COGNITIVE PROCESSING INFLUENCES POSTURAL CONTROL DURING QUIET STANDING

by

Mylène Claude Dault

A thesis
presented to the University of Waterloo
in fulfillment of the
thesis requirement for the degree of
Doctor of Philosophy
in
Kinesiology

Waterloo, Ontario, Canada, 2001

National Library of Canada
Acquisitions and Bibliographic Services
395 Wellington Street
Ottawa ON K1A 0N4
Canada

Bibliothèque nationale du Canada
Acquisitions et services bibliographiques
395, rue Wellington
Ottawa ON K1A 0N4
Canada

Your file Votre référence

Our file Notre référence

0-612-65230-0

Canada

BORROWER'S PAGE

The University of Waterloo requires the signatures of all persons using or photocopying this thesis. Please sign below, and give address and date.

ABSTRACT

Performance of concurrent activities is required in many of our daily activities. It therefore is critical to determine how postural control and cognitive processing interact. Results from previous studies have found that postural control and tasks requiring cognitive processing influence each other; however, results are inconsistent. Some studies showed increased postural sway while others showed decreased or no change in postural sway when individuals were asked to perform a cognitive task. Hence, this thesis proposes to investigate how and why postural control and various cognitive processes influence each other. A series of five studies were conducted to address this issue.

For all five studies presented in this thesis, participants were asked to perform various tasks requiring cognitive processing while standing on a force platform that monitored their centre of pressure (COP) displacements. COP displacement provides information on the control of posture since it is closely related to the center of mass (COM) displacements. The length of the trials and the postural sway measures were constant across all studies to allow comparison of the different manipulations of the cognitive tasks.

Results from all studies presented in this thesis indicated that young healthy participants increase frequency and decrease amplitude of COP displacement. These changes in postural control occurred in all studies regardless of the type of the cognitive task, instructions to stand as still as possible, the motor and sensory requirements of the

cognitive task and practice. The final study investigated how the elderly were able to control posture while performing a cognitive task; results indicated that they responded differently than young individuals by increasing both amplitude and frequency of COP displacement in only the medio-lateral direction.

Hence, the lack of consistency of results reported by previous studies may be attributed to various trial lengths and measures of postural control, the difficulty of the postural task, as well as age and pathology and not to the characteristics of the cognitive task. During quiet standing, young individuals consistently increased joint stiffness when performing a concurrent task. Increased stiffness control may allow the operational demands on the CNS to be reduced which allows young individuals to perform a cognitive task without being at greater risk of falling. On the other hand, elderly and pathological populations may not have the ability to control posture in the same manner, which may lead to greater risk of falling when in a dual-task situation.

ACKNOWLEDGEMENTS

I would first like to thank Dr. Jim Frank for his supervision of my doctoral work. Dr. Frank was very helpful in motivating me and calming me down when I started to panic, which seemed to happen often!! Many thanks for giving me the liberty of conducting the research I wanted and where I wanted. Thank you for sharing my love of running and most of all thank you for being very comprehensive and human.

I would also like to acknowledge the help of Dr. Fran Allard. Dr. Allard was always very helpful in making me think further than the tip of my nose! I always enjoyed having debates in your office! I hope that one day I develop your ability to remember every possible study that has been published!!

I would like to thank Dr. Alexander Geurts and Dr. Lucy Yardley for giving me the opportunity to collaborate with them in their lab.

Thank you to my good friend Dr. Lori A. Vallis, without her I don't think I would have made it! Lori was my confidante, my rock, my second mom and my best friend. Thank you for being there for me. Lori, we finally survived this Pot hole Digger (PhD)!

Merci à Sylvain et Michelle avec qui j'ai pu partager ma passion du sport et libérer mes frustrations en FRANÇAIS!!! Thank you to Jen, Allan, Tom, Jeannette, Luiz and Karina

and Mike for your support and outlasting friendship. Thank you to all the members of the GapLab.

Thank you to my cousin Debbie and her husband Drew. You guys were my anchor to the real life and showing me there is much more to life than a PhD!!!

J'aimerais aussi remercier Dr. Claude Dugas pour avoir cru en moi et m'avoir écouté et motivé dans mes périodes de désespoir! Sans toi Claudius, je n'aurais jamais tenté ma chance!

Thank you very much to all 100 individuals who participated in my studies.

Last but not least, my family.
Et en dernier lieu, les personnes à qui je dédie mon doctorat au complet: ma soeur Roxanne, ma mère Yvonne et mon père Bernard. Sans leur soutien continu je n'aurais pas pu accomplir mon rêve. Merci de toujours être là et surtout merci de croire en moi!

To my late uncle Claude.

À mon oncle Claude qui est décédé à l'âge de 24 ans sans avoir eu l'opportunité d'accomplir ses rêves... Merci Claude d'avoir été là pour moi!

To an exceptional woman, my sister Roxanne.

À ma sœur Roxanne, une jeune femme exceptionnelle qui m'impressionne à tous les jours.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Postural control

Postural control is essential to the production of many of our daily activities, which allow us to interact with our environment. Postural control when maintaining upright stance can be defined as the ability to maintain the body's center of mass (COM) within the base of support by counteracting gravitational or external forces as well as internal forces produced by voluntary movements (Massion, 1992; Winter et al., 1990). Postural control is also the ability to maintain specific body segments aligned with other segments, with the environment or with both (Horak and Macpherson, 1996). Sensory information from the proprioceptive, visual and vestibular systems is essential to maintain upright stance. The central nervous system (CNS) integrates these sensory inputs and generates appropriate motor outputs to maintain upright stance. Some researchers suggest that postural control is maintained by using postural strategies. A postural strategy can be defined as a high-level plan that is controlled by the CNS for achieving stability over the base of support and the type of postural strategy used is dependent on the environment and on the goal of the activity (Horak and Macpherson, 1996). Research has shown that postural control is influenced by changes in the environment, such as the support surface, and by removing or altering sensory information (Horak and MacPherson, 1996; Massion, 1992). By investigating how pathologies involving the higher centers of the CNS such as Parkinson's disease, stroke and cerebellar lesions influence postural control, researchers have gained insight into the neural substrates of postural control (Bronstein et al., 1990; Chong et al., 1999; Horak and MacPherson, 1996). Many pathologies involving the higher centers of the CNS result in modifications of postural control suggesting that higher centers play a key role in the control of posture.

On the other hand, recent models have been developed suggesting that postural control can be controlled at a lower level simply by manipulating ankle stiffness (Winter et al., 1998-2001). According to Winter et al. (1998), the CNS controls the body COM by setting the appropriate muscle tone which will determine the joint stiffness needed to maintain upright stance in a particular situation. If the body is modelled as an inverted pendulum, the centre of pressure (COP) under the feet can be modified in order to maintain the COM within the base of support. Therefore, COM is the controlled variable and COP is the controlling variable (Winter et al., 1998). This model suggests that because there is relatively no phase lag between the movement of the COP and the COM, demonstrating that the system is proactive and not reactive, information from the sensory systems is not used for the maintenance of quiet standing and postural control is regulated by pure muscle stiffness.

Dual-tasking

We often are called upon to perform more than one task concurrently during our daily activities. Rarely do we stand without being involved in another activity that requires cognitive processing, such as engaging in a conversation. For these reasons, many studies have been interested in understanding how postural control is influenced by the execution of tasks that require the involvement of cognitive processes. Fearing (1925) was the first to attempt to investigate how attentional demands can influence postural control; participants reduced their sway when asked to count how many times they heard a particular sound, suggesting that cognitive processes may in fact influence postural control. It was not until 60 years later that Kerr et al. (1985) examined how tasks involving working memory interact with postural control. Results showed that whenstanding in a difficult posture (tandem stance), individuals modified their performance of a visuo-spatial task whereas performance of a verbal task was not modified. Since these observations, researchers have used dual-task paradigms to examine if attention is needed to maintain postural control and if various postures can modify the performance of tasks involving cognitive processes; however, these studies have provided inconclusive results. Therefore, this thesis proposes to investigate how and why postural control and various cognitive processes influence each other in an attempt to understand the different results of previous studies.

Changes seen in the performance of the secondary task

Following in the footsteps of Kerr et al. (1985), many researchers continued investigating the effects of the Brooks visuo-spatial task (Brooks, 1967) and a nonspatial version of the same task while maintaining upright stance (Andersson et al., 1998; Maylor et al., 2001; Maylor and Wing, 1996). The Brooks task consists of asking participants to mentally place a number in a 4x4 matrices and remember the placement of each number. They examined whether a visuo-spatial task would cause greater interference with postural control than nonspatial tasks because visual processing is required for both the performance of the visuo-spatial task and maintenance of upright stance. Similar to the findings of Kerr et al.(1985), Andersson et al. (1998) revealed a deterioration of the performance of a visuo-spatial task when comparing sitting to standing but did not include a nonspatial version of the task. However, others have found no difference for performance of a visuo-spatial and verbal task between sitting and standing (Maylor et al., 1996; Maylor et al., 2001). Maylor et al. (1996) examined the impact of performing various tasks involving the different components of working memory while maintaining upright stance. Results demonstrated that participants were less random on a random number generation task when in a standing position compared to sitting; in contrast, participants became faster at a silent counting task when standing compared sitting. It has also been shown that RT increased as the difficulty of the postural task increased or as sensory information is modified or removed (Lajoie et al.,1993-1996; Redfern and Jennings, 1998; Shumway-Cook and Woollacott, 2000; Teasdale et al., 1993). Hence, some studies have found deterioration whereas others have found no changes or even improvement on certain cognitive tasks when ithe difficulty of the postural task was increased.

Changes seen in postural control during quiet standing

Modifications of postural sway have also been observed in dual-task situations. Results have been diverse as some studies have shown increased sway, others showed decreased sway or no changes with the addition of the secondary task when standing. Shumway-Cook et al. (1997) found that participants increased postural sway when executing a verbal task but not a visuo-spatial task. Others showed increased postural sway with the execution of a RT task but only in elderly individuals and especially when sensory information was modified (Shumway-Cook and Woollacott, 2000; Teasdale et al. 1993). Geurts and Mulder (1994) found that individuals with lower limb amputations were less stable in a dual-task situation at the beginning of their rehabilitation than at the end. The execution of the Stroop task also was shown to result in an increase in postural sway in elderly adults and pathological populations such as amputees (Geurts et al., 1991; Melzer et al., 2001).

In contrast, Kerr et al. (1985) found that participants decreased postural sway when performing a secondary task but this was dependent on the order of presentation of the experimental conditions. Decreased postural sway also has been found when participants performed a mathematical task (Hunter and Hoffman, 2001; Maylor and Wing, 1996; Nienhuis et al., 2001). Some studies have shown decreased postural sway when executing a RT task (Vuillerme et al., 2000).

Results from other studies have shown that when performing the Brooks visuo-spatial task, which requires participants to listen, memorize and say aloud the placement of the numbers in each box of the matrices, participants modified their postural sway depending on the phase of the task: encoding, maintenance and retrieval (Maylor et al., 2001; Maylor and Wing, 1996). Participants demonstrated lower sway velocity during encoding (first 15s of the 25s trial) and higher sway velocity during maintenance (last 10s of the 25s trial) when compared to the no task condition, indicating that certain phases of the task may be more attention demanding (Maylor et al., 2001; Maylor and Wing, 1996). However, these results are confounded because sway velocity was reduced from the first 15s to the last 10s of the 25s trial in the no task condition (Maylor et al., 2001). Carpenter et al. (2001) found that frequency of sway is much higher in the first 15s compared to the last 30s, 60s and 120s. Therefore, the changes seen between encoding and maintenance may not necessarily be a result of the phase of the task but rather to differences in the segments of the trial that were analysed. Andersson et al. (1998) found that performance of the Brooks visuo-spatial task resulted in increased sway for young participants and decreased sway for patients who experience vertigo and dizziness.

Other studies found no changes in postural control with the addition of a RT task (Redfern and Jennings, 1998; Lajoie et al., 1993-1996; Marsh and Geel, 2000). No clear pattern can be drawn from these studies as they reported increased sway, decreased sway and no sway modifications with the addition of a secondary task.

Changes seen in postural control following a perturbation

Other aspects of postural control that have been examined using dual-task paradigms include postural recovery from a perturbation. Stelmach et al. (1990) found that elderly adults took longer to recover from a postural perturbation when placed in a dual-task situation. Furthermore, young and elderly initiated a step response following a perturbation with less displacement of the center of mass (COM) while performing a concurrent cognitive task (Brown et al., 1999). Maki et al. (2001) recently showed that a performance of a pursuit-tracking task is not affected immediately after a perturbation but deteriorates during a later component of the stabilizing response. The authors suggest that the primary reaction following a perturbation may be automatic whereas the stabilizing response is not. In contrast, Redfern et al.(2001) found an increased RT for a period of up to 250 ms after perturbation onset.

Results from these studies do not seem to provide a clear conclusion as to how and why postural control and cognitive processes influence each other. The following section will address the experimental differences in previous studies in an attempt to clarify the various results and how these differences have been addressed in the present thesis.

Experimental differences in previous studies

Even though all the studies presented in the previous section used a dual-task paradigm in which participants were asked to maintain upright stance while performing a secondary task, many characteristics of these research protocols differed. Differences that might explain the wide variety of findings include measures of COP displacement, length of trial, type and difficulty of cognitive task, sensory modality used in the cognitive task, instructions given to participants about the relative importance of the postural and cognitive tasks and the effects of practice of the postural and cognitive task.

