen, 2002; Riley et al., 2003), or not change at all (Yardley, Gardner, Leadbetter & Lavie et al., 1999) when performing tasks of increased cognitive load.

When looking at the literature on studies, where postural sway was found to increase, a study by Mitra et al. (2013) had a group of participants perform a quiet stance task and a separate group perform a visuopostural task. The visuopostural task had participants actively controlling posture in the ML direction. Alternatively in the quiet stance group participants did not focus, nor control their posture. The participants in both groups performed a spatial, non-spatial and no additional task along with their assigned postural task. The spatial task involved making judgments about the relative locations of familiar university buildings from particular vantage points. The non-spatial task involved answering questions about the academic and operational aspects of the university. The results of the study displayed that AP sway was greater in both of the cognitive tasks relative to the no-task condition; however, this was only the case for the group performing the quiet stance task and not for the visuopostural group (Mitra et al., 2013). Similarly, in a separate study by Mitra & Frazier (2004), postural sway was shown to increase while performing a cognitive task. In that study, participants performed a visual search task under immersive visualization conditions while standing in an open or closed stance. Participants were also told to minimize their sway while performing the search task, but as well some of the trials were told that sway was not of interest and to focus on the search task. Regardless of whether they had instructions to minimize sway or not during the visual search task participants swayed more and also made more errors as the search load increased (Mitra & Frazier, 2004).

Along with the copious amounts of literature that displays an increase in postural sway, there is also an extensive amount that shows a decrease in sway. In a study performed by Prado et al. (2007) they had participants (young and old) perform a quiet stance task accompanied with visual cognitive tasks. The cognitive tasks consisted of four conditions: (inspection versus search) and (near versus far) in different variations. Baseline tasks were performed with eyes open and closed. The inspection task had the participants starting at a blank target holding their gaze. Whereas, the search task participants viewed blocks of text and had to count how many appearances a certain letter made. Both tasks were performed close up as well as far away (near versus far). The results for the young adults showed that as the complexity of the tasks increased, postural sway decreased (Prado, Stoffregen & Duarte, 2007). Stins et al. (2011) had participants perform quiet stance while performing a backwards-counting task and viewed a decrease in COP sway and an increase in mean power frequency compared to baseline.

1.4 Attentional Focus and Postural Control

Directing focus of attention can alter performance of a skill as well as postural control. An IF directs attention to the body's movements when performing a task, whereas, an EF directs attention to the effects of the movement (Wulf, Höb & Prinz, 1998). An immense amount of literature has displayed that when using an EF of attention, performance is better than when using an IF of attention (Wulf et al., 1998; Shea & Wulf, 1999; McNevin & Wulf, 2002). Whether it is learning to balance on a stabilometer (Wulf & McNevin, 2003; Wulf, Weigelt, Poulter & McNevin, 2003), learning a golf pitch shot (Wulf & Su, 2007; An, Wulf & Kim, 2013), or just simply controlling balance (Landers, Wulf, Wallmann & Guadagnoli, 2005; Wulf, Landers, Lewthwaite & Töllner, 2009), EF of attention has displayed improved learning and performance of the task. It is believed that an EF of attention promotes better performance over the IF, because it establishes greater effectiveness and efficiency of the movement being performed (Wulf, 2007). When using an IF of attention, it is believed that the individual adapts a more conscious form of control. By adapting a more conscious control with the IF it is believed that a constraint to the motor system occurs that interferes with the automatic mode of control by utilizing the unconscious, fast, and reflexive control processes (Wulf, 2013).

A study by Riley et al. (1999) had participants perform quiet stance with their eyes closed while touching a curtain. They had two groups perform a touching task that was either touch-relevant or touch-irrelevant. Touch-relevant participants were instructed to keep the curtain as still as possible, whereas, touch-irrelevant participants were not aware that maintaining contact with the curtain was pertinent through the touch trails. They found for the touch-relevant condition that postural sway was reduced compared to the no touch condition and also the touch-irrelevant condition (Riley, Stoffregen, Grocki & Tuvey, 1999). The reduction in postural sway in the touch-relevant condition was thought to occur because it promoted an EF of attention and therefore had the participants focus on the effects of the movement instead of the movement itself.

McNevin & Wulf (2002) performed a similar study to Riley et al. (1999) and had participants stand still while touching a hanging sheet. They were instructed to focus on keeping the sheet steady (EF) or keeping their finger steady (IF). The found increased sway frequency for the EF. It was concluded that it was due to improved control of posture and possibly increased ankle muscle stiffness (McNevin & Wulf, 2002).

1.5 Ankle Stiffness and Postural Sway

Winter et al. (1998) have suggested that an ankle strategy is a main contributor to postural control while performing quiet stance as well as when experiencing small perturbations. Joint stiffness, and in this specific context passive ankle stiffness, refers to the relationship between the position of a joint and the torque produced about it (Lang & Kearney, 2014). The passive ankle strategy is typically used for postural stabilization when instabilities are minimal (Creath, Kiemel, Horak, Peterka & Jeka, 2005). When instability is minimal, stance is characterized as mostly unperturbed, although there are always minor internal perturbances occurring, such as heart rate, breathing and muscle activity (Soames & Atha, 1981, 1982). The characterization of unperturbed stance consists of low frequency, and semi-random motion of the COM, which is classed as normal postural sway (Lang & Kearney, 2014). In terms of postural sway, when the body's COM is ahead of the COP, the body's angular velocity is going clockwise (meaning sway is in the forward direction). If the body sways too far in the forward direction the body then senses this and corrects the forward sway resulting in the COP moving anteriorly to the COM and thus moves the body resulting in a counterclockwise movement and thus posterior sway occurs (Winter et al., 1996). These movements are happening about the ankle joints with the control of the ankle dorsi flexors and plantar flexors to control AP sway (Winter 1996). The ankle dorsi flexors consist of the tibialis anterior, extensor halluces longus and extensor digitorum longus. The ankle plantar flexors consist of the soleus, medial and lateral gastrocnemius, plantaris, as well as the tibialis posterior, flexor digitorum longus and peroneus longus and brevis. These muscle groups act to move COP backwards and forwards, and thus control COM. The trunk sways back and forth like an inverted pendulum, in which the pivot is about the ankle joints (Winter et al., 1996).

Ankle stiffness can be either passive or active depending on the contributors around the ankle (Warnica, Weaver, Prentice & Laing, 2014). Active stiffness occurs through the increased co-contraction of muscle activation of antagonistic muscles that cross the ankle joint, which are the dorsi flexors and plantar flexors. Passive stiffness occurs from the non-contractile elements around the ankle, such as ligaments as well as non-activated muscles. External devices, such as an ankle foot orthotic, can be used in order to help individuals with increased ankle muscle stiffness, as viewed in some individuals suffering from Parkinson's disease (Warnica et al., 2014). Previous research has determined that passive ankle stiffness alone is insufficient to stabilize the body (Morasso & Schieppati, 1999; Loram & Lakie, 2002; Morasso & Sanguineti, 2002). There is evidence that underlies the presence of fairly constant passive stiffness during quiet stance, whereas, active stiffness has been shown to change as the task changes through cognitive and sensory updates (Kang & Lipsitz, 2010). Therefore, when assessing ankle stiffness across a variety of cognitive tasks, active stiffness will display greater changes compared to passive stiffness.

When performing quiet relaxed stance, AP sway amplitude is inversely proportional to the estimated stiffness about the ankle with the frequency of postural sway being shown to increase with increased stiffness (Winter et al., 1998). With this being said, it is suggested that passive ankle stiffness is preset by the central nervous system in order to control the body's COM when performing quiet stance. This assumes that the muscles behave like springs in order to keep the COM and COP in phase as the body swings (Winter, 1995). When referring to the inverted pendulum model, it proposes that when there is an increase in ankle stiffness that occurs either actively or passively, there should be a decrease in sway amplitude and an increase in sway frequency (Winter et al., 1998).

1.6 Theories behind the Stiffening Strategy

Approximately two-thirds of a human's body mass is located two-thirds up the height of their body. This makes humans unstable and therefore they require a control system to continuously act to keep posture stable (Winter, 1995). Winter et al. (2003) have outlined the mechanisms that are involved in the control of posture, and are continuously defending against the gravitational and internal forces in order to maintain safe posture. There are various mechanisms involved in the maintenance of posture, one of which involves an ankle strategy and serves in the AP control of postural sway. The ankle strategy aids in the defense against gravitational and internal forces used to maintain safe posture, therefore bringing about an added cost of energy. Winter et al. (1998) have demonstrated that in relaxed quiet stance, AP sway amplitude is inversely proportional to the estimated stiffness about the ankle, meaning that when AP sway amplitude is high, ankle stiffness will be low.

There are separate views on how active ankle stiffness is conceived. One idea proposes that ankle stiffness occurs due to the use of an EF of attention, which is more of an automatic control of posture resulting in a freeing of cognitive resources for secondary tasks (McNevin & Wulf, 2002). A separate view, by Huffman et al. (2009), proposes that ankle stiffness occurs in order to more closely monitor postural control due to a threat and therefore requires an increase in cognitive resources. There are other views, like that of Dault et al. (2001b), who proposes that stiffness occurs as a result of individuals adapting to a less attention demanding co-contraction mode that frees up attentional resources, which is along similar lines to that of McNevin & Wulf (2002).