Type and duration of postural control measures

Centre of pressure (COP) displacement was measured in all studies but the type of equipment and measures calculated varied. Some studies looked at sway path, which is a measure of the total distance of the COP displacement but does not provide insight into how posture is controlled in anterior-posterior (AP) versus medio-lateral (ML) direction (Fearing, 1925; Marsh and Geel, 2000; Melzer et al., 2001; Shumway-Cook et al., 1997; Shumway-Cook and Woollacott, 2000). Others calculated maximum range of COP displacements either in both AP and ML directions or just in the AP direction (Melzer et al., 2001; Stelmach et al., 1990; Vuillerme et al., 2000). These measures focus only on the occasional large exertion of the COP and do not offer a precise representation of the average control. Measures of velocity also have been used and some offer information about the tightness of the control (Geurts et al., 1991; Geurts and Mulder, 1994; Hunter and Hoffman, 2001; Marsh and Geel, 2000; Maylor et al., 2001; Melzer et al., 2001; Stelmach et al., 1990). If the calculation is done by simply dividing the sway path by the trial duration, it does not provide any more information than the sway path alone. Others examined either the standard deviation (SD) or root-mean-square (RMS) of the COP displacement in ML and AP directions (Geurts and Mulder, 1994; Geurts et al., 1991; Hunter and Hoffman, 2001; Kerr et al., 1985; Marsh and Geel, 2000; Maylor et al., 2001; Redfern and Jennings, 1998). Equilibrium scores given by a commercial analysis program and percentage of weight distribution were also used in a number of studies (Andersson et al., 1998; Barin et al, 1997; Maylor and Wing, 1996). Hence, in order to reduce the possible variability caused by different measures, mean-power-frequency (MPF) and RMS measures were used in all the studies presented in this thesis because they represent reliable measures in both the frequency and time domain (Carpenter et al., 2001; Goldie et al., 1989). COP often is used to illustrate how balance is maintained since the CNS is able to control COM by modifying the net motor pattern at the ankle joint, which is reflected by displacement of the COP (Winter et al., 1990). Chapter 5 will further investigate postural control mechanisms by examining changes seen in COM displacement as well as the changes in ankle stiffness. If we model the body as an inverted pendulum, the changes seen in COP and COM should reflect a modification in ankle stiffness (Winter, 1995).

The length of trials also varies from one study to another, ranging from 5s to 120s intervals. Carpenter et al. (2001) recently found that with increased trial duration the reliability of RMS and MPF of COP displacement increased. They recommended that a trial duration of at least 60 s should be used in order to ensure a reliable measure of RMS and MPF of COP displacement. Hence, all studies presented in this thesis used trials of at least 60s to compare results between studies without having to consider changes that occur with varying trial length.

Type and difficulty of cognitive task

Research on postural control and secondary task influences has used various types of tasks. Different results have been found with no clear pattern. For instance, Andersson et al. (1998) , Kerr et al. (1985), Maylor and Wing (1996) and Maylor et al. (2001) and have all used the Brooks visuo-spatial task but used different trial lengths (ranging from 12s to 30s) and different measures. Globally, results from these studies showed that the visuo-spatial task caused greater interference than the verbal version of the same task. However, it may not necessarily mean that visuo-spatial tasks cause greater interference because the visuo-spatial task may have simply been more difficult to execute when compared to the verbal version as Shumway-Cook et al. (1997) found greater interference with the verbal task and not the visuo-spatial task. Chapter 2 of this thesis addresses the issue of task type and difficulty by asking participants to perform tasks of a different type and difficulty while standing in an easy versus challenging posture.

Sensory and motor requirements of the cognitive task

Many authors have argued that visually based tasks cause greater interference in dual-task paradigms because postural control is maintained by using visual sensory information (Kerr et al., 1985; Maylor and Wing, 1996; Teasdale et al., 1993). Hunter and Hoffman (2001) did not see any changes between a mathematical task presented using vision or audition; postural sway was decreased during performance of both tasks. However, movement of the eyes to focus on various targets did produce increased ML sway. Therefore, they argued that the mathematical task may not have required as much eye movement as in reading a word or a phrase and vision may explain differences in dual-task performance. Therefore, the involvement of vision and visual feedback is examined in Chapters 2, 3 and 4 of this thesis.

Yardley et al. (1999) found that articulation needed to respond to the cognitive task was related to an increased sway path of the COP displacement and that tasks that did not involve articulation did not result in any changes. Therefore, motor coordination or changes in respiration may be implicated in the changes found in the previous dual-task paradigms, which required articulation of the cognitive task. Thus, response demands of the cognitive task may be an important factor to investigate. Chapter 4 of this thesis addresses the effect of articulation in dual-task paradigms.

Instructions given to participants

In dual-task paradigms, participants can either be asked to focus on the primary task (postural control), focus on the secondary task(cognitive task) or focus on both tasks. In many studies, participants were asked to concentrate on standing as still as possible (Geurts et al., 1991; Geurts and Mulder, 1994; Hunter and Hoffman, 2001; Kerr et al., 1985; Maylor et al., 2001; Maylor and Wing, 1996; Melzer et al., 2001; Shumway-Cook et al., 1997; Shumway-Cook and Woollacott, 2000; Vuillerme et al., 2001). In a few of these studies, participants were also asked to perform the secondary task as well as they could and as quickly as possible (Geurts et al., 1991; Geurts and Mulder,1994; Marsh and Geel, 2000; Melzer et al., 2001; Shumway-Cook and Woollacott, 2001; Shumway-Cook et al., 1997). Hunter and Hoffman (2001) suggested asking participants to stand as still as possible which might have increased concentration on postural sway and lead to modification of "normal" control of postural sway. Thus, depending on what participants were told to focus on, concentration could have modified the outcome. In Chapter 3 of this thesis, conscious focus and the use of visual feedback is explored to examine if different results can be found depending on what participants are asked to focus on.

Effects of practice

Another factor that may partly explain the diversity of the results in previous studies is the effects of practice. It is well established that performance of a novel task requires more attentional resources than does performance of a learned task (Magill, 1993). Most cognitive tasks used in previous studies have been novel to the participants, thus demanding more attention and leaving less attentional resources for postural control.

Practice has been shown to decrease attentional demands of a given task; therefore, the effects of practice in both young and elderly individuals are examined in Chapter 6 to see if the modifications observed in postural sway could be attenuated with practice.

Summary

Results from research examining the interaction between postural control and the execution of a cognitive task are very divergent and do not provide a clear explanation of these relations. Each chapter of this thesis examines a possible explanation, enumerated in the previous section of this introduction, that could provide some insight as to why postural control is modified with the execution of a cognitive task. Chapter 2 focuses on the implications of task type and difficulty. Chapter 3 looks at instructions given to participants, conscious focus and the use of visual feedback when performing an auditory task. Chapter 4 relates to the possible role of articulation in dual-task paradigms. Chapter 5 examines if the changes seen in COP and COM are also accompanied by changes in ankle stiffness with the addition of a cognitive task. Chapter 6 investigates how practice may affect the relations between postural control and cognitive processes. Consequently, the studies that comprise this thesis manipulated different components of cognitive processes and postural control in an attempt to examine the relationship between these two entities. The length of the trials, the postural control measures and the age and health of the population of participants were consistent across all of the studies except for the fifth study where an elderly group was added.

REFERENCES

Alexander NB (1994). Postural control in older adults. Journal of the American Geriatric Society, 42(1): 93-108.

Andersson G, Yardley L and Luxon L (1998). A dual-task study of interference between mental activity and control of balance. The American Journal of Otology, 19: 632-637.

Barin K, Jefferson GD, Sparto PJ and Parnianpour M (1997). Effect of aging on human postural control during cognitive tasks. Biomedical Sciences Instrumentation 33:388-93.

Bronstein JD, Gresty MA and Panagi C (1990). Visual control of balance in cerebellar and parkinsonian syndromes. Brain, 113: 767-779.

Brooks LR (1967). The suppression of visualization by reading. Quarterly Journal of Experimental Psychology 19:289-299.

Brown LA, Shumway-Cook A and Woollacott MH (1999). Attentional demands and postural recovery: the effects of aging. Journal of Gerontology A: Biological Sceinces and Medical Sciences. 54(4): M165-71.

Carpenter MG, Frank JS and Winter DA and Peysar GW (2001). Sample duration influences center of pressure summary measures. Gait & Posture, 13: 35-40.

Chong KY, Horak FB, Frank J, Kaye J (1999). Sensory organization for balance: Specific deficits in Alzheimer's but not in Parkinson's disease. Journal of Gerontology: Medical Sciences, 54A(3): M122-M128.

Fearing FS (1925). Factors influencing static equilibrium: An experimental study of the effects of controlled and uncontrolled attention upon way. The Journal of Comparative Psychology, 5: 1-24.

Geurts ACH and Mulder TW (1994). Attention demands in balance recovery following lower limb amputation. Journal of Motor Behavior, 26(2):162-170.

Geurts ACH, Mulder TW, Nienhuis B and Rijken RAJ (1991). Dual-task assessment of reorganisation of postural control in persons with lower limb amputation. Archives of Physical Medecine and Rehabilitation, 72:1059-64.

Goldie PA, Bach TM, Evans OM (1989). Force platform measures for evaluating postural control: reliability and validity. Archives of Physical Medicine and Rehabilitation, 70:510-7.

Horak FB and MacPherson JM (1996). Postural orientation and equilibrium. In Handbook of Physiology, Section 12, Chapter 7 (pp.255-292).

Hunter MC and Hoffman MA (2001). Postural control: visual and cognitive manipulations. Gait & Posture, 13:41-48.

Kerr B, Condon SM and McDonald LA (1985). Cognitive spatial processing and the regulation of posture. Journal of Experimental Psychology, 11(5): 617-622.

Lajoie Y, Teasdale N, Bard C and Fleury M (1993). Attentional demands for static and dynamic equilibrium. Experimental Brain Research. 97:139-144.

Lajoie Y, Teasdale N, Bard C and Fleury M (1996). Upright standing and gait: Are there changes in attentional requirements related to normal aging? Experimental Aging Research, 22:185-198.

Magill RA (1993) Motor learning: Concepts and applications. Indianapolis, Indiana: Brown & Benchmark.

Maki BE, Norrie RG, Zecevic A, Quant S, Kirshenbaum N, Bateni H and McIlroy WE (2001). Initiation and execution of rapid postural reactions and stepping movements: which phases require visuospatial attention? Duysens J, Smits-Engelsman BCM and Kingma H (Eds). Control of posture and gait: Proceedings from the Symposium of the International Society for Postural and Gait research (pp.573-576).

Marsh AP and Geel SE (2000). The effect of age on the attentional demands of postural control. Gait & Posture 12:105-113.

Massion J (1992). Movement, posture and equilibrium: interaction and coordination. Progress in Neurobiology. 38: 35-56.

Maylor EA and Wing AM (1996). Age differences in postural stability are increased by additional cognitive demands. Journal of Gerontology, 51B(3): P143-P154.

Maylor EA, Allison S and Wing AM (2001). Effects of spatial and nonspatial cognitive activity on postural stability. British Journal of Psychology 92:319-338.

Melzer I, Benjuya N and Kaplanski J (2001). Age-related changes of postural control: Effect of cognitive tasks. Gerontology 47:189-194.

Nienhuis B, Geurts ACH, Duysens J (2001). Are elderly more dependent on visual information and cognitive guidance in the control of upright balance? Duysens J, Smits-Engelsman BCM and Kingma H (Eds). Control of posture and gait: Proceedings from the Symposium of the International Society for Postural and Gait research (pp.585-588).

Redfern MS and Jennings JR (1998). Influence of attention on standing posture. Proceedings from the Satellite Meeting to the Society for Neuroscience Conference, Los Angeles CA.

Redfern MS, Muller MLTM, Jennings JR and Furman JM (2001). Attentional dynamics inolder adults during perturbations. Duysens J, Smits-Engelsman BCM and Kingma H (Eds). Control of posture and gait: Proceedings from the Symposium of the International Society for Postural and Gait research (pp. 598-601).

Shumway-Cook A, Woollacott M (2000) Attentional demands and postural control: the effect of sensory context. . Journal of Gerontology A: Biological Sciences and Medical Sciences, 55(1): M10-6.

Shumway-Cook A, Woollacott M, Kerns A and Baldwin M (1997). The effects of two types of cognitive tasks on postural stability in older adults with and without a history of falls. Journal of Gerontology, 52A(4): M232-M240.

Stelmach GE, Zelaznik HN and Lowe D (1990). The influence of aging and attentional demands on recovery from postural instability. Aging, 2(2): 155-161.

Teasdale N, Bard C, LaRue J and Fleury M (1993). On the cognitive penetrability of posture control. Experimental Aging Research. 19: 1-13.

Vuillerme N, Nougier V and Teasdale N (2000). Effects of a reaction time task on postural control in humans. Neuroscience Letters 291:77-80

Winter DA, Patla AE and Frank JS (1990). Assessment of balance control in humans. Medical Progress through Technology, 16:31-51.

Winter DA, Patla AE, Prince F, Ishac M and Gielo-Perczak K (1998). Stiffness Control of Balance in Quiet Standing. Journal of Neuropysiology, 80:211-1221.

Winter DA. (1995) A.B.C. of balance during standing and walking. Waterloo, ON: Waterloo Biomechanics.

Yardley L, Gardner M, Leadbetter A and Lavie N (1999). Effect of articulation and mental tasks on postural control. Neuroreport, 10(2):215-219.

CHAPTER 2

INFLUENCE OF A VISUO-SPATIAL, VERBAL AND CENTRAL EXECUTIVE WORKING MEMORY TASK ON POSTURAL CONTROL

Mylène C. Dault, James S. Frank and Fran Allard
Gait & Posture 14(2):110-116.

ABSTRACT

In this study, participants were required to perform different working memory (WM) tasks (a verbal task, a visuo-spatial task with 2 levels of difficulty and a central executive task) under different challenges to postural control (sitting, shoulder width stance and tandem stance). When a WM task was added, changes in postural sway were characterised by an increase in frequency and decrease in amplitude of sway indicating a tighter control. We found no changes in postural control between the different types of WM tasks, which might support a general capacity limitation hypothesis. However, no changes were found in performance of the WM task when postural stance was modified and no changes were found in postural sway when the difficulty level of the visuo-spatial task was modified. Consequently, the results seem to indicate that the addition of a WM task, regardless of task type, forces the CNS to choose a tighter control strategy.

INTRODUCTION

For many years, researchers have attempted to determine the nature of the interaction between attention and postural control. Dual-task paradigms often have been employed to try to explain the complex interaction between attention and postural control. Postural sway has been shown to either increase (Andersson et al.,1998; Shumway-Cook et al., 1997; Shumway-Cook and Woollacott, 2000) or decrease (Fearing, 1925; Kerr et al., 1985) when participants attend to a secondary task. In other studies, performance of the secondary task was impaired (Andersson et al., 1998; Kerr et al., 1985; Lajoie et al., 1993-1996, Teasdale et al., 1993). Numerous types of secondary tasks and postural stance positions, as well as different postural control measures have been used in these studies. Thus, these factors may have contributed to the varying results reported.

The secondary tasks used in dual-task paradigms can involve one or more of the processes related to working memory (WM). Baddeley (1986) suggests a model of WM composed of three subcomponents: a central executive system involved in controlling attention, a visuospatial sketch pad (VSSP) involved in manipulating visual images and an articulatory loop, involved in verbal processing. Maylor and Wing (1996) examined the influence of these components on postural control in young and older participants. Changes were found in postural sway when participants were asked to perform tasks that involved the VSSP. Postural sway increased for the older participants and decreased for the young. When asking participants to perform WM tasks that challenged the central executive and the articulatory loop components of Baddeley's WM model, he found that postural sway remained unchanged. However, when comparing performance of these WM tasks in seated vs standing positions, he found a decline in performance of the WM tasks.. Contrary to the findings of Maylor and Wing (1996), Shumway-Cook et al. (1997) found that postural control was modified during the execution of a verbal task, but not during a spatial task. Although Shumway-Cook et al. (1997) examined the same type of stance (shoulder width stance) as Maylor and Wing (1996), they reported total distance traveled by the center of pressure whereas Maylor and Wing (1996) reported only anterior-posterior sway measures. Kerr et al. (1985) examined the attentional demands of a more difficult postural task, tandem stance. They found that performance of a visuo-spatial task, and not of the verbal task, was affected during tandem stance. Their results also revealed that steadiness in postural control was increased when participants executed a WM task, independent of task type. However, this result was attributed by the authors to the order of presentation of the tasks i.e. learning effect.

The main goal of this study was to examine the factors that may contribute to the variability of findings in previous studies: first, by examining the effects of different types of WM tasks on postural control; second, by investigating the impact of varying levels of difficulty of the WM task on postural control; third, by examining the impact of varying levels of difficulty of the postural stance on the execution of the WM tasks. By asking participants to perform three different WM tasks which were selected to challenge each of the subcomponents of Baddeley's WM model, our purpose was to provide greater insight as to which factorwill produce greater interaction with postural control (Baddeley, 1998). Participants were asked to sit or stand in two different postural stances while performing three different WM tasks one of which had two different levels of difficulty. Because results have been diverse as to which component of WM interferes the most with postural control, we hypothesized that the type of WM task will not be of great importance and that a dual-task interference caused by a general capacity limitation will occur. We also predicted that greater changes in postural control will be found when participants are asked to perform a more difficult WM task and that more errors will be made in the WM task when participants are standing in a more challenging posture.

METHODOLOGY

Participants

Twenty university students, 11 male and 9 female (mean age=23 ± 3.11 years old), participated in this study. All procedures were approved by the Office of Human Research, University of Waterloo. Anthropometric measures such as height, foot length and heel-to-ankle distance were taken.

Postural task

Participants were required to either stand on the force plate or sit on a chair while performing one of three WM tasks or while simply fixating on a point placed 150 cm in front of them. Two standing postures of varying levels of difficulty were executed. Standing with feet shoulder width apart was defined as the easy and less novel postural stance whereas standing with feet in tandem position (heel-to-toe) was defined as the more difficult and more novel postural stance. For shoulder width stance trials, participants aligned their toes to the front edge of the force plate and the stance width was determined by their foot length. For tandem stance trials, participants placed their preferred foot (participants' choice) at the front of the force plate and the other foot was placed so that the metatarsophalangeal joint was aligned with the heel of the front foot. A tracing of their feet was taken before the first trial to ensure that participants always placed their feet at the same place for every trial. Participants were instructed to stand quietly with arms at their side and to execute the working memory tasks as quickly as possible they without making any errors. As control measures for the execution of the WM tasks, participants were also asked to perform the various secondary tasks in a seated position.

Working memory tasks

The three WM tasks were chosen to engage the three subcomponents of Baddeley's WM model: the visuo-spatial component, the articulatory loop and the central executive system (Baddeley, 1986).

The visuo-spatial WM task was a modified version of the Manikin test in which participants named in which hand a manikin was holding a black or white circle by saying "left" or "right" (Benson and Gedye, 1963). The manikin was shown on a 19-inch computer monitor placed at eye level in front of the participant. The manikins were displayed in 4 different positions: upright, inverted or lying on their side (Figure 2.1). The task had two levels of difficulty. In the easy condition, the manikins faced away from the participant (spatial easy) whereas in the difficult condition the position of the manikin varied between facing away and towards the participant (spatial difficult) requiring mental rotation in multiple planes. The speed of presentation was determined by the participants; when the answer was given by the participant, the next manikin appeared. Participants were instructed to respond to as many manikins as possible without making any errors during the 60s trial. Number of items classified and errors were recorded.

The verbal WM task involved categorizing words into categories: winter or summer, meat or not meat, and hard or soft. The words appeared on the computer monitor that was positioned at eye level in front of the participant. Participants were asked to state aloud in which category the word appearing on the monitor belonged. As in the Manikin tasks, participants were instructed to respond to as many words as possible in 60s without making any errors. The speed at which the words were presented depended on the speed at which participants responded. Number of items classified and errors were recorded.

The third task consisted of random number generation (RNG) (Baddeley et al., 1998). Participants were asked to vocally generate random numbers from 1 to 10 inclusively. The numbers were generated following a metronome set at one beat per second for a period of 60s. The index of randomization of the numbers was calculated following an algorithm suggested by Evans (1978). The values obtained from this study were slightly different than the values suggested in Evans (1978) because only 60 numbers were included in this study compared to 100 in Evans (1978). A no task trial (NT) was also conducted for each standing posture as a control measurement.

Equipment

The verbal and visuo-spatial tasks were presented on a computer monitor. The monitor was connected to a portable computer that generated the presentation of slides. The monitor was placed 150 cm from the participant when he or she was standing on the force plate and 200 cm from the participant when seated.

Centre of pressure (COP) data were measured using an AMTI force plate. Data were sampled at a frequency of 20 Hz and filtered with a dual-pass Butterworth filter with a 5Hz cutoff frequency. Root mean square (RMS) of the COP displacement with bias removed and mean power frequency (MPF) of the COP displacement over 60 s. were calculated in the anterior-posterior (AP) and medio-lateral (ML) direction. RMS values provide information on the amplitude variability of COP displacement about the mean position (bias) of the COP. MPF values provide information on the frequency of the sway control (Carpenter et al., 2001).

Procedures

All 20 participants performed all experimental conditions, which consisted of the control condition (NT), the verbal secondary task condition, the two visuo-spatial conditions (spatial easy and spatial difficult) and the central executive task (RNG) while either sitting, standing in shoulder width stance or standing in tandem stance. The verbal and the visuo-spatial conditions were performed on separate days, 1 week apart. The NT and RNG trials were executed on both testing sessions to determine the reliability of our method between two testing sessions and to establish any learning effects. The visuo-spatial and the verbal tasks were only performed once. The first 10 participants performed the visuo-spatial tasks in the first testing session and performed the verbal task in the second testing session. The other 10 participants performed the verbal task in the first testing session and the visuo-spatial tasks in the second. Prior to testing, participants were shown 4 different manikins and 4 different words and were asked to respond as quickly as possible in order to make sure that they understood the tasks. They were also asked to practice the RNG task for a period of about 30 s or until they were able to follow the metronome without any hesitations. Participants were instructed to complete as many WM task items as possible (except for the RNG task) without making any errors during the 60s trial. Performance of the WM task started at the same time as the recording of the postural sway and lasted 60s. Participants were instructed to focus on performing the WM task in the dual task trials. During the NT trials, participants were asked to fixate a middle point in the computer monitor. Therefore, the point of visual focus remained the same for all tasks.

Secondary task condition was blocked within each stance and order of presentation of secondary tasks was randomized. Stance conditions were presented in random order. All experimental conditions are shown in Table 2.1.

Statistical analysis

A two-way repeated measures ANOVA was conducted to analyze the effects of different stance conditions (shoulder width vs tandem vs seated) and task difficulty on the number of errors and items classified for the visuo-spatial tasks. A separate one-way repeated measures ANOVA was conducted for the verbal task on the number of items classified; no error occurred in the execution of the task. A one-way repeated measures ANOVA was executed to determine the effects of different stance conditions on the index of randomization (RNG task).

A logarithm transformation was performed, in order to ensure a normal distribution of the postural control measures. Because of the use of multiple dependent measures, a MANOVA was conducted to examine main and interaction effects of secondary task condition and stance condition. Where significant multivariate effects were detected, univariate follow-up procedures were conducted. First, a reliability test was performed by using a repeated measures two-way ANOVA (testing session x task) to compare the NT trials and the RNG trials between the two testing sessions. Separate ANOVAs were conducted for each stance condition.

RESULTS

Working memory task performance

Errors were found only in the execution of the visuo-spatial tasks. Results revealed an average error rate of 11.31%; however, no significant difference in percentage of errors was found between the different stances or between the different levels of difficulty of the visuo-spatial task.

The number of items classified for the verbal and visuo-spatial tasks was not influenced by stance difficulty. As shown in Figure 2.2, the number of items classified remained the same when participants were seated, standing in shoulder width stance and standing in tandem stance. Results from the visuo-spatial task revealed that significantly fewer responses were given during the spatially difficult compared the spatially easy task for all postural stances combined ($F(2,26)= 27.08; p < 0.001$): 38. responses were given during the spatially easy task compared to 31.23 for the spatially difficult task, i.e. 19.54% fewer (see Figure 2.2).

Similar to the results found for verbal and visuo-spatial tasks, the index of randomization of the RNG task did not reveal any significant changes between each postural stance. Therefore, participants were able to generate numbers that were as random when sitting, as when standing in shoulder width stance and tandem stance.

Postural control measures

The MANOVA analysis revealed main effects for the secondary task condition *(Wilks' Lambda* $F(16,514)= 2.88; p<0.0001$*)* and stance condition *(Wilks' Lambda* $F(4, 168) = 234.33;$

$p < 0.0001$); no interactions were found. Univariate follow-up procedures are presented below for the main effect of secondary task condition for each stance condition. The stance condition main effect was not analysed further as it is well known that tandem stance is a more difficult posture to maintain and the goal of this study was not to compare the two types of stance but to see if a more difficult posture would result in a greater disruption in postural sway when a WM task was added. To determine if there were any differences among secondary task conditions, a one-way ANOVA with repeated measures (5 levels of secondary task condition: Spatial Easy vs Spatial Difficult vs Verbal vs RNG vs NT condition) was executed for each stance type. Post-hoc analysis enabled us to compare the NT conditions to the different types of WM tasks as well as the different levels of difficulty of the visuo-spatial tasks. Because the shoulder width and tandem stance are not oriented in the same axis, i.e. antero-posterior or medio-lateral, separate ANOVAs were performed on postural control measures for each stance.

The reliability analysis revealed that the NT condition and the RNG task showed no difference in postural control performance measures when performance was compared on the first and second testing days. Therefore, the average of the RNG task and of the NT for sessions one and two was used for the statistical analysis of the postural control measures.

Influence of the type of working memory task on postural control measures

Shoulder width stance

Frequency measures (MPF)

A significant effect of secondary task condition was found for MPF ($F(4,76)= 4.86; p< 0.05$) in AP direction, as shown in Figure 2.3. When comparing the NT condition to the WM task conditions, post hoc analysis revealed an increase in AP MPF for: the verbal task (48.19 %), the spatial easy task (38.87%), the spatial difficult task(56.74%) and the RNG task (45.54%). No significant changes were found between the different types of WM tasks. No statistically significant changes in secondary task condition were found in the frequency of the sway in ML direction.

Amplitude measures (RMS)

A significant effect of secondary task condition was found for RMS ($F(4,76)= 2.99; p < 0.05$) in AP direction as shown in Figure 2.3. When comparing to the NT condition to WM task conditions, post hoc analysis revealed a decrease in AP RMS for: the spatial easy task (15.95%), the spatial difficult task (16.69%) and the RNG task (15.27%). No significant changes were found for the verbal task. No changes were found between the different types of WM tasks. No significant amplitude changes in secondary task condition were found in ML direction.

In sum, most of the changes in postural sway during shoulder width stance occurred in AP direction and were characterized by a decrease in amplitude and an increase in frequency of sway. No changes were found between the different types of WM tasks for all COP measures.

Tandem stance

Frequency measures

A significant effect of secondary task condition was found for MPF ($F(4,76)= 9.82; p < 0.0001$) in ML direction, as shown in Figure 2.4. When comparing the NT condition to the WM task conditions, post hoc analysis revealed an increase in ML MPF for: the verbal task (47.83%), the spatial easy task (42.76%), the spatial difficult task (36.94%) and the RNG task (46.33%). No significant changes were found between the different types of WM tasks. No secondary task condition effect was found for frequency of the sway in AP direction.

Amplitude measures

A significant effect of secondary task condition was found for RMS ($F(4,76)= 2.75; p<0.05$) in ML direction, as shown in Figure 2.4. When comparing the NT condition to the WM task conditions, post hoc analysis revealed a decrease in ML RMS for: the verbal task (11.73%), the spatial easy task (15.60%) and the spatial difficult task (8.65%). No changes were found for RMS in both directions for the RNG task. No changes were found between the different types of WM tasks. No statistically significant changes in secondary task conditions were found for amplitude of sway in AP direction.