Studies involving attentional focus have consistently shown, that when adapting an EF of attention, motor learning and postural control is improved, compared to an IF of attention (Wulf, 2013). A study performed by McNevin & Wulf (2002) had participants minimize the movement of a sheet that was hanging from the ceiling while using IF and EF tasks. The results displayed that the EF of attention had a higher frequency (MPF), compared to the IF and control task. McNevin & Wulf (2002) concluded that the increase in MPF for the EF condition promotes improved postural stability through an increase in muscle/joint stiffness by creating a more automatic control of attention. This conclusion comes from the framework proposed by Winter et al. (1998) that enhanced postural stability occurs due to an ankle strategy. A similar conclusion was drawn from Dault et al. (2001b) from their findings that working memory (WM) tasks increases frequency and decreases amplitude of COP while performing cognitive tasks. When looking at the results between the four working memory tasks performed, there were no differences, the only differences viewed were between the baseline condition and the four working memory conditions. There was an increase in frequency and decrease in amplitude viewed in all four working memory tasks that the authors attributed to an improved control of posture. They concluded that the enhanced control was a result of the participant adapting to a less-attention demanding co-contraction mode that requires less attention than a separate way to control opposing muscles, which is the reciprocal innervation mechanism (Dault et al., 2001b).

The opposing view of how stiffening is conceived is that it is attentionally demanding and occurs as a protective mechanism that administers a better control of posture. Huffman et al. (2009) set out to determine if postural threat modified the conscious control of posture. They had participants stand on a platform that was situated either at ground level (low threat) or 3.2 m above the ground (high threat) to measure the relationship between postural control and conscious control. What they found was that participants demonstrated more conscious control for their posture when on the elevated platform compared to ground level. When on the elevated platform, there was an increase in frequency and increased backwards lean compared to baseline (Huffman, Horslen, Carpenter & Adkin, 2009). In opposition to McNevin & Wulf (2002), who attributed increased frequency to a more automatic control, Huffman et al. (2009) believe that increased frequency accompanied with a backwards lean is an indication of a more conscious control of posture. They concluded that when on the elevated platform, participants exhibited a more conscious control of their posture due to the added threat, which thus reduced automaticity of postural control (Huffman et al., 2009).

Carpenter, Frank & Silcher (1999) performed a similar protocol, they had participants on low (0.19 m) and high (0.81 m) platforms that were both either unrestricted or restricted. Being restricted meant they could not take a step forward onto another platform of equal height. The participants performed all platform conditions with vision/no vision and vestibular/no vestibular settings. Carpenter et al. (1999) found that, when on the high platform with vision, there was an increase in sway frequency and decrease in COP amplitude, compared to low platform eyes open condition. When vision was occluded they did not see this difference. However they did not attribute their findings to a more conscious control of posture, though they did attribute the increased stiffening to fear.

Stins et al. (2011) performed a study in order to determine the commonalities and differences in postural control during distraction of attention and during an anxiety-provoking situation. The attentional distraction task was a dual-task scenario using number subtraction (counting backwards by 7's) and the anxiety-provoking task was standing on a 1 m high platform. They added the use of surface electromyography in order to detect muscle activity of active ankle stiffening muscles (gastrocnemius (MG), tibialis anterior (TA), extensor digitorum longus, rectus femoris (RF) and vastus medialis). They found that the COP amplitude decreased and sway frequency increased when performing the cognitive task, when compared to baseline. They also discovered that there was no difference in amplitude or frequency for the height condition compared to baseline. They did however find significantly lower sample entropy for the height (anxiety condition) compared to the cognitive condition. This suggests that the two have separate postural control processes that appear to be related to the amount of attentional investment. Meaning a possible higher attentional investment for the height condition compared to the cognitive condition. In terms of the EMG results, they found increased activity of the rectus femoris and tibialis anterior muscles, accompanied with a decreased activity of the gastrocnemius in their height condition (Stins, Roerdink & Beek, 2011). The EMG results were consistent with those of Brown et al. (2006) and Carpenter et al. (2001) who had attributed their results to increased ankle stiffness. Stins et al. (2011) however did not attribute their EMG findings to increased stiffness due to a backward lean that was viewed in the anxiety provoking condition. Similar to Huffman et al. (2009) they found a greater anticipatory control for the height condition compared to baseline. They attributed this to a possibly greater conscious postural control for the height condition. They refuted McNevin, & Wulf’s (2002) idea that active ankle stiffening is a marker of a shift to a more automatic control of posture. Switching to a more automatic control of posture is an energy efficient strategy, whereas, increased co-contraction is energetically inefficient and exhibiting a stiffer control of posture is attention-demanding (Morasso & Sanguineti, 2002). Therefore, when controlling posture in a more automatic way active ankle stiffening is unlikely occurring.

Examining the separate views on how ankle stiffness is conceived, it becomes apparent that these views exist on a broad spectrum. Stins et al. (2011) concluded that cognitive and affective perturbations could possibly have two separate control processes due to the separate investments made in postural control. Stins et al. (2011) also concluded that active ankle stiffening is not a marker of an EF of attention, and it is unlikely occurring when controlling posture in a more automatic way. Further research is required in order to continue to separate these views and shed light on whether active ankle stiffening is actually occurring when postural control is in a more automatic mode.

CHAPTER TWO: INTRODUCTION

2.1 Introduction

Postural control is the coordination of the body's position in space for the purposes of balance and orientation (Shumway-Cook & Woollacott, 2000). There are three main systems involved in the control of posture, consisting of the visual, vestibular and somatosensory systems. These three systems help to control posture and stability and they adapt depending on the task and environment (Woollacott et al., 1986; Shumway-Cook & Horak, 1986).

The control of posture in upright stance was once believed to be automatic and a reflexive process that required limited attentional resources. Although postural control appears like it would be fairly automatic, literature has shown that it requires attention (Woollacott & Shumway-Cook, 2002) and can be altered through cognitive manipulations (Mitra et al., 2013; Mitra & Frazier, 2004; Andersson et al., 2002; Riley et al., 2003; Dault et al., 2001a; Dault et al., 2001b; Lajoie et al., 1993; Stins et al., 2011; Prado et al., 2007; Polskaia et al., 2015; McNevin & Wulf, 2002). The literature that has looked at postural control during cognitive tasks remains uncertain, however an increase in postural sway has been attributed to a weakened control of posture (Mitra et al., 2013). It has been shown in these studies that postural sway can decrease (Andersson et al., 2002; Riley et al., 2003), increase (Mitra et al., 2013; Mitra & Frazier, 2004) or remain unchanged (Yardley et al., 1999).

Attentional focus studies have outlined that performing an EF, compared to an IF of attention, results in a reduced postural sway due to promoting a more automatic control of posture (Wulf et al., 1998; Shea & Wulf, 1999; McNevin & Wulf, 2002). It is believed that an

EF promotes better performance compared to an IF, because it establishes greater effectiveness and efficiency of the movement being performed (Wulf, 2007). The explanation behind an IF outlines that it conforms to a more conscious form of control. This then causes a constraint on the motor systems that interferes with the automatic mode of control by utilizing unconscious, fast, and reflexive control processes. Where the EF moves focus away from these allowing them to run efficiently (Wulf, McNevin & Shea, 2001).

Studies that have found a decrease in postural sway when performing cognitive tasks, similar to EF of attention findings, have been attributed to allowing a more automatic control of posture (Dault et al., 2001b; Stins et al., 2011), and also improved control of posture. The characteristics that have been outlined to represent a more automatic postural control consist of a decreased sway amplitude (Huxhold, Li, Schmiedek & Lindenberger, 2006) decreased sway variability and mean velocity (Maylor et al., 2001) and increased sway frequency (McNevin & Wulf, 2002). This seems to have created some confusion in the literature due to the components of increased passive ankle stiffness put forth by Winter et al. (1998), that consists of an increase in frequency and a decrease in sway amplitude. Winter et al. (1998) have suggested that an ankle strategy is a main contributor to postural control while performing quiet stance and when experiencing small perturbations.

The composition of increased ankle stiffening is quite clear, though there remain conflicts as to how an increase in ankle stiffening is conceived and whether it is brought on when posture is in its more natural automatic mode (McNevin & Wulf, 2002; Dault et al., 2001b), or when there is a threat placed on posture making it more consciously controlled (Huffman et al., 2009; Stins et al., 2011). By looking at postural control variables and also muscle activation in the ankle muscles, it will be made clearer if a stiffening strategy exists when in a more automatic mode of postural control.

2.2 Purpose

The objective of this study was to examine variables of postural control and ankle muscle activation, while performing two separate continuous cognitive tasks of varying difficulty, an EF of attention task, all paired with a feet together postural task. More specifically, the study set out to; 1) determine if the use of a continuous cognitive task (SNS and DNS) demonstrates distinct characteristics of a more automatic control of posture, compared to an EF and FT postural task and to 2) examine which condition, if any exhibits the characteristics of increased passive ankle stiffness proposed by Winter et al. (1998), as well as displaying increased ankle muscular co-contraction, which is a suggested neuromuscular mechanism that stiffens posture.

2.3 Hypotheses

1. The continuous cognitive tasks (SNS/DNS) will display improvements in postural control (i.e. smaller postural sway). This will occur by shifting attention away from the control of posture to the cognitive task, freeing resources and allowing the control of posture to occur in a more automatic form (Donker, Roerdink, Greven & Beek, 2007; Wulf, McNevin & Shea, 2001).
2. The continuous cognitive tasks (SNS/DNS) will display the characteristics of increased passive ankle stiffness, put forth by Winter et al. (1998) (increased MPF and decreased sway amplitude), due to conflicting similarities of a shift to a more automatic control of

posture, and a marker of ankle stiffness. However, there will not be any heightened ankle muscular co-contractions across the conditions due to ankle stiffening not being present.