In summary, for the tandem stance, most of the changes occurred in ML direction and were characterized by a decrease in amplitude and an increase in frequency of sway. No changes were found between the different types of WM tasks for COP measures.

Influence of the postural stance difficulty

The MANOVA revealed no significant interaction between secondary task condition and stance condition indicating that both stances were affected in the same way by the secondary task conditions. Therefore, postural stance difficulty did not affect the relationship between postural control and attention.

DISCUSSION

In this study, participants were required to perform different WM tasks under different challenges to postural control. We evaluated both WM task performance and postural control. In this dual-task paradigm, results indicate that postural control was modified, whereas the performance of the WM task remained constant. Most changes in postural sway occurred in the plane in which the postural stance was the least stable. For the shoulder width stance, changes in postural sway occurred in the sagittal plane whereas for the tandem stance, changes occurred in the frontal plane. These modifications were characterised by an increase in frequency and decrease in amplitude of sway indicating a tighter control of postural sway (Carpenter et al., 1999).

Our first goal was to examine the effects of different types of WM tasks on postural control. Results demonstrate that no significant differences were found between the different types of WM tasks. All tasks resulted in an increase in frequency and a decrease in amplitude of postural sway. These results contrast with previous research done by Kerr et al. (1985), Maylor and Wing (1996) and Shumway-Cook et al. (1997) who had found changes in either cognitive task or postural control between the different types of tasks. These differences in results might be related to methodological issues such as sensitivity of the apparatus used to measure postural control, the postural control measures taken and length of trials. Recent work in our laboratory suggests that recordings of 60 s or more provide a more reliable measure of balance performance (Carpenter et al., 2001). Previous studies have used trials varying between 12 s to 30 s, therefore the length of the recordings may not have been long enough to detect low frequency changes. In addition, previous studies have not looked at frequency components of postural sway. Our results indicate that the larger changes in postural sway were found in the mean power frequency for which values were increased by up to 57%.

Recent studies looking at the effects of stress and cognitive load on handwriting and aiming tasks have also found similar results to ours (Van Galen and Van Huygevoort, 2000; Van Gemmert and Van Galen, 1997-1998). They revealed that no matter what type of attentional load is being used, such as auditory stress or counting tasks, participants respond by increasing the pressure they put on the pen (Van Galen and Van Huygevoort, 2000; Van Gemmert and Van Galen, 1997-1998). This was interpreted as an increased stiffness because of co-contraction in order to control neural noise. Therefore, it could be argued that simply adding a task puts a load on the central nervous system (CNS) and that the type of task is not of great importance. Ghez (1991) explains that opposing muscles can be controlled by two mechanisms; reciprocal innervation and co-contraction. Therefore, the CNS may have chosen to control postural muscles in a co-contraction mode since it is less attention demanding compared to the reciprocal innervation mechanism.

The second goal of this study was to investigate the impact of varying levels of difficulty of the memory tasks on postural control. Changes in the performance of the different levels of the visuo-spatial task were found. Participants were able to classify a smaller number of items in the spatial difficult task compared to the spatial easy task. This reduction in the rate of classification could be evidence for increased difficulty; i.e. in order to perform without errors the participant had to slow down. Nonetheless, this change in difficulty level of the WM task did not produce changes in postural control. Hence, the changes found in postural control when a WM task was added do not seem to be related to the WM task difficulty. Yardley et al. (2001) also found that participants demonstrated changes in postural sway when performing a a secondary task but they chose not to address this change. When examining the results table, we can clearly see that the high mental load tasks produced greater changes in postural sway than the low mental load tasks. Therefore, our different levels of difficulty may not have been drastic enough to produce a re-weighting of attention allocation.

The third goal of this study was to examine the impact of varying levels of difficulty of the postural stance on the execution of the WM tasks. Our results indicate that performance of the WM tasks remained the same throughout the three postures. Therefore, the level of difficulty of the postural stance did not have an effect on the execution of the WM task. In addition, no interaction was found in postural measures between secondary task condition and stance condition. This indicates that the addition of the WM task produces the same changes during the shoulder width and tandem stances. Previous results by Geurts and Mulder (1994) and Stelmach et al. (1990) have found differences in postural control when comparing a dual-task paradigm during a static postural stance to during a dynamic postural stance. In addition, Lajoie et al.

(1993) and Yardley et al. (2001) found that participants increased reaction times when executing a reaction time task while maintaining a static posture compared to a more dynamic posture. Because both postural stances used in the present study are static, we could argue that the different levels of difficulty of the postural tasks may not have been dissimilar enough to produce changes in attentional demands. Also, the measurements used, such as error rate and items classified, might not have been sensitive enough to detect any changes.

CONCLUSION

In summary, we found no changes in postural control between the different types of WM tasks, which may support a general capacity limitation hypothesis. However, our result did not show any changes in performance of the WM when postural stance was modified and no changes were found in postural sway when the difficulty level of the visuo-spatial task was modified. Consequently, changes that occurred in this dual task paradigm do not seem to be related to a general capacity limitation. However, the different level of difficulty may not have been drastic enough to produce significant changes. The results seem to indicate that the addition of a WM task, regardless of task type, forces the CNS to choose a co-contraction control strategy which provides a tighter control of postural sway (Ghez, 1991). Yardley et al. (1999) recently revealed that articulation rather than mental load is responsible for increased postural sway path when performing a secondary task. Articulation is known to produce changes in respiration (Conrad and Schönle, 1979) and respiration is also known to modify postural control (Jeong, 1991). Considering that all of the WM tasks performed in the present study employed articulation, this recent finding requires further investigation.

ACKNOWLEDGEMENTS

The authors would like to thank Gary Peysard for his help during testing and Mike Amos and Allan Adkin for their helpful comments in reviewing this paper. This study was funded by NSERC grants to Mylène C. Dault and James S. Frank.

REFERENCES

Andersson G, Yardley L and Luxon L (1998). A dual-task study of interference between mental activity and control of balance. The American Journal of Otology 19: 632-637.

Baddeley A, Emslie H, Kolodny J and Duncan J (1998). Random generation and the executive control of working memory. The Quarterly Journal of Experimental Psychology 51A(4): 819-852.

Baddeley A (1986). Working Memory. Oxford: Clarendon Press. 1986.

Baddeley A (1998). Working memory.C R Acad Sci III 321(2-3): 167-73.

Benson, AJ. and Gedye, JL (1963). Logical processes in the resolution of orientational conflict. RAF Institute of Aviation Medicine Report 259 Farnborough: UK.

Carpenter MG, Frank JS and Silcher CP (1999). Surface height effects on postural control: A hypothesis for a stiffness strategy for stance. Journal of Vestibular Research 9(4): 277-86.

Carpenter MG, Frank JS and Winter DA and Peysar GW (2001). Sample duration influences center of pressure summary measures. Gait & Posture 13: 35-40.

Conrad B amd Schönle P (1979). Speech and respiration. Archiv fur Psychiatrie und Nervenkrankheiten 226: 251-268.

Evans FJ (1978). Monitoring attention deployment by random number generation: An index to measure participative randomness. Bulletin of the Psychonomic Science 12(1): 35-38.

Fearing, FS (1925). Factors influencing static equilibrium: An experimental study of the effects of controlled and uncontrolled attention upon way. The Journal of Comparative Psychology 5: 1-24.

Geurts ACH and Mulder TW (1994). Attention demands in balance recovery following lower limb amputation. Journal of Motor Behavior 26(2): 162-170.

Ghez C (1991) Muscles: Effectors of the motor system. In Kandel, E, Schwartz, JH and Jessell, TM. Principles of Neural Science, 3rd edition,Chapter 36 (pp.548-563).

Jeong BY (1991). Respiration effect on standing balance. Archives of Physical Medicine and Rehabilitation 72:642-5

Kerr B, Condon SM and McDonald,LA (1985). Cognitive spatial processing and the regulation of posture. Journal of Experimental Psychology 11(5): 617-622.

Lajoie Y, Teasdale N, Bard C and Fleury M (1993). Attentional demands for static and dynamic equilibrium. Experimental Brain Research 97: 139-144.

Lajoie Y, Teasdale N, Bard C and Fleury M (1996). Upright standing and gait: Are there changes in attentional requirements related to normal aging? Experimental Aging Research 22: 185-198.

Maylor EA and Wing AM (1996). Age differences in postural stability are increased by additional cognitive demands. Journal of Gerontology 51B(3): P143-P154.

Shumway-Cook A, Woollacott M, Kerns A and Baldwin M (1997). The effects of two types of WM tasks on postural stability in older adults with and without a history of falls. Journal of Gerontology 52 (4): M232-M240.

Shumway-Cook A, Woollacott M (2000). Attentional demands and postural control: the effect of sensory context.. Journal of Gerontology 55(1): M10-6.

Stelmach GE, Zelaznik HN and Lowe D (1990). The influence of aging and attentional demands on recovery from postural instability. Aging 2(2): 155-161.

Teasdale N, Bard C, LaRue J and Fleury M (1993). On the cognitive penetrability of posture control. Experimental Aging Research 19: 1-13.

Van Galen GP, Van Huygevoort M (2000). Error, stress and the role of neuromotor noise in space oriented behaviour. Biological Psychology 51: 151-171.

Van Gemmert, AWA, Van Galen GP (1998). Auditory stress effects on preparation and execution of graphical aiming: A test of the neuromotor noise concept. Acta Psychologica 98: 81-101.

Van Gemmert AWA, Van Galen GP (1997). Stress, neuromotor noise, and human performance: A theoretical perspective. Journal of experimental psychology 23(5): 1299-1303.

Yardley L, Gardner M, Bronstein R, Buckwell D and Luxon L (2001). Interference between postural control and secondary task performance in patients with peripheral vestibular disorder and healthy controls. Journal of Neurology, Neurosurgery and Psychiatry 71: 48-52.

Yardley L, Gardner M, Leadbetter A and Lavie N (1999). Effect of articulation and secondary tasks on postural control. Neuroreport 10(2): 215-219.

Table 2.1: Experimental conditions and type of data recorded.

	Spatial Easy	Spatial Difficult	Verbal	RNG	No Task
Tandem stance	C + P	C + P	C + P	C + P	P
Shoulder width stance	C + P	C + P	C + P	C + P	P
Sitting	C	C	C	C	-

Legend:

C: cognitive task error, items classified or index of randomization.

P: postural sway data (RMS and MPF).

-: no data was recorded.

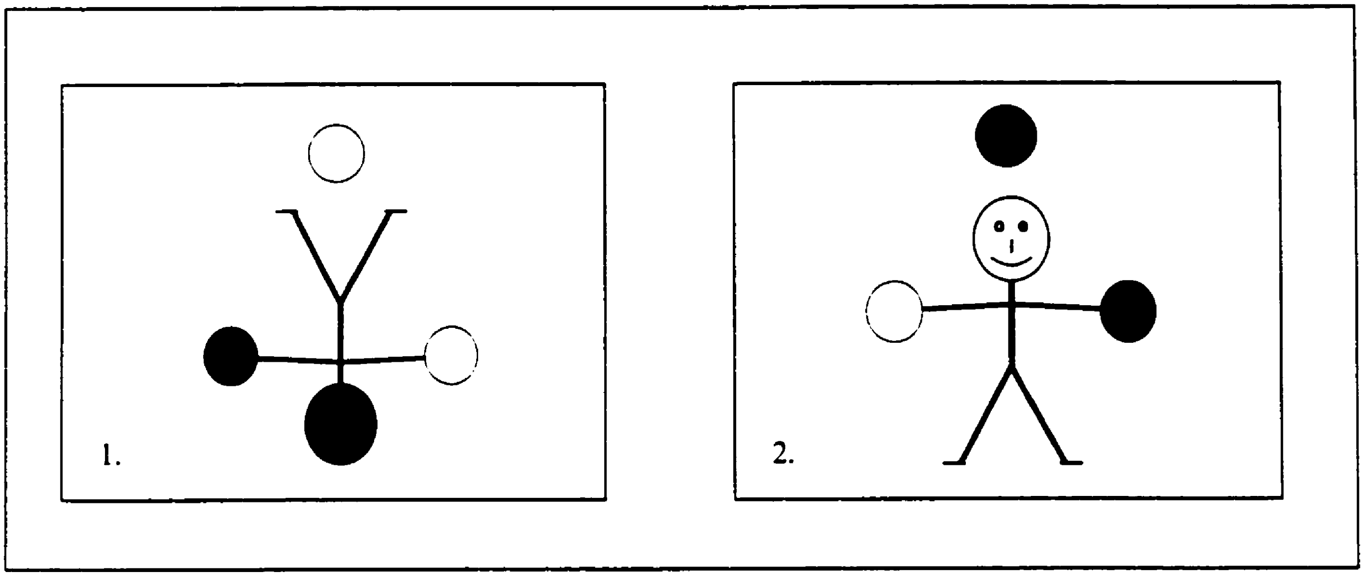

Figure 2.1: Example of the visuo-spatial task (Answers: 1. Left; 2. Left).