CHAPTER THREE: MANUSCRIPT

Postural control and ankle muscle stiffness during continuous cognitive tasks and external focus of attention

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Not submitted

Postural control and ankle muscle stiffness during continuous cognitive tasks and external focus of attention

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Abstract

The objective of this study was to determine if the use of a continuous cognitive task demonstrates characteristics of an automatic postural control, and to examine active ankle stiffening. Fifteen young adults performed feet together stance, external focus of attention and two cognitive counting tasks (single number sequence and double number sequence). Surface electromyography signals were collected from the tibialis anterior and medial gastrocnemius. SNS and DNS had decreased sway area and ML sway variability compared to FT. As well as decreased AP sway variability compared to EF and FT. The AP MPF increased for SNS compared to FT, as well ML MPF for SNS and DNS increased compared to FT. Ankle muscle Co-contraction indices revealed no differences across conditions.

Keywords: dual-task, cognitive task, postural control, ankle stiffening, attentional focus

Word Count: 120 words

1. Introduction

The control of posture in upright stance was once believed to be automatic and a reflexive process, though literature has shown that it requires attention (Woollacott & Shumway-Cook, 2002) and can be altered through cognitive manipulations (Mitra et al., 2013; Mitra & Frazier, 2004; Andersson et al., 2002; Riley et al., 2003; Dault et al., 2001a; Dault et al., 2001b; Lajoie et al., 1993; Stins et al., 2011; Prado et al., 2007; Polskaia et al., 2015; McNevin & Wulf, 2002). The literature that has looked at postural control during cognitive tasks remains uncertain, however an increase in postural sway has been attributed to a weakened control of posture (Mitra et al., 2013). It has been shown in these studies that postural sway can decrease (Andersson et al., 2002; Riley et al., 2003), increase (Mitra et al., 2013; Mitra & Frazier, 2004), or remain unchanged (Yardley et al., 1999).

Studies using attentional focus have outlined that performing an external focus (EF) of attention, compared to an internal focus (IF) of attention, results in a reduced postural sway due to promoting a more automatic control of posture (McNevin & Wulf, 2002; Wulf et al., 1998; Shea & Wulf, 1999). The explanation behind an IF outlines that it conforms to a more conscious form of control. This causes a constraint on the motor systems that interferes with the automatic mode of control by utilizing unconscious, fast, and reflexive control processes. Where an EF moves focus away from these allowing them to run efficiently (Wulf, 2013).

Studies that have found a decrease in postural sway when performing a concurrent cognitive task have also been attributed to allowing a more automatic control of posture (Dault et al., 2001a; Stins et al., 2011), and also an improved control of posture. The characteristics that have been outlined to represent a more automatic postural control consist of decreased sway amplitude (Huxhold et al., 2006), sway variability and mean velocity (Maylor et al., 2001) and increased sway frequency (McNevin & Wulf, 2002). This has created some confusion in the literature due to the components of passive ankle stiffness put forth by Winter et al. (1998) that encompasses an increase in frequency and a decrease in sway amplitude, which are similar attributes to an increased automatic control.

The composition of increased ankle stiffening is quite clear, though there remain conflicts as to how an increase in ankle stiffening is conceived. Explanations include that ankle stiffening increases when posture is in its more natural automatic mode (Dault et al., 2001a; McNevin & Wulf, 2002), or when there is a threat placed on posture making it more consciously controlled (Stins et al., 2011; Huffman et al., 2009). By looking at both postural variables and also muscle activation in the ankle muscles, it will be made clearer if a stiffening strategy exists when in a more automatic mode of postural control.

The objective of this study was two-fold and set out first to determine if the use of a continuous cognitive task demonstrates distinct characteristics of a more automatic control of posture, compared to an EF and feet together postural task. The study secondly set out to examine which conditions exhibits the characteristics of passive ankle stiffness proposed by Winter et al. (1998) as well as displaying increased ankle muscular co-contractions, which is a suggested neuromuscular mechanism that stiffens posture.

It was hypothesized for the first objective that the continuous cognitive tasks would display improvements in postural control; smaller sway amplitude (Huxhold et al., 2006), smaller sway variability and MV (Maylor et al., 2001), and also increased MPF (McNevin & Wulf, 2002). It was hypothesized for the second objective that the continuous cognitive tasks would display the characteristics of passive ankle stiffness (Winter et al., 1998), which consist of increased MPF and decreased sway amplitude, due to conflicting similarities of a shift to a more automatic control of posture, and a marker of ankle stiffness. However, there would not be any heightened ankle muscular co-contractions across the conditions due to ankle stiffening not being present.

2 Methodology

2.1 Participants

Fifteen young healthy adults were tested, with an average age of 24 ± 3.37, of which 5 were male. Prior to the testing session, participants signed an informed consent form and completed a health questionnaire. The health questionnaire determined whether they had any kind of past injury, or any condition that may affect their postural control, and subsequently excluded them from participating. Participants were asked to hold off on ingesting any caffeine, cold or stimulant medication for at least 4 hours prior to the testing session, in order to have them tested with clear comprehension. This study was granted approval by the local Institutional Research Ethics Board at the University of Ottawa in compliance with the Declaration of Helsinki. There were no participants excluded from the testing session.

2.2 Apparatus

To evaluate muscle activation, surface electromyography data was recorded using four wireless surface electrodes (Delsys Inc., Natick, MA, United States) placed on the muscle bellies of the tibialis anterior (TA) and medial gastrocnemius (MG) muscles on each leg at a sampling rate of 1000 Hz. To evaluate postural control, an AMTI force platform (ORG-6- 1000, Watertown, MA, USA) was used to record the body's projection of ground-reaction forces at a sampling rate of 500 Hz. The number sequence cognitive tasks were presented to the participants using an audio player. The audio player was connected to speakers placed on either side of the participant. For the EF conditions, two 'L' shaped devices (Fig. 1) were constructed from two flat metal strips. The first metal strip was placed vertically along the lateral length of the foot and the other placed horizontally along the lateral length of the lower leg. The two strips were connected at the ankle joint and allowed a pivoting movement in the anterior-posterior (AP) direction. The apparatus was secured to the participant using two Velcro straps. One strap attached around the mid-foot and the other around the lower leg, while still allowing natural movement. Three markers extended 9 cm outward from the metal strips, one over the lateral malleolus, one near the small toe and one over the middle of the lower leg. The device did not obstruct ankle movement in the medial-lateral (ML) direction. To evaluate maximum voluntary contraction two force transducers were used at a sampling rate of 1000 Hz, one for each leg. They were attached to metal plates that could be either pushed or pulled while an individual was seated, with their feet strapped tightly to the metal plates (Fig. 2).

2.3 Postural Task

The postural task consisted of standing as still as possible on the force platform with hands alongside the body and feet together, staring straight ahead at a circular marker positioned at eye level. The circular marker was 5 cm across, and positioned 3 m from the front edge of the force plate. The participant's feet were marked after the first trial to ensure a standard position throughout the testing session. This position was used for all four conditions.

2.4 External Focus Cognitive Task

Based on previous studies involving an IF condition and control task there have been a large amount of studies that have found no differences between the two (Wulf et al., 1998; Wulf & McNevin, 2003; Wulf et al., 2003). For this reason, the researchers chose not to include an IF condition. For the EF cognitive task, participants wore the "L" shaped apparatus described above (Fig. 1). Participants were instructed that as they swayed forward and backward, the top marker also moved forward and backward, and the bottom two markers remained still. Before each EF trail began, participants could look down to see where the markers were positioned, then were asked to maintain the same position of the top marker relative to the bottom two (Richer et al., 2017) for the duration of the trial, as they looked straight ahead at the dot positioned on the wall at eye level. As this was purely a mental task, focus was placed on the effect their sway had on the apparatus. Upon completion of each trail, participants were asked their percentage of focus on the EF task, to ensure focus was being properly allocated. If a score of 50% or lower was expressed, the trial was redone at the end of the experimental protocol.

2.5 Cognitive Tasks

The two continuous cognitive tasks were designed to be performed silently, and therefore participants relayed their answers only upon completion of the trail to eliminate any interference caused by articulation. Furthermore the participants were instructed not to use their fingers or mouths to aid in counting the three digit numbers to maximize cognitive effort (Polskaia et al., 2015). Error score limits used for the cognitive task conditions were designed to match the difficulty of the cognitive task, and were modeled after a previous study (Polskaia et al., 2015).

2.5.1 Single Number Sequence Cognitive Task

The SNS cognitive task required participants to silently count a single pre-selected digit from a 60 second pre-recorded audio file. The audio file consisted of a string of 3-digit numbers, with one 3-digit number delivered every 3 seconds for a total of 20 3-digit numbers. The digit that was chosen was selected at random, and changed after each trail. Each SNS trail was different in order to eliminate the possibility of memorization. If the participants' error score was greater than three, the trial was redone at the end of the experimental protocol.

2.5.2 Double Number Sequence Cognitive Task

The DNS cognitive task required participants to silently count two single pre-selected digits from a 60 second pre-recorded audio file. The audio file consisted of a string of 3-digit numbers with one 3-digit number delivered every 3 seconds for a total of 20 3-digit numbers. The two numbers that were selected to be counted were chosen at random, and changed after each trail. Each DNS trail was different in order to eliminate the possibility of memorization. If the participant's combined error score was greater than six, the trial was redone at the end of the experimental protocol.