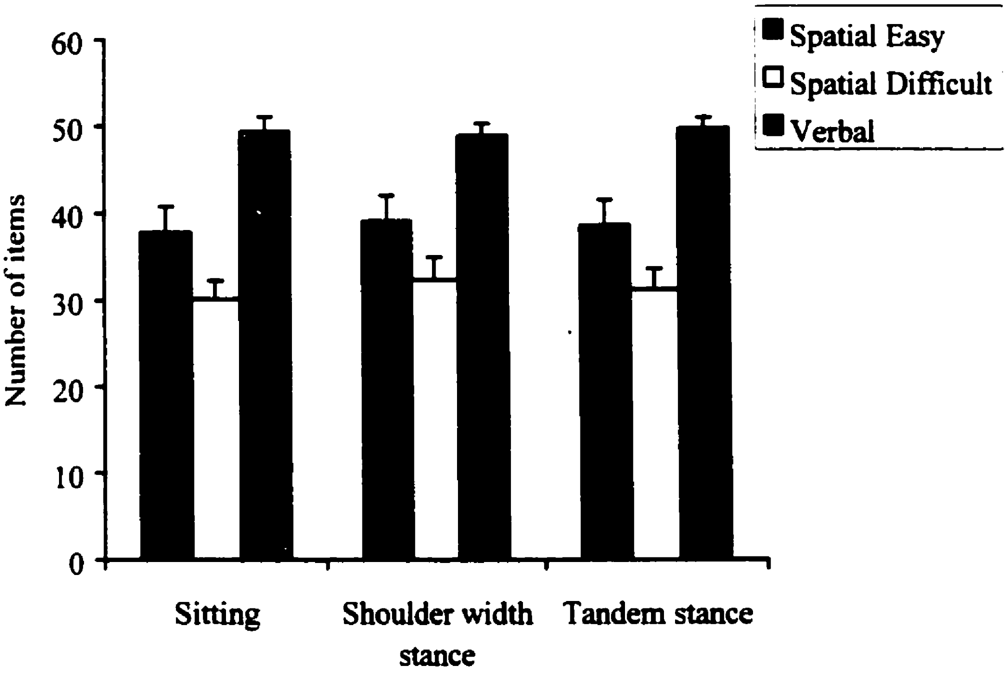

Figure 2.2: Performance of the visuo-spatial and verbal tasks for each postural stance.

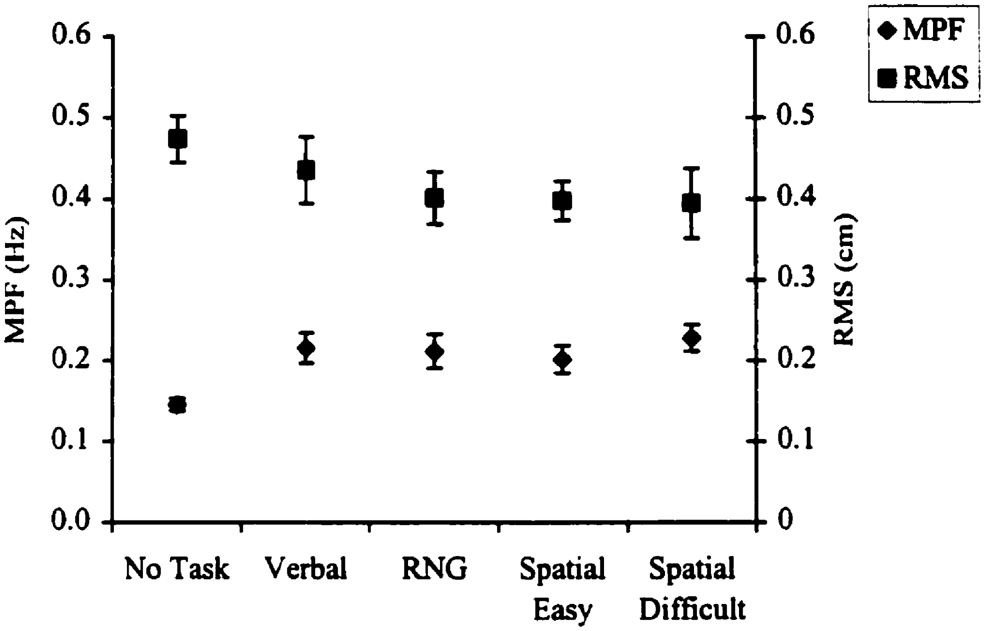

Figure 2.3: Mean and standard error values for mean power frequency and root mean square in anterior-posterior direction during shoulder width stance (RNG = random number generation).

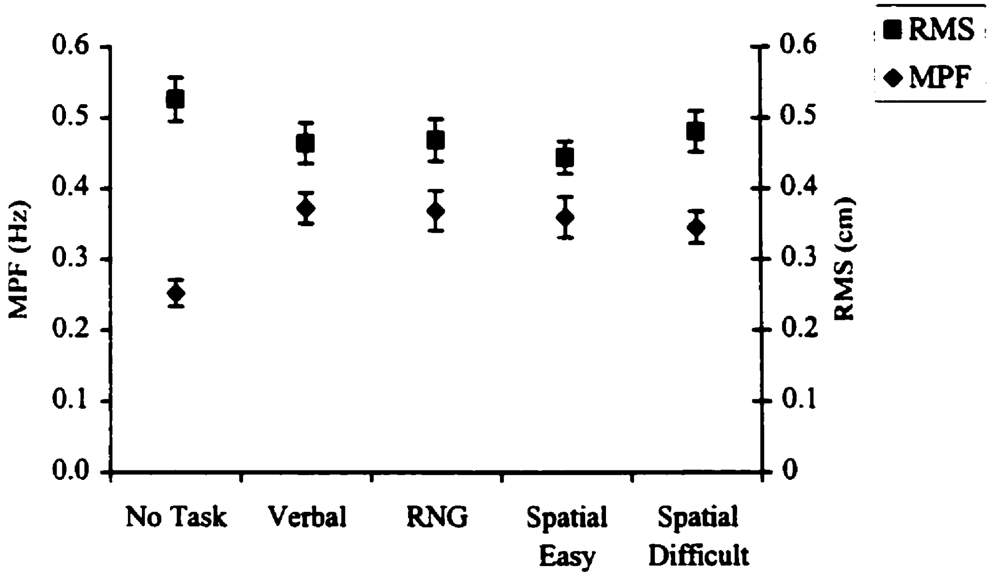

Figure 2.4: Mean and standard error values for mean power frequency and root mean square in medio-lateral direction during tandem stance (RNG = random number generation).

CHAPTER 3

CAN POSTURAL SWAY BE CONSCIOUSLY MODIFIED?

Mylène C. Dault, Mark G. Carpenter, Fran Allard and James S. Frank

ABSTRACT

The goal of this study was to determine if the changes found in postural control when fear is increased and when a secondary task is added can be influenced by focusing on postural sway. Participants were asked to perform a secondary task while standing at a low (40 cm) and a high surface height (100 cm). Results indicate that consciously focusing on postural sway can be helpful by reducing amplitude of sway when in a normal environment. Providing additional visual information, through visual feedback, seemed to counteract the effect of fear as postural sway decreased with increased surface height and prevented participants from being affected by the addition of the secondary task.

INTRODUCTION

Numerous studies have focused on understanding the interaction between postural control and psychological processes, such as attention and fear (Adkin et al., 2000; Carpenter et al., 1999; Dault et al., 2001; Fearing, 1925; Hunter and Hoffman, 2001; Kerr et al., 1985; Lajoie et al., 1993; Maki et al., 1991; Maylor and Wing, 1996; Riley et al., 1999; Shumway-Cook et al., 1997; Shumway-Cook and Woollacott, 2000). Different paradigms have been used resulting in very diverse findings, however one conclusion is clear: postural control can be affected by different manipulations relating to increased attentional demand and fear.

Dual-task paradigms have often been used to examine the interaction between postural control and attentional processes. Some researchers have shown that posture is modified by either increasing (Shumway-Cook et al., 1997; Shumway-Cook and

Woollacott, 2000) or decreasing postural sway (Dault et al., 2001; Fearing et al.,1925; Hunter and Hoffman, 2001; Kerr et al., 1985) in a dual-task situation. Others have shown changes in the outcome of the secondary task performance when comparing sitting to standing postures (Kerr et al., 1985; Maylor and Wing, 1996). Recently some studies have tried to explain this divergence of results based on the type of secondary task or on the sensory modality used to execute these tasks (Dault et al., 2001; Hunter and Hoffman, 2001). Results have indicated that neither task type nor sensory modality can explain the disparate conclusions; both Dault et al. (2001) and Hunter and Hoffman (2001) found that postural sway was reduced when executing a secondary task regardless of task type or sensory modality. Another possibility, proposed by Hunter and Hoffman (2001), is that postural changes might be related to a "concentration" factor. Information on the instructions to participants with respect to the direction of attention is rarely given. Were participants asked to stand quietly or to stand as still as possible? Do attentional instructions make a difference - can the direction of focus modify the interaction between postural control and a secondary task?

Fear of falling also has been associated with alterations in postural control (Adkin et al., 2000; Carpenter et al., 1999; Maki et al., 1991). Recent work by Carpenter et al. (1999) and Adkin et al. (2000) has found that increased fear, produced by increasing the standing surface height, resulted in a tighter control of postural sway. Still it is not yet understood by which mechanism fear influences postural control. One possibility is that fear of falling causes an individual to focus more on postural sway, resulting in a more conscious control, thus by-passing the usual automatic control. Another possibility is that fear of falling causes individuals to focus on environmental factors making them more aware of the postural threat (i.e. increased surface height).

Therefore, the goal of this study was to determine if the changes found in postural control when fear is increased and when a secondary mental task is added can be influenced by focusing on postural sway. Three main questions are addressed: 1) Can we consciously modify postural sway? 2) Can increased sensory information help us to consciously modify postural sway? 3) Do these two manipulations, consciously focusing on minimising sway and consciously focusing with increased sensory information, influence the interaction between postural control and the execution of a secondary task or between postural control and increased fear as shown in previous studies? If yes, do the manipulations influence this interaction in the same way?

METHODOLOGY

Participants

Thirty university students participated in this study (age range between 19 and 25 years old). Participants showed no vestibular or balance deficits as verified by the Romberg and Fukuda Tests (Newton, 1989). All procedures were approved by the Office of Human Research, University of Waterloo.

Procedures

Participants were asked to stand on an AMTI force plate with their toes aligned to the front edge of the force plate. Stance width was determined by the length of their foot.

The force plate was mounted to a marble plate (50 cm x 25 cm x 25 cm) and placed on a Pentalift Pro Series hydraulic lifting platform. The force plate was placed 50 cm and 120 cm from the front and back edge of the platform, respectively, and was bounded on all four sides by a wooden surround that was at equal height with the force plate (see Figure 3.1). Force plate data was sampled at a frequency of 20 Hz. COP displacement in the anterior-posterior (AP) and medio-lateral (ML) planes was calculated separately by using an in-house processing program. The data was then filtered at 5 Hz using a dual pass Butterworth filter.

A foot tracing of each participant was taken before the first trial to ensure a constant foot placement for each trial. A spotter was positioned immediately behind the participant in case of a loss of balance. The participants were asked to look straight ahead at a green square (10 x 10 cm) placed 6 m in front of the force plate at eye level. Prior to the start of the experimental trials, a 60 s quiet standing trial with eyes open was performed by all participants in order to eliminate the first trial effect as shown by Adkin et al. (2000). This single trial was not included in the statistical analysis. A 120 s control quiet standing trial (control trial) was performed at low (40 cm) and high height (100 cm) to ensure homogeneity between groups.

Participants were randomly divided into three groups: the first group was asked to stand quietly (control group); the second group was asked to focus on standing as still as possible (focus group); and the third group was asked to focus on standing as still as possible by using visual feedback (visual feedback group). Visual feedback was used to increase sensory information and help participants become more aware of their sway (Hamman and Krausen, 1990; Rougier, 1999; Shumway-Cook et al.,1988). The visual feedback component consisted of asking participants to concentrate on standing as still as possible by aligning a horizontal line on an oscilloscope to a fixed target line (screen = 10.2 x 8.2 cm, placed 1.5 m in front of the participants). The moving horizontal line represented the moment of force in AP direction.

All groups performed 2 experimental conditions: no task condition (NT) and secondary task condition (see Table 3.1). The secondary task consisted of simultaneously verbally shadowing a story (murder novel on tape) that was presented on an audiotape using earphones and a portable cassette player (Barroso, 1983). If the participants lost track of the story, they were instructed to catch up as quickly as they could and continue. Prior to recordings, participants practised repeating the story for a few seconds in order for them to become familiar with the task. Both experimental conditions were completed at a low height (40 cm) and then at a high height (100 cm). Trial duration was 120 s. A rest period (120 s) was provided between each trial in order to prevent fatigue. Order of presentation is described in Table 3.1.

Statistical Analysis

The dependent variables were root mean squared with bias removed (RMS), which gives information on the variability of amplitude of sway, mean power frequency (MPF), which provides information on the frequency of sway and, mean position (MP) of the COP displacements in anterior-posterior (AP) and medial-lateral (ML) directions.

MPF was determined by using a Fast Fourier Transformation (FFT) of the filtered COP data.

Prior to statistical analysis, a logarithmic transformation was performed on all measurements to ensure normal distribution of the data. A one-way ANOVA was performed on the control trials to ensure that the groups were homogeneous. Two separate analyses were then conducted to compare each postural control manipulation to the control group. A three-way mixed design ANOVA (focus and control groups x task x height) was performed on all six dependent variables in order to compare the focus group to the control group. A second three-way mixed design ANOVA (feedback and control groups x task x height) was conducted to compare the visual feedback group to the control group. Main and interaction effects with p values less than 0.05 were considered significant. Post-hoc analysis was performed using planned comparisons for significant main and interaction effects.

RESULTS

Quiet stance control trials

The one-way ANOVA revealed homogeniety across the groups for all measures; no significant difference was found between the three groups of participants.

Control group vs focus group

The three-way ANOVA revealed a significant main effect of height ($F(1,18)= 7.37$; $p<0.01$), as well as a significant interaction between height and task ($F(1,18)= 4.43$; $p<0.05$) for COP mean position (MP) in antero-posterior (AP) direction. Post-hoc analysis revealed that participants shifted their COP MP further back when height was increased but only when they were executing the secondary task. No significant changes were found for MP in ML direction. A significant group by height interaction was found in AP RMS ($F(1,18)=7.49$; $p<0.01$) and in AP MPF ($F(1,18)=4.40$; $p<0.05$) (see Figures 3.2 and 3.3). Post-hoc analysis revealed that the focus group had significantly lower RMS of sway at low height when compared to the control group and demonstrated a significantly lower MPF at high height when compared to the control group. Only the focus group was affected by the change in height as revealed by a significant decrease in MPF of sway and an increase in RMS of sway with surface height increase. No significant changes were observed in the control group, although there was a trend toward an increase in MPF and a decrease in RMS when height was increased. A significant secondary task effect was found for AP MPF ($F(1,18)= 16.79$; $p<0.001$), AP RMS ($F(1,18)= 9.38$; $p<0.01$), ML MPF ($F(1,18)= 24.85$; $p<0.0001$) and ML RMS ($F(1,18)=50.59$; $p<0.01$). Post-hoc analysis revealed that when the secondary task was added, MPF of sway was increased and RMS was decreased in both ML and AP directions and for both the focus and the control groups (see Figures 3.2 and 3.3).