2.6 Procedure

The experimental protocol consisted of three dual-task conditions and one control condition. The control condition consisted of performing only the postural task and the three dual-task conditions involved a combination of the postural task with three cognitive task conditions (EF, SNS, and DNS). Instructions for the postural task were provided once at the beginning of the testing session, in order to avoid participants prioritizing posture over cognition during the three dual-task conditions. The session consisted of twenty-four, 60-second trials, six per condition (including 6 for FT). The conditions were performed in blocks of three, and blocks were randomized to eliminate an order effect. If errors occurred outside the error parameters, the trials were redone at the end of the experimental protocol. Participants were not made aware if mistakes were made.

2.7 Maximum Voluntary Contraction

Maximum voluntary contractions (MVC) were performed after the experimental protocol was complete. There were three MVC pull trials (maximum tibialis anterior force) and three MVC push trials (maximum medial gastrocnemius force), all 10 seconds in duration. They were obtained via sitting isometric toe and heel presses against resistance provided by metal plates in which participant's feet were firmly strapped to. Force data and also EMG data were collected during each trial. The MVC values for each muscle and leg were defined as the maximum force observed over a 0.5s interval during the middle 4 seconds for all MVC trials. The highest value for each muscle of each leg were used.

2.8 Data Analysis

Centre of pressure (COP) was obtained from the ground-reaction forces collected by the force platform. Afterwards, Matlab software (MathWorks Inc., MA, USA) was used to attain outcome measures such as area of 95% confidence ellipse (sway area), standard deviation (SD) of centre of pressure (COP) in the AP and ML direction (sway variability), and mean velocity in the AP and ML direction. A Fast Fourier Transform (FFT) analysis was performed on the COP data using BioProc3 Software (D.G.E. Robertson, Ottawa, Canada) to obtain mean power frequency (MPF) in the AP and ML direction. Muscle activation of the TA and MG of each leg was obtained using surface Electromyography. Using BioProc3 Software (D.G.E. Robertson, Ottawa, Canada) all EMG data was full-wave rectified, linear enveloped and filtered using a 4th order low-pass Butterworth filter at 6Hz. Maximum force was obtained via force transducers and displayed using BioProc3 Software (D.G.E. Robertson, Ottawa, Canada). Co-contraction indices (CCI) were determined from the normalized EMG data. The CCI calculation used is from the altered approach of Warnica et al. (2014), and originally based on the CCI equation used by Hubley-Kozey et al. (2009).

CCI Calculation

$\% \text{ MVC} = (\text{EMG}_{TA}/\text{EMG}_{MG}) \times 100$

$\text{CCI} = [\% \text{ EMG}_{TA}/\% \text{ EMG}_{MG} \times (\% \text{ EMG}_{TA} + \% \text{ EMG}_{MG})]$

$\% \text{ EMG}_{TA} = 5.334 \qquad \% \text{ EMG}_{MG} = 4.259$

$\text{CCI} = [5.334 / 4.259 \times (5.334 + 4.259)]$

2.9 Statistical Analysis

Condition (FT, EF, SNS, and DNS) analysis of variance (ANOVA) with repeated measures was performed on all previously mentioned force platform outcome measures. Condition (FT, EF, SNS and DNS) x muscle (RTA, RMG, LTA, and LMG) ANOVA with repeated measures was performed on EMG (% of MVC) data. Condition (FT, EF, SNS, and DNS) ANOVA with repeated measures was performed on the CCI outcome measures. All data are expressed as means with standard deviation. If Mauchly's test of sphericity was violated, a Greenhouse-Geisser correction was performed. Statistical significance was set at $p < .05$. When necessary, Newman-Keuls post-hoc analysis was performed to establish the location of significance.

3 Results

3.1 Area of 95% Confidence Ellipse

The main effect of condition, $F\,(3, 42) = 5.73$, $p < .005$, $\eta_p^2 = .29$, on sway area was statistically significant (Fig. 3). Post-hoc analysis reveled that sway area for SNS ($p < .005$) and DNS ($p < .005$) conditions were significantly smaller than FT.

3.2 Standard Deviation of Centre of Pressure

The main effect of condition, $F\,(3, 42) = 9.94$, $p < .00005$, $\eta_p^2 = .41$, on sway variability in the AP direction was statistically significant (Fig. 4). Post-hoc analysis indicated EF ($p < .05$), SNS ($p < .0005$) and DNS ($p < .0005$) were statistically smaller than FT. As well post-hoc analysis indicated SNS ($p < .05$) and DNS ($p < .05$) were statistically smaller than EF.

The main effect of condition, $F\,(3, 42) = 4.35$, $p < .01$, $\eta_p^2 = .24$, on sway variability in the ML direction was statistically significant (Fig. 4). Post-hoc reveled SNS ($p < .05$) and DNS ($p < .01$) were statistically smaller than FT.

3.3 Mean Velocity

The main effect of condition, $F\,(3, 42) = 19.71, p < .000001, \eta_p^2 = .58$, on mean velocity in the AP direction was statistically significant (Fig. 5). Post-hoc analysis indicated that mean velocity in the AP direction for SNS and DNS were greater than EF ($p < .0005$ and $p < .0005$, respectively) and FT ($p < .0005$ and $p < .0005$, respectively).

The main effect of condition, $F\,(3, 42) = .39, p > 0.05$, on mean velocity in the ML direction was not statistically significant (Fig. 5).

3.4 Mean Power Frequency (MPF)

The main effect of condition, $F\,(3, 42) = 3.55, p < .05, \eta_p^2 = .20$, on MPF in the AP direction was statistically significant (Fig. 6). Post-hoc analysis revealed that MPF in the AP direction for SNS was significantly larger than FT ($p < .05$).

The main effect of condition, $F\,(3, 42) = 3.37, p < .05, \eta_p^2 = .19$, on MPF in the ML direction was statistically significant (Fig. 6). Post-hoc analysis reveled that MPF in the ML direction for SNS and DNS were larger than FT ($p < .05$ and $p < 0.05$) respectively.

3.5 Surface Electromyography

The main effect of muscle and condition on muscle activation was superseded by a muscle x condition interaction, $F\,(9, 126) = 2.81, p < .05, \eta_p^2 = .13$ (Fig. 7). Post-hoc analysis indicated that for the left TA DNS was significantly larger than EF ($p < .05$) and SNS ($p < .05$). Post-hoc analysis also indicated that the left TA for FT, EF, SNS, and DNS were larger than the right TA

FT ($p < .00005$), EF ($p < .00005$), SNS ($p < .00005$) and DNS ($p < .00005$) respectively. Post-hoc analysis revealed the left MG EF was significantly larger than the right MG EF ($p < .05$). The left MG DNS was significantly larger than the right MG DNS ($p < .05$).

The main effect of muscle, F (3, 42) = 2.32, $p > .05$, on EMG was not statistically significant. The main effect of condition, F (3, 42) = 2.10, $p > .05$, on EMG was not statistically significant.

3.6 Co-Contraction Indices

The main effect of leg, F (3, 42) = 1.876, $p > .05$, on CCI was not statistically significant (Fig. 8).

4. Discussion

The objective of this study was to examine variables of postural control and ankle muscle activation. The first hypothesis was partially confirmed, results showing several, but not all of the outcome measures displayed characteristics of an enhanced control of posture for the continuous cognitive tasks. For the second hypothesis it was supported by the results of the study. The continuous cognitive tasks (SNS and DNS) both displayed characteristics of passive ankle stiffness, in addition to not demonstrating any increased ankle muscular co-contractions viewed across the conditions.

4.1 Variables of Automatic Postural Control

The results of the present study demonstrated a number of characteristics associated with an enhanced automatic control of posture for the continuous cognitive tasks compared to FT as well as some enhanced characteristics compared to EF. The sway area for SNS and DNS were significantly smaller compared to FT (Fig. 3), this is in line to that of Huxhold et al. (2006). The present study also demonstrated the AP sway variability was significantly smaller for the SNS and DNS compared to FT and EF, and in the ML direction SNS and DNS were smaller compared to FT (Fig. 4) in accordance to findings by Polskaia et al. (2015). MPF in the AP direction was larger for SNS compared to FT, and larger in the ML direction for SNS and DNS compared to FT (Fig. 6). Similar to McNevin & Wulf (2002), who viewed increased MPF for their EF task compared to their baseline and IF tasks. However, in opposition to the hypothesis the AP MV was larger for SNS and DNS compared to EF and FT, and no change was viewed across the four separate conditions in the ML direction (Fig. 5). Although MV is thought to decrease when in a more automatic mode a study by Potvin-Desrochers et al. (2017) showed an increase in MV for the cognitive tasks. The study also showed an increase in sample entropy for the cognitive tasks, which is a marker of automatic postural control.

In a study by Polskaia et al. (2015) they had decreased sway area and sway variability in the AP and ML directions in the continuous cognitive tasks compared to IF and EF tasks. They attributed the changes to a more stable control of posture in the continuous cognitive tasks. These results are in congruency to previous literature (Andersson et al., 2002; Riley et al., 2003; Dault et al., 2001a; Stins et al., 2011). An improved postural control is often attributed to the use of an automatic control of posture (Andersson et al., 2002; Stins et al., 2011; McNevin & Wulf, 2002).

An enhanced control of posture is believed to occur when performing a continuous cognitive task due to a shift in attention away from the control of posture, which often functions in a reflexive state (McNevin & Wulf, 2001). The results of this study display that by withdrawing attention away from the control of posture through the use of continuous cognitive tasks, the control of posture was enhanced, compared to FT. The cognitive tasks were continuous; therefore, there were no breaks within the trials where participants could engage in focusing on the postural control processes (Wulf et al., 1998; McNevin et al., 2003).