Control group vs visual feedback group

The three-way ANOVA revealed a significant main effect for group in AP MPF ($F(1,18)= 30.37$; $p<0.0001$), AP RMS ($F(1,18)= 27.51$; $p<0.0001$) and ML MPF ($F(1,18)= 9.01$; $p<0.01$). Post-hoc analysis revealed that the visual feedback group had a higher MPF and lower RMS in AP direction and had a lower MPF in ML direction when compared to the control group at both the low and high surface height. A significant main effect for height was only found in AP RMS (F(1,18)= 3.10; $p<0.05$). Post-hoc analysis indicated that AP RMS decreased when surface height was increased for both the control and the feedback groups. A significant task effect was found in AP MPF (F(1,18)=8.09; $p<0.01$), in ML MP (F(1,18)=6.13; $p<0.05$), in ML MPF (F(1,18)= 13.81; $p<0.005$) and in ML RMS (F(1,18)=13.50; $p<0.005$). A significant interaction between group and task for MPF (F(1,18)= 6.13; $p<0.05$) indicated that only the control group increased MPF of sway in AP direction when the secondary task was performed (see Figure 3.2). The interaction between group x task in AP RMS was almost significant (F(1,18)=3.10; $p<0.09$) suggesting that only the control group decreased RMS of sway in AP direction when the secondary task was performed (see Figure 3.3). The feedback group was not affected by the addition of the secondary task in AP direction. In ML direction both groups showed the same changes in postural sway when the secondary task was executed, i.e. an increase in MPF and a decrease in RMS.

DISCUSSION

Can we consciously modify sway?

Observed differences in the focus group compared to the control group under the low surface height support the notion that sway can be modified by conscious focus. Results indicated that when focusing on postural control individuals where able to decrease the amplitude of their postural sway when in a normal environment, i.e. low surface height. However, no significant changes were found in the frequency of postural sway. These findings are similar to those by Fitzpatrick et al. (1992) who found that participants were able to reduce postural sway by modifying ankle stiffness when asked to concentrate on standing as still as possible.

Can increased sensory information help us to consciously modify postural sway?

The visual feedback group also revealed a reduction of postural sway when standing at the low surface height. Similar to the focus group, the feedback group demonstrated a significant decrease in AP RMS compared to the control group. In addition, the visual feedback group also showed a significantly higher AP MPF when compared to the control group. It is interesting to note that these changes in postural sway were direction specific; visual feedback was only provided in AP direction and the reduction in postural sway was found only in that direction. This is not surprising as numerous studies have shown a reduction in postural sway when visual feedback was present (Hamman and Krausen, 1990; Rougier, 1999; Shumway-Cook et al., 1988). The augmented visual information may allow the central nervous system (CNS) to monitor postural sway more closely and reduce sway magnitude. Furthermore, Riley et al. (1999) recently suggested that changes reported in postural control during a touch-task may not only be related to increased sensory information but to the fact that postural control is modified in relation to the constraints of the "supra-postural" task such as touching an object. This suggests that visual feedback plays two roles: one of providing information about postural sway and one of engaging the higher centres of the CNS with a "supra-postural" task as suggested by Riley et al. (1999). In addition, numerous studies have shown that postural sway in AP direction is decreased when fixating on a near object compared to a far object (Bles et al., 1980; Dijkstra et al., 1992; Lee and Lishman, 1975;

Paulus et al., 1989; Stoffregen et al., 1999; Stoffregen et al., 2000). The visual fixation point, in the present study, was much closer for the feedback group (1.5 m) compared to the control group (6 m). Therefore, the visual feedback task may not only have provided increased sensory information about postural sway and increased attentional load because of task constraints but also provided better information about sway because of the proximity of the object of fixation. These factors might explain why participants in the visual feedback group were able to modify postural sway when compared to the control group.

Do these two manipulations influence the interaction between postural control and the execution of a secondary task, and between postural control and increased fear, as shown in previous studies?

Hunter and Hoffman (2001) recently addressed the question of whether "concentration" can influence postural sway and if it should be considered when comparing other manipulations to a control task condition. Our results indicate that concentrating does have an effect on postural control and influences other manipulations such as increased surface height. In young healthy individuals, increase in surface height has been shown to increase MPF and decrease RMS of the COP (Adkin et al., 2000; Carpenter et al, 1999). This trend was also observed in the present study. Participants who focused on minimising postural sway had an opposite effect to that of the control group as it interacted with height. Although the control group reduced postural sway , participants in the focus group displayed the opposite behavior with increased height, i.e. decrease in MPF and an increase in RMS. Focusing on postural sway did not interact with effects of a secondary task on postural control. Participants in the focus group reacted in the same way as the control group when the secondary task condition was compared to the NT condition, as shown by an increase in MPF and a decrease in RMS. These results are similar to results found by Dault et al. (2001) and Hunter and Hoffman (2001). Hence, focusing on postural sway does not influence the relationship between postural control and the execution of a secondary task but seems to increase the influence of fear on postural sway.

The effects of focusing on postural sway by using visual feedback were different than those resulting from simply consciously focusing without additional sensory information. No significant interaction was found between the visual feedback and the control groups with height changes. Both the visual feedback and the control groups were affected in the same way by increased surface height as revealed by a decrease in AP RMS. On the other hand, a significant interaction was found between the visual feedback and the control groups with the addition of the secondary task. The control group showed a significant increase in AP MPF and a decrease in AP RMS with the addition of the secondary task whereas the feedback group did not exhibit any changes with the addition of the task, indicating that visual feedback may have produced a ceiling effect. When participants were asked to focus on standing as still as possible by using visual feedback, they were able to display a tighter control of postural sway regardless of the other manipulations such as increased surface height and performance of a secondary task.

CONCLUSION

In conclusion, these results indicate that when asked to consciously focus on postural sway individuals are able to reduce the amplitude of their sway but only when standing in a normal environment. Providing additional visual information seemed to counteract the effect of fear because postural sway decreased with increased surface height. When executing a secondary task, consciously focusing of postural sway did not modify the interaction found in previous studies (Dault et al., 2001; Fearing et al., 1925; Hunter and Hoffman, 2001; Kerr et al., 1985). On the other hand, providing additional visual information prevented participants from being affected by the addition of the secondary task. Hence, visual feedback seemed to be an interesting way to produce better control of balance regardless of other environmental or psychological constraints. Also, it is possible that when using visual feedback, participants chose to modify the performance of the secondary instead of modifying postural control but because performance of the secondary task was not recorded we cannot verify this hypothesis. Further research is needed to investigate whether these results would be similar in elderly individuals.

ACKOWLEDGEMENTS

This study was funded by Natural Sciences and Engineering Research Council of Canada (NSERC) grants to Mylène C. Dault, Mark G. Carpenter and James S. Frank. The authors would like to thank Mike Amos and Gary Peysar for their help during data collection.

REFERENCES

Adkin A, Carpenter M, Frank JS and Peysar G (2000). Postural control is scaled to level of postural threat. Gait & Posture, 12, 87-93.

Barroso F (1983). An approach to the study of attentional components in auditory tasks. Journal of Auditory Research, 23(3), 157-180.

Bles W, Kapteyn TS, Brandt T and Arnold F(1980). Acta Otolaryngical 89, 534-540 .

Carpenter MG, Frank JS and Silcher CP (1999). Surface height effects on postural control: A hypothesis for a stiffness strategy for stance. Journal of Vestibular Research, 9(4), 277-86.

Dault MC, Frank JS and Allard F (2001). Influence of a visuo-spatial, verbal and central executive working memory task on postural control. Gait & Posture 14: 110-116.

Dijkstra TH, Gielen CC and Melis BJ (1992). Postural responses to stationary and moving scenes as a function of distance to the scene. Human Movement Science, 11, 195-203.

Fearing FS (1925). Factors influencing static equilibrium: An experimental study of the effects of controlled and uncontrolled attention upon way. The Journal of Comparative Psychology, 5, 1-24.

Fitzpatrick RC, Taylor JL and McCloskey DI (1992). Ankle stiffness of standing humans in response to imperceptible perturbation: Reflex and task-dependent components. Journal of Physiology, 454, 533-547.

Hamann KF and Krausen C (1990). Clinical application of posturography: body tracking and biofeedback training. In: Brandt T, Paulus W, Bles W, Dieterich M, Krafczyk S and Straube A, (Eds.). Disorders of posture and gait. (pp.265-268). Stuttgart: Georg Thieme Verlag.

Hunter MC and Hoffman MA (2001) Postural control: visual and cognitive manipulations. Gait & Posture, 13, 41-48.

Kerr B, Condon SM and McDonald LA (1985). Cognitive spatial processing and the regulation of posture. Journal of Experimental Psychology, 11(5), 617-622.

Lajoie Y, Teasdale N, Bard C and Fleury M (1993). Attentional demands for static and dynamic equilibrium. Experimental Brain Research, 97, 139-144.

Lee DN and Lishman JR (1975). Visual proprioceptive control of stance. Journal of Human Movement Studies 1, 87-95.

Maki BE, Holliday PJ, Topper AK (1991). Fear of falling and postural performance in the elderly. Journal of Gerontology, 46A(4), M123-131.

Maylor EA and Wing AM (1996). Age differences in postural stability are increased by additional cognitive demands. Journal of Gerontology, 51B(3), P143-P154.

Newton R (1989). Review of tests of standing balance abilities. Brain Injury 3(4), 335-343 .

Paulus W, Straube A, Krafszyk S and Brandt T (1989). Differential affects of retinal target displacement, changing size and changing disparity in the control of anterior/posterior and lateral body sway. Experimental Brain Research 78, 243-252.

Riley MA, Stoffregen TA, Grocki MJ, Turvey MT (1999). Postural stabilization for the control of touching. Human Movement Science 18, 795-817.

Rougier P (1999). Influence of visual feedback on successive control mechanisms in upright quiet stance in humans assessed by fractional Brownian motion modelling. Neuroscience Letters, 266, 157-160.

Shumway-Cook A, Anson D, Haller S (1988). Postural sway biofeedback: Its effect on reestablishing stance stability on hemiplegic patients. Archives of Physical Medicine and Rehabilitation, 69, 395-400.

Shumway-Cook A, Woollacott M (2000). Attentional demands and postural control: the effect of sensory context. Journal of Gerontology, 55A(1) M10-16.

Shumway-Cook A, Woollacott M, Kerns A and Baldwin M (1997). The effects of two types of WM tasks on postural stability in older adults with and without a history of falls. Journal of Gerontology, 52A(4), M232-240.

Stoffregen TA, Pagulayan RJ, Bardy BG, Hettinger LJ (2000). Modulating postural control to facilitate visual performance. Human Movement Science 19, 203-220.

Stoffregen TA, Smart LJ, Bardy BG and Pagulayan RJ (1999). Postural stabilization of looking. Journal of Experimental Psychology, 25, 1641-1658.

Table 3.1: Description of concentration groups and the experimental conditions performed at a low height (40 cm) and high height (100 cm).

Control group	**Focus Group**	**Feedback group**
1) First trial (60 s)*	1) First trial •	1) First trial*
2) Quiet stance (control trial) (120 s)	2) Quiet stance (control trial)	2) Quiet stance (control trial)
3) Quiet stance (120 s)	3) Standing as still as possible	3) Standing as still as possible by using the visual feedback
4) Quiet stance while executing the mental task (120 s)	4) Standing as still as possible while executing the mental task	4) Standing as still as possible by using the visual feedback while executing the mental task

* this experimental condition is performed at the low height only.

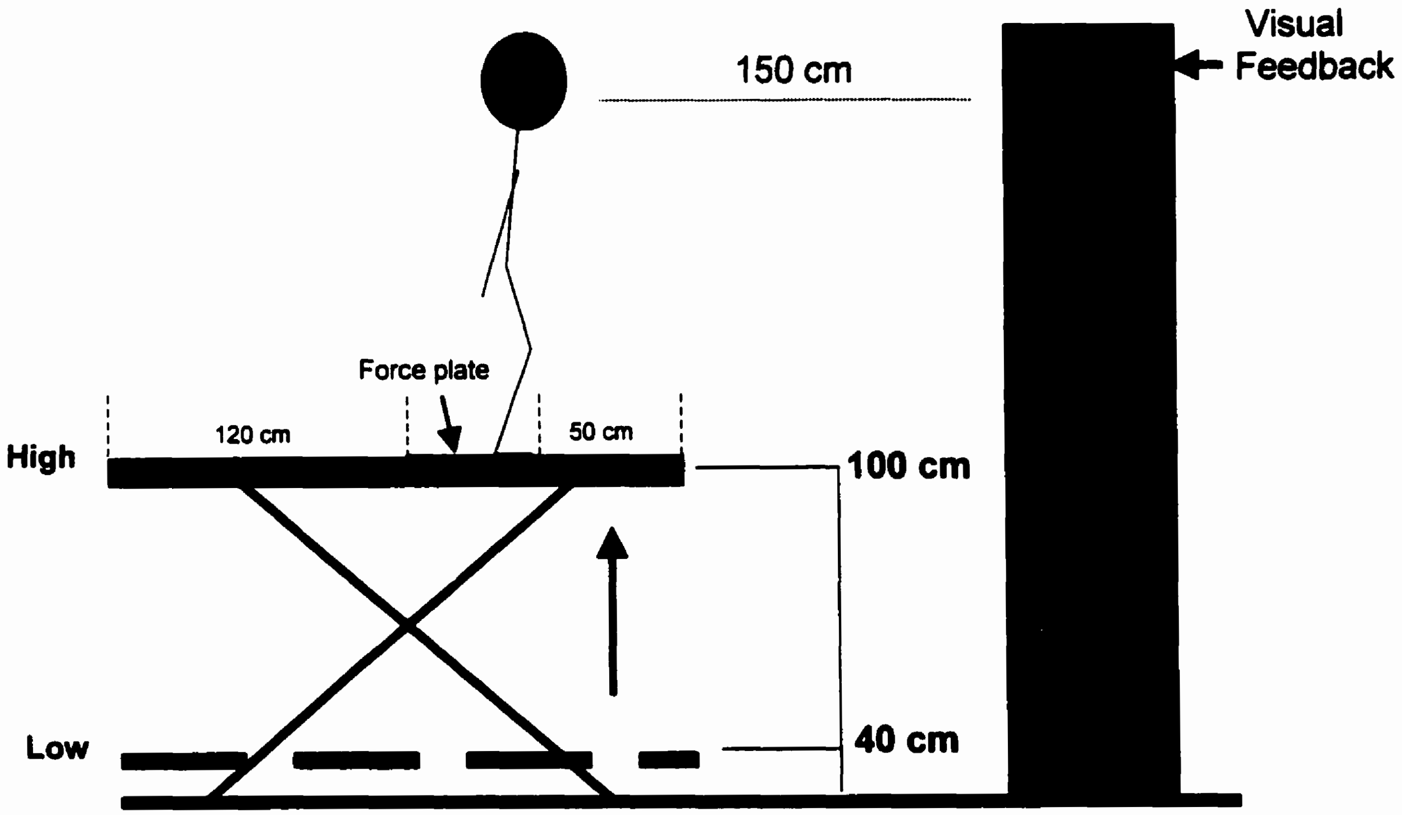

Figure 3.1 Illustration demonstrating the experimental set up at low and high height.

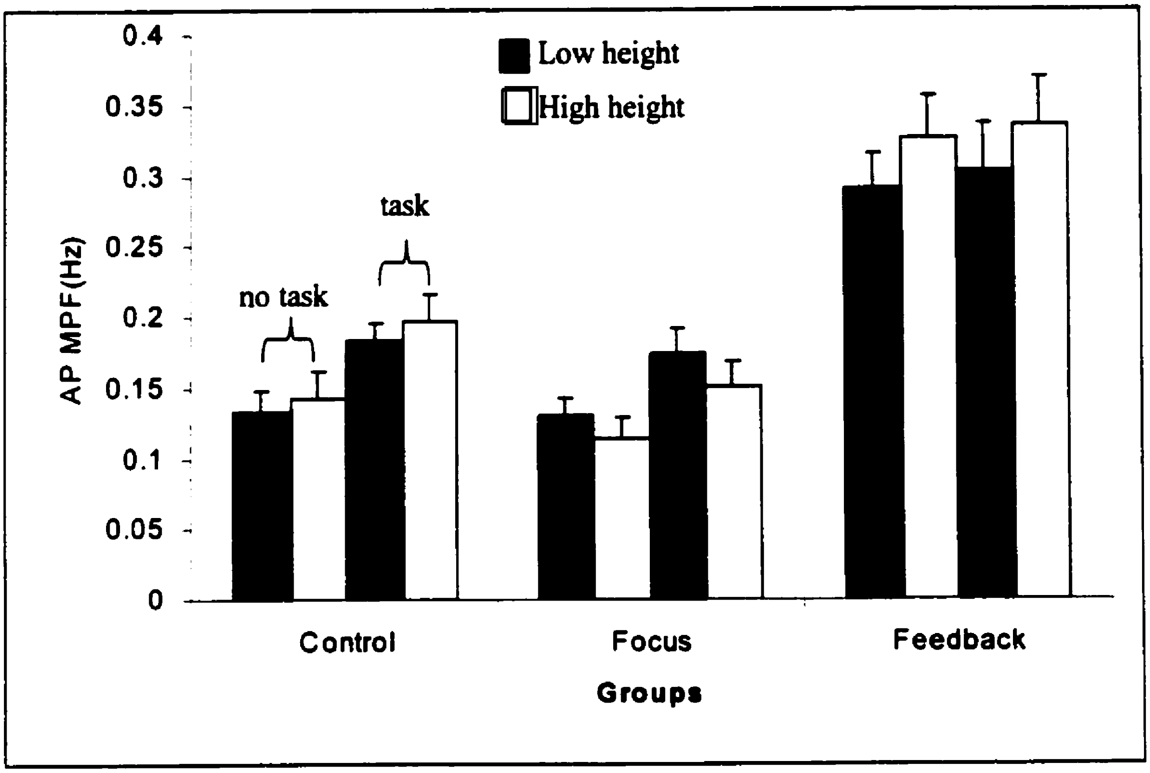

Figure 3.2: Mean and standard error values for MPF in AP direction for all groups during the no task and task conditions at low and high height.

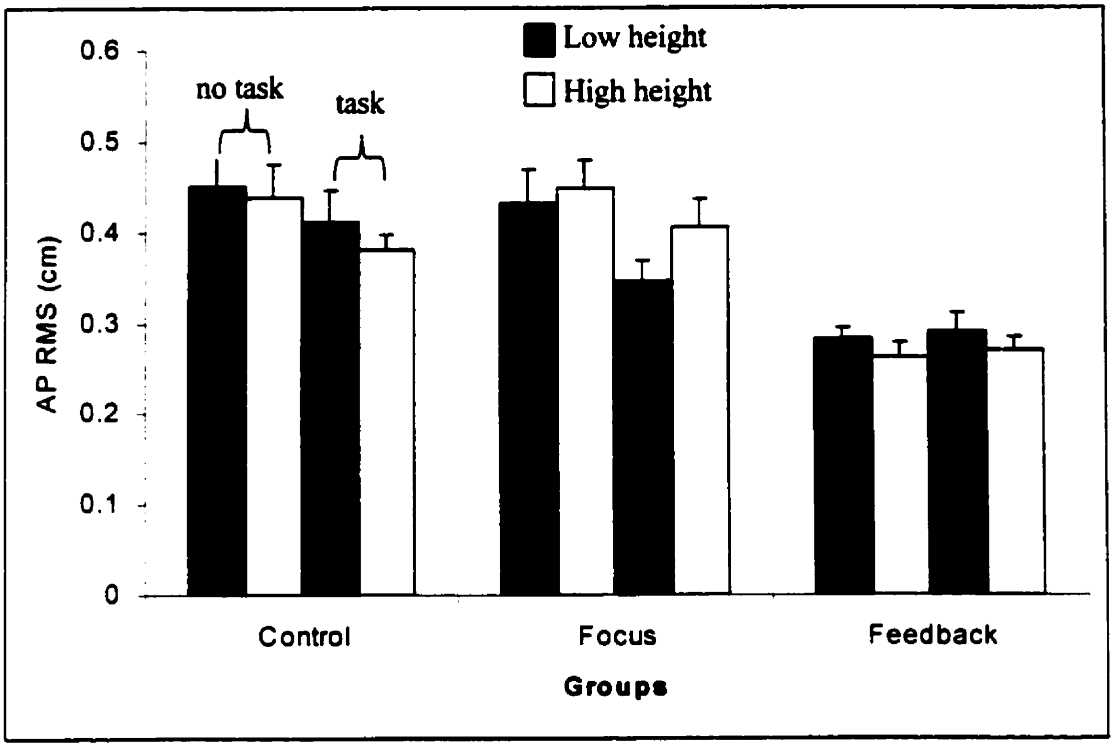

Figure 3.3: Mean and standard error values for RMS in AP direction for all groups during the no task and task conditions at low and high height.

CHAPTER 4

CAN ARTICULATION EXPLAIN MODIFICATIONS IN POSTURAL CONTROL DURING DUAL-TASK PARADIGMS?

Mylène C. Dault, Lucy Yardley, James S. Frank

ABSTRACT

Most secondary tasks used in dual-task studies of the interaction between postural control and attention have employed verbal responses. However, changes in respiration during speech production are known to produce changes in postural control. Hence, the goal of this study was to determine whether articulation can explain the changes found in postural sway when a secondary task is being performed. Participants were asked to stand on a force platform while executing secondary tasks that were performed silently or required a verbal response, and that required high or low levels of attention. Performance of all tasks produced an increased sway frequency and decreased sway amplitude relative to the no task baseline. Tasks that required vocalization resulted in a more pronounced increase in postural sway frequency, which led to an increased sway path. It appears that changes in sway that accompany performance of secondary tasks are complex, and are partly due to the perceptual-motor requirements of the task, such as articulation, rather than only attentional load.

INTRODUCTION

Dual–task paradigms are commonly used to examine the interaction between attention and postural control. Numerous studies have suggested that when performance of a secondary task results in changes in postural control, this is due to cognitive interference, caused by competing demands for attentional resources (e.g. Brown et al., 1999; Dault et al., 2001a; Dault et al., 2001b; Geurts and Mulder, 1994; Shumway-Cook and Woollacott, 2000). Because most of the secondary tasks performed in these studies have relied almost exclusively on verbal responses, Yardley et al. (1999) addressed the issue that changes seen in postural sway in dual-task paradigms might be due to the processes involved in articulation rather than competing attentional demands. In fact, Yardley et al. (1999) found an increase in sway path *only* when participants were asked to execute a task requiring articulation, and not during secondary tasks performed silently.

Production of speech requires coordination between articulatory processes and phonatory and respiratory processes (Conrad and Schönle, 1979). The duration of expiration during speech is ten times longer than during quiet respiration, producing significant changes in the respiration pattern. Changes in respiration during speech production can produce changes in postural control. Bouisset and Duchêne (1994) found an increase in sway amplitude, sway path and sway area during deep breathing, when compared to quiet breathing. Jeong (1991) found that holding your breath after inspiration causes more sway than holding your breath after expiration. Postural sway also increased when respiration rate was increased (Jeong, 1991). In addition, research has shown that the control of muscles involved in respiration is also important in the control of posture (Yates and Miller, 1998; Rimmer et al., 1995).

Changes in respiratory time ratio (relation of duration of inspiration versus expiration) have also been found when participants were asked to perform tasks using their 'inner voice', or subvocally responding (articulation movement but no vocalization), when compared to normal respiration patterns (Conrad and Schönle, 1979). Respiration patterns during the silent arithmetic task resembled patterns observed during speech. Therefore, speech does not need to be present to see changes in respiratory patterns when participants are asked to execute secondary tasks. These modifications were more pronounced when participants were executing an arithmetic task compared to when they were reading or executing an automatic sequence (such as counting from 1 to 10).

Yardley et al. (1999) suggested that the changes found in sway path during tasks that required articulation might not be solely attributable to respiration, but could be partly a result of central interference between motor programs for posture and for articulation. However, their study did not include a pure motor task that did not involve articulation, and so the interference caused by motor programming could not be investigated. It is also important to note that increased arousal because of effort or anxiety, which is often accompanied by changes in respiration and heart rate, can also produce changes in postural sway, such as displacement of the position of the centre of pressure and increase in frequency coupled with a decrease in amplitude of sway (Adkin et al., 2000; Carpenter et al., 1999; Carpenter et al., 2001; Maki and McIlroy, 1996).

The present study was designed to look in more depth at these postural sway changes by examining not only sway path, as in previous studies (Bouisset and Duchêne, 1994; Yardley et al., 1999), but also by looking at changes in amplitude variability of sway and frequency components of the sway pattern. Secondary tasks were chosen to follow the continuum of respiration changes found by Conrad and Schönle (1979), i.e. a quiet breathing task, a silent mentally challenging task, a motor task without vocalization, a nonsense vocalization task and a mentally challenging task with vocalization. The goal of this study was to determine whether articulation can explain all the changes found in postural sway when a secondary task is being performed.

METHODOLOGY

Participants

Twenty participants (mean age = 29.8 ± 6.12 years) volunteered. Each participant was informed of the experimental conditions and gave written consent for their participation in the study prior to initiating of the testing session. All procedures were approved by the Ethics Committee of the Department of Psychology at the University of Southampton (Southampton, UK).

Postural task

Participants were asked to stand quietly on the force platform while executing a series of tasks. Three different postural conditions were used: 1) seated; 2) standing on a stable surface; 3) standing on an unstable surface. The seated posture was used as a baseline measurement for the secondary task and for heart rate measurements. In the stable surface condition, participants stood directly on the force platform. During the unstable surface condition, participants were asked to stand on a wooden board supported by an air-filled circular rubber tube inflated at 1.2 bar, which was placed on the force platform (Yardley et al., 1999). The position of the participant's feet was traced before the first trial to ensure that participants always placed their feet at the same place for every trial. Participants were instructed to stand quietly with arms at their side and focus on an "x" placed 4.5 m in front of them at eye level.

Secondary tasks

Five different tasks were executed: no task, a silent task, a combination task, an articulation task and a motor task. For the no task condition (NT), participants were simply asked to stand quietly without performing any additional task. The silent task consisted of asking participants to listen to letters that formed words that were included in a non-sense phrase, for example, "m-y s-i-s-t-e-r h-a-s e-a-t-e-n t-h-e p-i-a-n-o f-o-r m-e". Phrases were pre-recorded on an audio tape. The narrator said "next word" in between each group of letters that formed a word so that participants knew which letters had to be grouped together to form a word. At the end of the trial, participants were asked to say aloud the phrase they had memorised. This task was intended to maximise attentional load with no articulation. The combination task was similar to the silent task, the only difference being that participants had to repeat each letter aloud immediately after hearing it, as well as form the words and say the phrase aloud at the end of each trial. This task was intended to stimulate both attention and articulation processes. The articulation task involved asking participants to repeat letters aloud without having to form any words. The random letters were separated into blocks and the narrator said "next block" between each block, in order to resemble the temporal pattern of the silent and the combination tasks in which the letters formed words. This task was intended to stimulate only articulation processes. The motor task consisted of asking participants to bite on a plastic tube, opening and closing their jaw (see Figure 4.1). This task was chosen to examine the implication of motor coordination in the postural sway changes seen in dual-task paradigms.