4.2 Ankle Stiffening Strategy

As previously mentioned SNS and DNS displayed increased MPF and decreased postural sway compared to FT, which are markers of an enhanced control of posture (McNevin & Wulf, 2002; Huxhold et al., 2006) but also suggested characteristics of passive ankle muscle stiffness (Winter et al., 1998). This study however, displayed no differences for the CCI across the four separate conditions (Fig. 8), which suggest no change in ankle muscle co-contractions.

Studies that have concluded that ankle stiffening may be associated with a more automatic control of posture have used MPF and sway amplitude as a measurement of ankle stiffness (Dault et al., 2001a; McNevin & Wulf, 2002). Other studies that have displayed this increase in ankle stiffening consist of postural threat tasks (Carpenter et al., 1999; Carpenter et al., 2001), as well as impaired postural control (Melzer et al., 2001; Morasso & Sanguineti, 2002). Some of which employed the use of EMG and viewed increased co-activation of ankle muscles (Carpenter et al., 2001; Brown et al., 2006). These studies consisted of situations that would require increased cognitive resources for the control of posture and are energy inefficient (Morasso &Sanguineti, 2002).

Ankle muscle simulations performed by Morasso & Sanguineti (2002) give indication that ankle muscular co-contractions contribute to restoring posture, when control has been compromised. This occurs through increased postural stiffness of the ankle muscles. Morasso & Sanguineti (2002) believe that an increase in ankle stiffness is done through an exaggerated and energetically expensive activation of the ankle muscles. Therefore, it appears very unlikely that when young adults are in a more automatic mode of postural control, increased active ankle stiffness is occurring, which are along the lines of the results of the present study.

5 Conclusion

The continuous cognitive tasks removed attention from the control of posture allowing postural control processes that are often automatic and reflexive to remain this way. There was no change in ankle muscular co-contractions across any of the separate conditions, which supports the idea that increased active ankle stiffness is unlikely to occur when in a more automatic control of posture.

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Figure Captions

Fig 1. Device used for the external focus condition. Two flat metal strips both held in place by a Velcro strap, one on the lower leg and the other on the lateral side of the foot. Three markers extend outward laterally 9 cm each; one marker on the lower leg, one on the lateral malleolus and the last one on the lateral side of the foot

Fig 2. Apparatus used to collect maximum voluntary force of each participant. Participants sat in the chair with their feet placed flush against the two metal plates. Feet were strapped tightly to the metal plates using two Velcro straps per foot. Force transducers collected maximum force for push and pulls

Fig 3. Area of 95% confidence ellipse (cm^2) across the four separate conditions.
ϕ Significantly different from FT condition (*p* < .005)

Fig 4. Sway variability in the AP and ML directions (cm) across the four separate conditions
β Significantly different from the AP FT condition (*p* < .05)
α Significantly different from the AP FT condition (*p* < .0005)
Δ Significantly different from the AP external focus condition (*p* < .05)
* Significantly different from the ML FT condition (*p* < .05)
** Significantly different from the ML FT condition (*p* < .01)

Fig 5. Mean velocity in the AP and ML directions (cm.s-1) across the four separate conditions
α Significantly different from the AP FT condition (*p* < .0005)
λ Significantly different from the AP external focus condition (*p* < .0005)

Fig 6. Mean power frequency in the AP and ML directions (Hz) across the four separate conditions
β Significantly different from the AP FT condition (*p* < .05)
* Significantly different from the ML FT condition (*p* < .05)

Fig 7. EMG for the right TA, left TA, right MG and left MG across the four separate conditions
* Significantly different from the left TA external focus condition (*p* < .05)
** Significantly different from the left TA single number sequence condition (*p* < .05)
Φ Significantly different from the right TA FT condition (*p* < .00005)
λ Significantly different from the right TA external focus condition (*p* < .00005)
α Significantly different from the right TA single number sequence condition (*p* < .00005)
Δ Significantly different from the right TA double number sequence condition (*p* < .00005)
β Significantly different from the right MG external focus condition (*p* < .05)
ϒ Significantly different from the right MG single number sequence condition (*p* < .05)

Fig 8. Co-contraction indices across the four separate conditions (*p* > .05)

Fig 1.

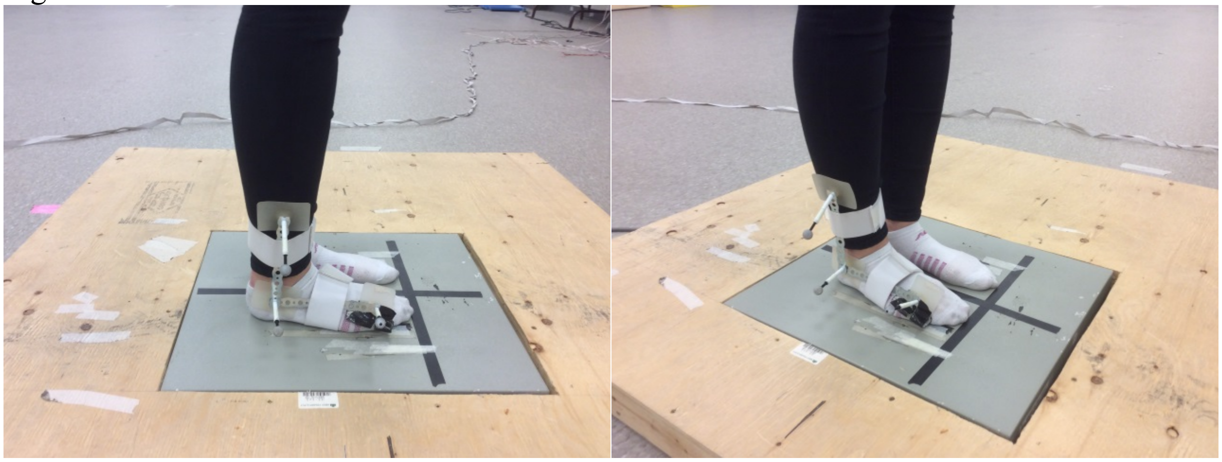


Fig 2.

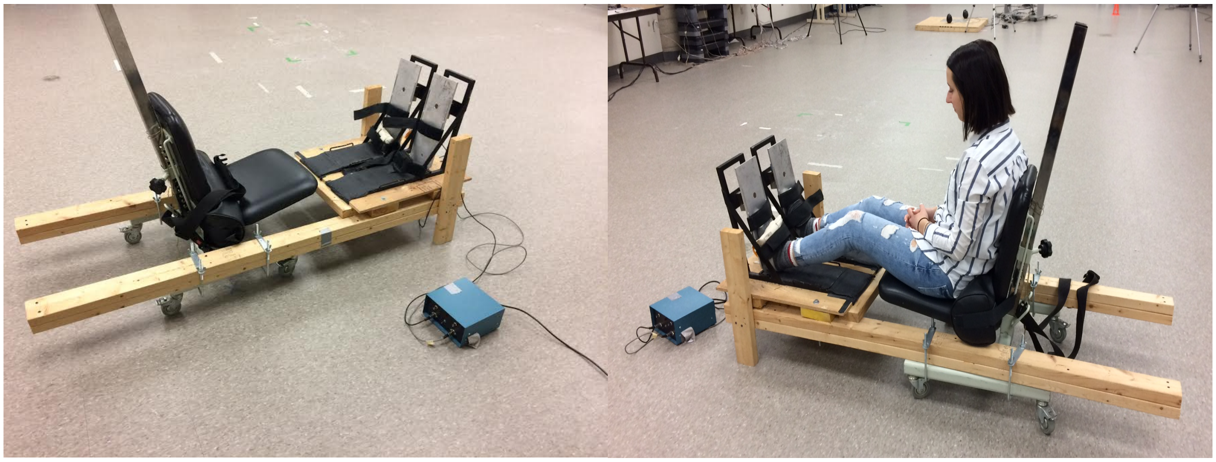


Fig 3.

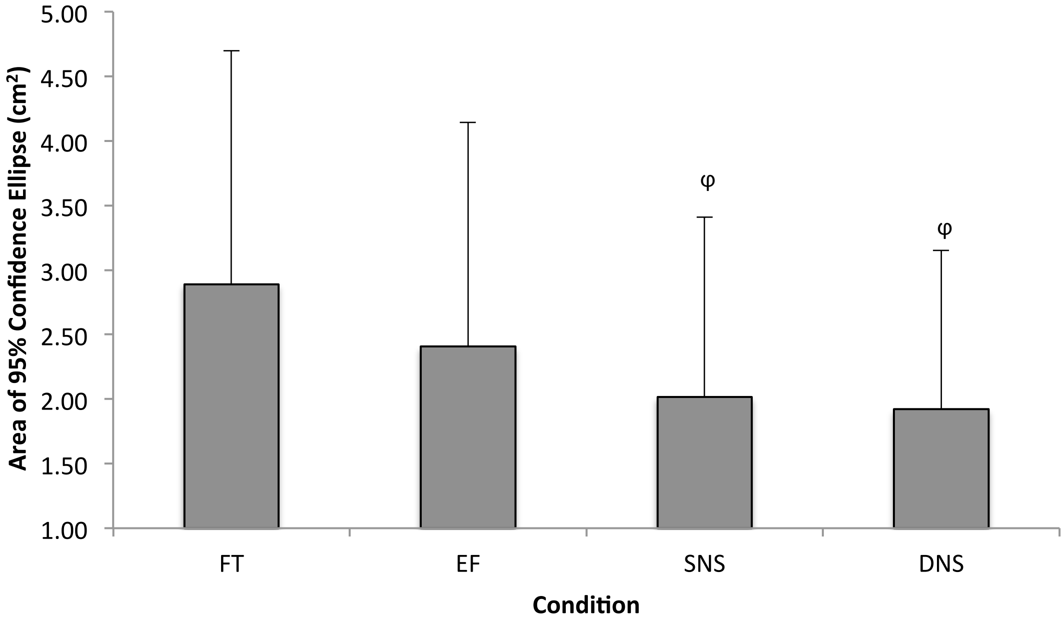

5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
Area of 95% Confidence Ellipse (cm²)
φ
φ
FT
EF
SNS
DNS
Condition

Fig 4.

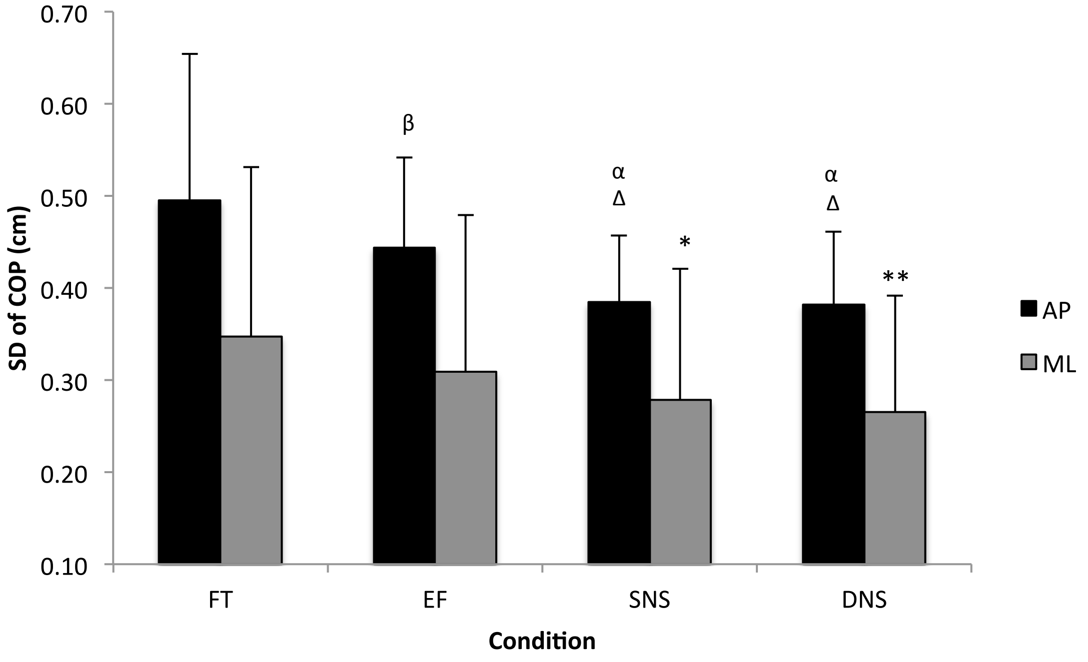

0.70
0.60
0.50
0.40
0.30
0.20
0.10
SD of COP (cm)
β
α
Δ
*
α
Δ
**
AP
ML
FT
EF
SNS
DNS
Condition

Fig 5.

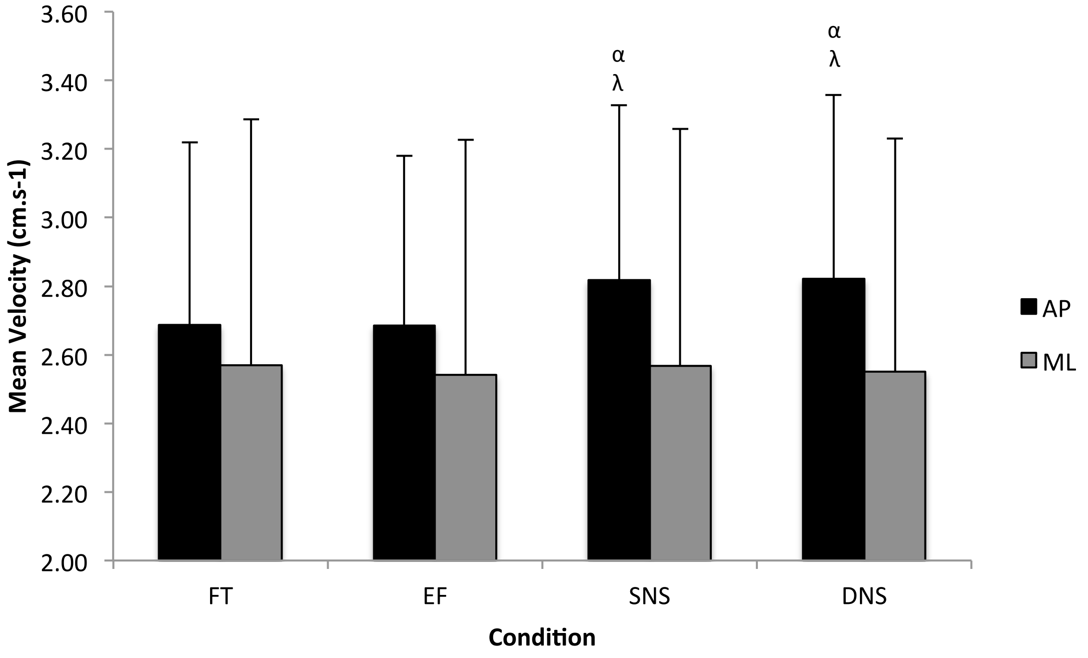

3.60
3.40
3.20
3.00
2.80
2.60
2.40
2.20
2.00
Mean Velocity (cm.s-1)
α
λ
α
λ
FT
EF
SNS
DNS
Condition
AP
ML

Fig 6.

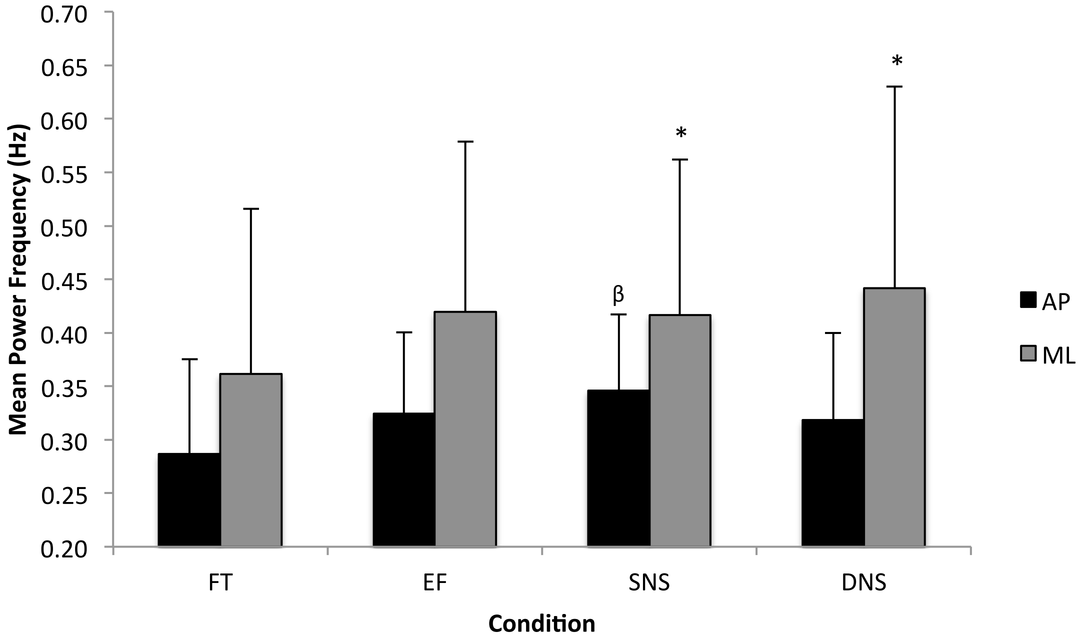

0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
Mean Power Frequency (Hz)
FT
EF
SNS
DNS
Condition
β
*
*
■ AP
■ ML

Fig 7.

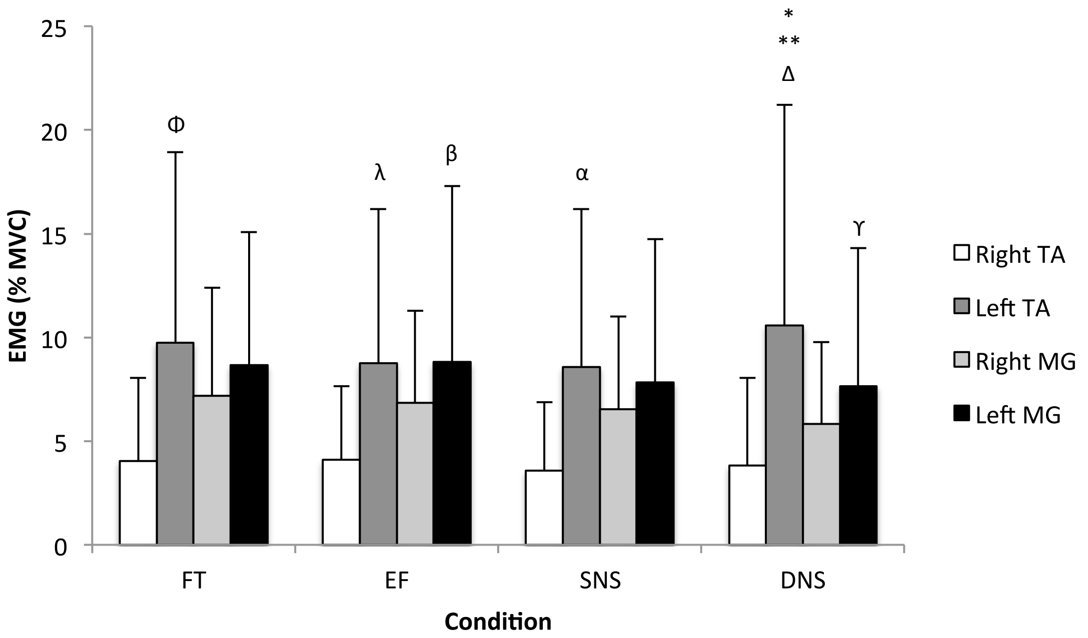
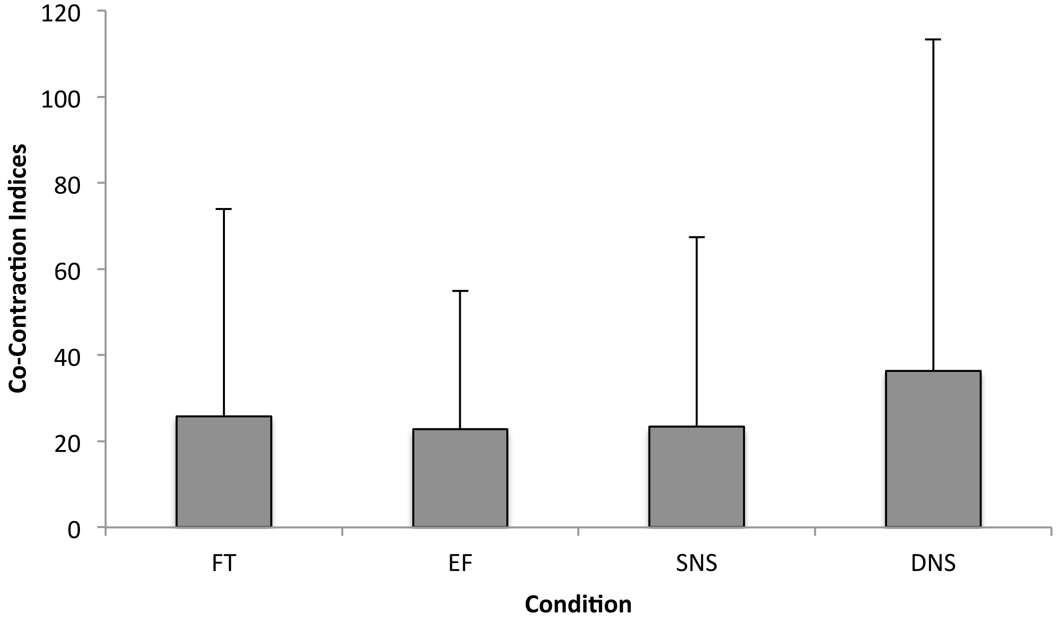

25
20
15
10
5
0
EMG (% MVC)
Φ
λ
β
α
*
**
Δ
ϒ
FT
EF
SNS
DNS
Condition
☐ Right TA
▨ Left TA
☐ Right MG
■ Left MG

Fig 8.


120
100
80
60
40
20
0
Co-Contraction Indices
FT
EF
SNS
DNS
Condition

CHAPTER FOUR: GENERAL DISCUSSION

The objective of this study was to examine variables of postural control and ankle muscle activation, while performing two separate continuous cognitive tasks of varying difficulty, an EF task, all paired with a postural task of quiet, feet together (FT) stance. More specifically, the study was two-fold and set out to; 1) determine if the use of a continuous cognitive task (SNS and DNS) demonstrates distinct characteristics of a more automatic control of posture, compared to EF and FT, and to 2) examine which condition, if any, exhibited the characteristics of passive ankle stiffness proposed by Winter et al. (1998), as well as displayed increased ankle muscular co-contractions, which are a suggested neuromuscular mechanism that stiffens posture. First, it was hypothesized that the continuous cognitive tasks would display improvements in postural control (i.e. smaller postural sway, decreased mean velocity, increased frequency and decreased sway variability). Secondly, it was hypothesized that the continuous cognitive tasks would display characteristics of passive ankle stiffness, which was put forth by Winter et al. (1998) (increased frequency and decreased sway amplitude), due to conflicting similarities between an automatic control of posture and a marker of passive ankle stiffness. However, it was believed there would be no heightened ankle muscular co-contractions across the conditions, due to active ankle stiffening not being present.

The results of this study in relation to the first objective, concerning the continuous cognitive tasks displaying traits relative to an automatic mode of postural control were partially confirmed. Not all outcome measures displayed the differences that were originally believed to occur. In terms of sway area (Fig. 3) SNS and DNS were both significantly smaller than FT, though not statistically different from EF. Similarly to the sway area, ML sway variability (Fig.

4) for SNS and DNS were significantly smaller than FT and not statistically different from EF. However, for AP sway variability (Fig. 4), SNS, DNS and EF were all significantly smaller, compared to FT. Also, SNS and DNS were statistically smaller compared to EF. For the ML MV (Fig. 5), there was no significance across the four separate conditions; however, AP MV (Fig. 5) for SNS and DNS were statistically larger, compared to the EF and FT. The ML MPF (Fig. 6) for SNS and DNS were significantly larger compared to FT. Lastly, the AP MPF (Fig. 6) was statistically larger for only SNS, compared to FT. The results for the first objective showed that the continuous cognitive tasks displayed traits of an automatic control of posture, compared to FT. The outcome for the second hypothesis was almost fully supported by the results of the study. The continuous cognitive tasks (SNS and DNS) both displayed the characteristics of passive ankle stiffness, in addition to not demonstrating increased muscular co-contraction viewed across the conditions (Fig. 8). SNS and DNS had significantly decreased sway amplitude (Fig. 3), and significantly higher ML MPF (Fig. 6), compared to FT. As well, SNS had significantly higher AP MPF (Fig. 6), compared to FT. However, when viewing the EMG activation for the left TA (Fig. 7), DNS was greater than EF and SNS, which does not conform to what was hypothesized.

4.1 Variables of Automatic Control of Posture

There remains conflicting evidence in the literature on what the control of posture does when paired with a cognitive task. Results of these studies have shown postural sway to worsen (Andersson et al., 2002; Brown et al., 2002; Dault et al., 2001a; Dault et al., 2001b), improve (Maylor & Wing 2000; Mitra, 2003; Mitra & Fraizer, 2004; Pellecchia 2003) or remain unchanged (Yardley et al., 1999). This study therefore sought out to display that performing a continuous cognitive task would indeed promote an improved postural control, compared to FT and EF of attention. It was believed the continuous cognitive tasks would promote an improved control of posture, due to a shift in focus away from controlling posture to the cognitive task, therefore allowing posture to be controlled through more automatic processes.

The components that have been put forth to demonstrate a greater automatic control of posture consist of a decreased sway amplitude (Huxhold et al., 2006), decreased mean velocity and sway variability (Maylor et al., 2001), and increased sway frequency (McNevin & Wulf, 2002; Dault et al., 2001b). Compared to FT, the SNS and DNS cognitive tasks displayed decreased sway area (Fig 3), as well as decreased ML sway variability (Fig. 4). The AP sway variability was significantly smaller for SNS and DNS cognitive tasks, compared to EF and FT (Fig. 4). In terms of the MPF, which is another attribute of an automatic mode of control, it was found that in the ML direction it was significantly higher for SNS and DNS cognitive tasks (Fig. 6), and higher in the AP direction for SNS when compared to FT (Fig, 6). For the ML MV against what was believed to occur, there was no change across the separate conditions (Fig. 5). As for AP MV the two continues cognitive tasks displayed an increase compared to the other two conditions (Fig. 5). Although MV is thought to decrease when in a more automatic mode a study by Potvin-Desrochers et al. (2017) showed an increase in MV for the cognitive tasks. The study also showed an increase in sample entropy for the cognitive tasks, which is a marker of automatic postural control.

The control task often demonstrates results similar to an IF, as shown in previous literature (Landers et al., 2005; Wulf et al., 1998, Experiment 1; Wulf et al., 2003). With the only instructions for the control task being to have the participant concentrate on standing still and to not fidget, it may have acted like an IF by having people internalize the command and focus on their posture during the task. An IF has the individual focus on the movement itself (Wulf et al., 1998), which is very similar to the instructions at the beginning of the present study. Therefore, during FT, when there is no cognitive task being performed focus on the control of posture is likely occurring. There have been various studies that suggest when a control task was included with no distinct focus instructions; it behaved similarly to the IF task (Wulf et al., 1998, Experiment 1; Wulf et al., 2003, Experiment 2; Landers et al., 2005; Wulf et al., 2009).

In opposition to the control task, continuous cognitive tasks have been shown to display increased control of posture, compared to an EF condition (Polskaia et al., 2015). As previously mentioned, the EF task has been shown in numerous accounts in the literature to promote better performance of a task or skill, compared to the IF and control conditions (Wulf & McNevin 2003; Wulf et al., 2003, Experiment 2; McNevin & Wulf 2002). It is believed that the EF promotes a performance advantage, due to the performer utilizing more automatic control processes (McNevin & Wulf, 2002). The continuous cognitive tasks displayed enhanced properties of a more automatic control of posture (Huxhold et al., 2006; Maylor et al., 2001), compared to FT. As well, the EF condition did not display as statistically different changes in those variables as the continuous cognitive tasks compared to FT. An explanation to the difference in changes may be that in the present study, the continuous cognitive tasks acted to move attention completely away from the control of posture and on to the cognitive task, whereas, the EF condition moved focus outside of the body, but still kept it on a component of the postural task. As such, attention was still partially kept on controlling posture by having the participant focus on keeping the markers around their ankles as still as possible.

By withdrawing attention away from the control of posture through the use of continuous cognitive tasks, the control of posture was enhanced, compared to FT. The cognitive tasks were continuous; therefore, there were no breaks within the trials where participants could engage in focusing on the postural control processes (Wulf et al., 1998; McNevin et al., 2003). Although the EF task was also continuous, the task may not have promoted a more effective control, due to the task being relatively close to the body. Therefore, creating a near-external focus that has been previously shown to act similarly to an IF condition (McNevin et al., 2003). The current study provides insight into links between the control of posture and cognitive tasks. When withdrawing attention from the control of posture during the continuous cognitive task, it is believed that the control of posture improves because the system is able to work more efficiently without interruptions.

4.2 The Stiffening Strategy

As previously discussed, decreased sway amplitude and increased sway frequency are characteristics that indicate a more automatic control of posture, as well as being outlined by Winter et al. (1998) as indicators of passive ankle stiffness. This has created an issue in the literature for studies where these traits occur. Leading to conclusions that ankle stiffness may be increased when in a more automatic control of posture. Therefore, the second objective was to examine which condition, if any, exhibits the characteristics of passive ankle stiffness proposed by Winter et al. (1998), as well as display increased ankle muscular co-contractions, which are a suggested neuromuscular mechanism that stiffens posture. The two paired together would thus give a more definitive indication if increased ankle stiffness were present. It was hypothesized that the continuous cognitive tasks would display increased frequency and decreased sway amplitude, though across the separate conditions, there would be no heightened ankle muscular co-contraction due to stiffening not being present.

The results of the study partially conformed to the hypothesis, where increased ML MPF (Fig. 6), and decreased sway amplitude (Fig. 3), were viewed in both continuous cognitive tasks, compared to FT; and increased AP MPF (Fig. 6) for SNS, compared to FT. When viewing the CCI, there was no significant difference across the separate conditions (Fig. 8). Lastly, the EMG results displayed conflicting results, as the DNS continuous task for the left TA presented increased activation, compared to the FT task (Fig. 7), although this was not coupled with increased MG activation for the same leg for the DNS condition.

In terms of the results for the EMG data, there was significantly elevated activation viewed for the left TA for DNS, compared to the left TA for EF and SNS. This result was in opposition of what was hypothesized, where there would be no difference in activation across the separate conditions. There was however no increased activation shown for the MG muscle for the DNS condition in the left leg, which displayed no muscular co-contraction, that indicates no increase in ankle stiffness for this condition.

Studies that have concluded that ankle stiffening may be associated with a more automatic control of posture have used sway frequency and sway amplitude as measurements, which are an indirect way to measure stiffness (Winter et al., 1998). Dault et al. (2001b) viewed decreased sway amplitude and increased frequency for their working memory cognitive tasks, compared to the postural task. It was concluded that the central nervous system might have chosen to control posture muscles in a more co-contraction mode, since it is less demanding, compared to the reciprocal innervation mechanism. Along similar lines, McNevin & Wulf (2002) concluded that the increased sway frequency that was viewed in their EF condition, when compared to the IF and control conditions was due to increased joint/muscle stiffness when in a more automatic mode of postural control. In comparison, the present study had different difficulty levels of continuous cognitive tasks that resulted in increased frequency and decreased amplitude, and paired with EMG measurements that concluded no increased co-contractions across the separate conditions.

There have been numerous studies that have displayed the traits of increased ankle stiffness through tasks, other than a continuous cognitive task. Some of these studies have employed the use of EMG to measure the increase in ankle muscle activation while performing these tasks. Though, there has been no study displaying this when performing basic quiet stance, paired with a continuous cognitive task. Studies that have displayed this increase consist of postural threat tasks (Carpenter et al., 1999; Carpenter, Frank, Silcher & Peysar, 2001), impaired postural control (Melzer et al., 2001; Morasso & Sanguineti, 2002) as well as emotionally provoking images (Azevedo et al., 2005; Facchinetti, Imbiriba, Azevedo, Vargas & Volchan, 2006). This list of studies consists of situations that would require increased cognitive resources and are energy inefficient (Morasso & Sanguineti 2002).

Carpenter et al. (1999) concluded that vision appears to play a heightened role in increased ankle stiffness when in an anxiety provoking situation. They viewed this through reciprocal changes in decreased sway amplitude RMS and increased MPF when participants stood on a platform where postural control was threatened. Similarly, Carpenter et al. (2001) had participants again stand on raised platforms, however, what differed is EMG was collected for the activation of lower leg muscles. Results of the study showed increased MPF, decreased sway amplitude, as well as an adaptation of an ankle stiffening strategy for the increased threat condition (Carpenter et al., 2001).

Alternatively, Melzer et al. (2001) had young and older adults perform single and dual-tasks combined with varying base of supports. They found that in the more challenging base of support, older adults adapted increased muscle activity in the TA and soleus muscles, compared to the muscle activation in the young adults. The authors concluded the increased active ankle stiffness for the older adults was more effective and safer, due to a lack in confidence to respond quickly enough to postural demands, because of the reduced base of support and increased cognitive demands brought on by the dual-task scenario (Melzer et al., 2001).

Ankle muscle simulations performed by Morasso & Sanguineti (2002), give indication that ankle muscular co-contractions contribute to restoring posture, when control has been compromised. This occurs through increased postural stiffness of the ankle muscles. Through the simulations, Morasso & Sanguineti (2002), also made it clear that an increase in ankle stiffness is done through an exaggerated and energetically expensive activation of the ankle muscles.

Therefore, it appears very unlikely that when young adults are in a more automatic mode of postural control, increased active ankle stiffness is occurring.

4.3 Summary of Findings

The current study aids in the support of literature that displays that continuous cognitive tasks improve the control of posture through the promotion of increased characteristics of an automatic mode of control. The continuous cognitive tasks removed attention from the postural control processes and had participants focus on the cognitive task, allowing postural control processes that are often automatic and reflexive to remain this way.

Studies that have viewed increased active ankle stiffness consist of different age related pathologies, anxiety-provoking situations; mainly situations that would require increased cognitive resources. These situations are also energy inefficient; therefore, it appears very unlikely that increased active ankle stiffness would occur when in a more automatic control of posture. This was indeed the case in the present study, where the continuous cognitive tasks promoted a more automatic control of posture, compared to the FT postural task. As well, there were no changes in ankle muscle activation across conditions to suggest that there was any active ankle stiffening occurring during the continuous cognitive tasks.

CHAPTER FIVE: CONCLUSION

5.1 Contribution to the Literature

Results obtained in the present study make contributions to the literature by aiding in the understanding that young adults tend to adapt a more stable control of posture, while performing a continuous cognitive task when performing basic postural control, in comparison to when they simply perform a single postural task (Andersson et al., 2002; Dault et al., 2003; Huxhold et al., 2006). The current set of results also favor the idea that increased ankle muscular co-activation does not occur in young adults, while they are in a more automatic mode of postural control (Stins et al., 2011). Due to the results of the present study, and also that increased active ankle stiffness has been shown to be energetically inefficient (Morassi & Sanguineti, 2002), it is therefore unlikely when the control of posture is considerably automatic.

5.2 Future Studies

Based on the results that were obtained in this study, future studies should include the use of an external perturbation or increased threat situation, in order to further explore the underlying properties behind the use of an active ankle stiffening strategy in young adults. Future studies should also examine older adults in basic postural stance scenarios, while paired with a continuous cognitive task, to closer assess the differences between increased anxiety situations and cognitive task situations in these different populations. Lastly, future studies exploring this area of interest should also include the use of an EF task that is positioned further from the body. Previous studies have outlined that a near-body EF task acts similarly to an IF task (McNevin et al., 2003). The present study included an EF task that was 9 cm from the body, therefore, this may have caused results similar to a near-body EF condition.

5.3 Limitations

There are limitations in this study that are of most importance to make mention of. The first limitation to assess was the EF task. The EF condition yielded similar results across almost all of the outcome measures, compared to FT, which are not often viewed in studies involving an EF condition. In a previous study by McNevin et al. (2003), they examined the difference the distance between the body, and the EF task makes. It was concluded that the farther the distance from the body the better the EF is in promoting efficiency of the movement performed. The EF task in this study was quite close to the body, therefore, may not have been far enough from the participant in order to promote the ideal results expected of an EF condition. A second limitation of this study has to do with the two continuous cognitive tasks that were used. It is hard to quantify the degree of difficulty that exists between the two tasks in order to ensure a consistent, equal change in difficulty between the two. The difficulty levels between the tasks therefore remain subjective to the researchers and also the participants.

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APPENDIX A

Participant Sheet

Full Name:_____________________ Sex: M / F Age: _____

Weight (kg / lbs): _______ Height (cm / ft): _______
Hours of physical activity/week: _______

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:

Cognitive or attention problems (ADD, ADHD, etc.): yes/no
If yes, please describe:

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