Apparatus

A Kistler (model: 9281B) force platform with the software from the CODA motion analysis system (model: MPX 30) was used to monitor centre of pressure displacements. Data was sampled at a frequency of 20 Hz and filtered with a dual pass Butterworth filter with a 5 Hz cutoff frequency.

The unstable surface was constructed of two pieces of wooden board with an air-filled circular rubber tube inflated at 1.2 bar, which was placed on the force platform (Yardley et al., 1999). Participants wore a heart rate monitor (Polar™) and the average heart rate over the 60s trial was calculated to examine the effects of effort and cognitive task difficulty (Mulder and Mulder, 1981; Fowles, 1988). An audio tape player and a pre-recorded tape were used for the secondary tasks. The "biting apparatus" for the motor task consisted of a plastic tube with pressure sensors placed at each extremity (see Figure 4.1). The sensors emitted a sound when the pressure in the tube was increased due to the biting action. The beeping sound was recorded to verify that participants bit the tube in a constant fashion. No speed requirements were given only to bite at a constant pace.

Procedures

All experimental conditions were performed with eyes open and with eyes closed. Three postural positions (seated, stable surface and unstable surface) and five secondary tasks (no task, silent task, motor task, articulation task and combination task) were performed. The secondary task presentation was blocked within each postural task condition, and order of presentation of secondary tasks was randomized. Postural task conditions were presented in random order. Secondary tasks started at the same time as the recording of the postural sway and lasted 60s.

Root mean square (RMS) of the COP displacement with bias removed and mean power frequency (MPF) of the COP displacement over 60s were calculated in the anterior-posterior (AP) and medio-lateral (ML) direction. RMS values provide information on the variability of COP displacement about the mean position (bias) of the COP and were used as an amplitude measurement. MPF values provided information on the frequency of the sway control. Sway path was calculated by taking the coordinates of two consecutive points and calculating the distance between the two by using the Pythegorian theory and adding all the distances together.

Performance of the combination and articulation tasks was analysed by looking at the number of words that participants were able to form and calculating the percentage of correct answers.

Statistical analysis

Postural control measures were subjected to a logarithmic transformation in order to ensure normal distribution. Because of the use of multiple dependent measures, a MANOVA (postural task (2) x vision (2) x secondary task (5)) was conducted to examine main and interaction effects of secondary task condition and postural condition. Where significant multivariate effects were detected, univariate follow-up procedures were conducted.

A repeated measures three-way ANOVA (postural task (3) x vision (2) x secondary task (2)) was performed to examine performance of the articulation and the combination tasks. A repeated measures three-way ANOVA (postural task (3) x vision (2) x secondary tasks (5)) was performed on the average heart rate recorded during each 60s trial.

RESULTS

Postural control measures

The MANOVA analysis revealed main effects for postural task (Wilks' Lambda F(5,356) = 972.48; $p< 0.0001$), vision (Wilks' Lambda F(5,356) = 99.47; $p< 0.0001$) and for secondary task (Wilks' Lambda F(20,1182)= 3.023; $p<0.0001$). An interaction was found between postural task and vision (Wilks' Lambda F(5,356) = 57.71; $p< 0.0001$) and between postural task and secondary task (Wilks' Lambda F(20,1182)= 1.67; $p<0.05$). Univariate follow-up procedures are presented below for the main effects and for the interactions.

A significant postural task main effect was found for sway path (F(1,19) = 519.29; $p< 0.0001$), AP RMS (F(1,19) = 290.70; $p<0.0001$), AP MPF (F(1,19) = 51.09; $p<0.0001$), ML RMS (F(1,19) = 478.44; $p< 0.0001$) and ML MPF (F(1,19) = 10.56; $p<0.0042$). A significant vision main effect was found for sway path (F(1,19) = 245.45; $p< 0.0001$), AP RMS (F(1,19) = 34.16; $p<0.0001$), AP MPF (F(1,19) = 64.71; $p<0.0001$), ML RMS (F(1,19) = 58.84; $p< 0.0001$) and ML MPF (F(1,19) = 24.85; $p<0.0001$). A significant interaction between postural task and vision was found for sway path (F(1,19) = 217.85; $p< 0.0001$), AP RMS (F(1,19) = 17.07; $p<0.0001$), AP MPF (F(1,19) = 35.36; $p<0.0001$), ML RMS (F(1,19) = 55.45; $p< 0.0001$) and ML MPF (F(1,19) = 15.96; $p<0.0001$). Post hoc analysis revealed that participants demonstrated increased sway path, AP RMS and ML RMS when vision was removed when standing on the stable and unstable surface. AP MPF was increased and ML MPF was decreased when vision was removed when participants were standing on the unstable surface only (see Table 4.1).

A significant secondary task main effect was found for sway path (F(4,76) = 6.01; $p< 0.003$), AP RMS (F(4,76) = 7.17; $p<0.0001$), AP MPF (F(4,76) = 5.17; $p< 0.01$), ML RMS

(F(4,76) = 3.87; p<0.01) and ML MPF (F(4,76) = 3.11; p<0.02). A significant postural task by secondary task interaction was found for AP RMS (F(4,76)=6.00; p<0.001) and was almost significant in ML RMS (F(4,76)=2.34;p=0.06). Post hoc analysis indicated that sway path was increased for only the articulation and combination tasks when compared to the no task condition (see Figure 4.2). When participants were standing on the stable surface, RMS was significantly decreased with the execution of all tasks compared to the NT condition in AP direction and with all tasks except the articulation task in ML direction (see Figure 4.3). When participants were standing on the unstable surface, the silent task was significantly lower than the NT in AP direction and all tasks except the motor task were significantly lower than the NT in ML direction (see Figure 4.4). Frequency of sway was increased with the execution of all secondary tasks when compared to the NT condition in AP direction but was only increased for the combination task in ML direction for both standing surfaces (see Figure 4.5). The combination task resulted in higher MPF when compared to the motor task in AP direction and to the motor and silent task in ML direction.

Secondary task performance

No significant differences were found between postural conditions, secondary tasks and visual condition with regards to secondary task performance. These results indicate that participants performed the silent and the combination task with equal success regardless of whether they were seated, standing on a stable surface, or standing on an unstable surface. In fact, participants showed 90.12% success when performing the task while standing on the unstable surface, 90.93% when on the stable surface and 92.17% when seated. This lack of difference in performance between the different postural conditions might be related to a ceiling effect.

Average heart rate

A significant postural task main effect was found (F(2,32) = 46.62; p<0.0001) indicating that average heart rate was significantly lower for the seated posture (75.27 beats per minute (bmp)) compared to standing on the stable (85.39 bmp) and unstable surface (87.44 bmp). No main effect of vision was found. A significant secondary task main effect was also found (F(4,64) = 33.26; p<0.0001). Post-hoc analysis revealed significant differences in heart rate between no task and all the secondary tasks except for the combination task (see Figure 4.6). The execution of the combination task resulted in significantly higher heart rate when compared to the articulation, motor and silent tasks.

DISCUSSION

The goal of this study was to examine if the changes found in postural control when a secondary task is executed are a result of competing demands for attentional resources or if they are simply due to changes in respiration or motor control of articulation.

Was postural control modified by the addition of a secondary task?

The addition of a secondary task resulted in modifications of postural sway. Participants demonstrated an increased sway path when executing the articulation and the combination task, i.e. only when vocalization was involved, when compared to all other tasks. These results are similar to those found by Yardley et al. (1999). For both standing surfaces and for all secondary tasks, frequency of sway was increased in AP direction. For the stable surface, amplitude of sway was decreased in both AP and ML direction with the addition of all the secondary tasks except for the articulation task in ML direction. For the unstable surface, interference of the secondary task mostly occurred in the ML direction; only the silent task was significantly different than the NT in AP direction. Dault et al. (2001a) have shown that greater dual-task interference occurs in the plane that the postural stance is least stable; in this study the ML direction appeared to be less stable for the unstable surface. Participants were required to stand with the same stance width on the unstable surface as on the stable surface. Many participants reported finding it difficult and wanted to stand at a larger stance width on the unstable surface. Another important aspect to consider is that variability was much larger in AP direction than in ML direction for the unstable surface, which might explain the lack of significant results in AP direction (see Figure 4.4).

The results found in the present study were consistent with those from previous studies (e.g. Dault et al., 2001a; Fearing, 1925; Kerr et al., 1985). Recent research has suggested that if we model the body as an inverted pendulum, increased frequency and decreased amplitude of sway can be related to increased stiffness (Carpenter et al., 1999; Carpenter et al., 2001; Winter et al., 1998). Our findings suggest that introduction of any secondary task appears to induce an increased stiffness.

Can articulation explain the changes seen in postural sway?

The increase in sway path during the vocalization tasks can be explained in our study by an additional increase in the frequency of sway on these tasks. Because changes in respiration rate seem to be related to changes in frequency (Bouisset and Duchêne, 1994), the present study may indicate that the vocalization needed to execute the articulation and the combination tasks could have provoked changes in the respiratory pattern that led to an increased frequency of sway (and hence the sway path).

Maki and McIlroy (1996) suggest that arousal may influence postural control by modulating attention, but can also affect postural performance through somatic or autonomic effects. Therefore, changes in sway path and sway frequency when participants are performing the articulation and combination tasks might in principle be attributable to heart rate and respiratory changes relating to increased arousal or increased task difficulty (Mulder and Mulder, 1981). However, in our study heart rate was not elevated by any of the tasks relative to the no task baseline, and so cannot have mediated task effects on sway.

Modifications found in amplitude of sway were the same for all tasks regardless of articulation. The silent task, which did not require any articulation, provoked the same changes in amplitude of sway as the tasks that required articulation and motor coordination. Hence, the changes seen in amplitude might not be attributable to motor coordination or vocalization. Although changes in respiratory ratio were smaller than those in tasks requiring vocalization, Conrad and Schönle (1979) nertheless saw changes in respiration when participants were asked to perform tasks using their 'inner voice'. Therefore, respiration could still play a role in the changes observed in amplitude of sway, however the tasks requiring vocalization in the present study (hence, greater respiratory rates) did not result in greater modifications than the tasks that did not require vocalization. We could argue that the changes observed in amplitude of sway with the addition of all secondary tasks are due to increased attentional load and not to changes in respiration or to motor programming required by the articulation processes. However, because no measurements of respiration were taken in the present study, we cannot completely discard the role of respiration in the changes seen in amplitude of sway.

Did changes in vision or in standing surface cause further changes to postural sway or modify task performance?

As expected, standing on an unstable surface resulted in increased instability, and the absence of vision when standing on the unstable surface resulted in even greater instability. Amplitude of sway was decreased in both AP an ML direction when participants were standing on the stable surface and in ML only when they were standing on the unstable surface with the addition of a secondary task. Participants were much more variable when standing on the unstable surface as shown by higher standard deviations in AP direction, which might explain why changes seen in amplitude of sway with the addition of a secondary task when standing on the unstable surface were only significant for the silent task in AP direction. When standing on both surfaces, participants increased frequency of sway in AP direction with the addition of the secondary task. The addition of a secondary task produced the same changes in postural sway for vision and no vision conditions. Even though participants were less stable while standing on the unstable surface with eyes closed they did not perform worse on the secondary tasks. Hence, vision and postural task difficulty did not modify the interaction between postural control and the execution of a secondary task because changes seen in amplitude and frequency of sway were related to increased stiffness for both postural tasks.

CONCLUSION

This study suggests that postural control is modified by the execution of different secondary tasks. Sway path and frequency were increased when executing tasks that required vocalization. These changes are probably due to changes in respiration rate and not motor programming as the motor task did not result in any changes in sway path, although we cannot confirm this because respiration rate was not monitored. Conversely, amplitude of sway was simply reduced by the addition of any secondary task, and showed no effects of vocalization or motor programming. These findings imply that the addition of a secondary task results in increased stiffness (Carpenter et al., 2001), where as vocalization results in a further increased frequency of sway, which leads to an increase in sway path. Changes in sway induced by performance of secondary tasks are partly due to the perceptual-motor requirements of the task, such as vocalization, rather than only attentional load. It is therefore necessary to describe secondary tasks and resulting postural modifications precisely when investigating this type of dual-task paradigm.

ACKNOWLEDGEMENT

The authors would like to thank Dr. Ann Ashburn for the use of her laboratory and Mr. Malcolm Burnett for his technical help during testing. This research was funded by NSERC and Fondation Baxter et Alma Ricard scholarships to Mylène C. Dault.

REFERENCES

Adkin AL, Frank JS, Carpenter MG and Peysar GW (2000). Postural control is scaled to level of postural threat. Gait & Posture, 12(2):87-93.

Bouisset S and Duchêne JL (1994). Is body balance more perturbed by respiration in seating than in standing posture? Neuroreport. 14;5(8):957-60.

Brown LA, Shumway-Cook A and Woollacott MH (1999). Attentional demands and postural recovery: the effects of aging. Journal of Gerontology, 54(4): M165-71.

Carpenter MG, Frank JS and Silcher CP and Peysar GW (2001). The influence of postural threat on the control of upright stance. Experimental Brain Research. 138:210-218

Carpenter MG, Frank JS, Winter DA, Peysar GW (2001). Sampling duration effects on centre of pressure summary measures. Gait & Posture. 13(1):35-40.

Conrad B. and Schönle P (1979). Speech and respiration. Archiv fur Psychiatrie und Nervenkrankheiten, 226: 251-268.

Dault MC, Frank JS and Allard F (2001a). Influence of a visuo-spatial and verbal working memory task on postural control. Gait & Posture14(2): 110-116.

Dault MC, Geurts ACH, Mulder TW and Duysens J (2001b). Postural control and cognitive task performance in healthy participants while balancing on different support-surface configurations. Gait & Posture. 14(3):178-185.

Fowles DC (1988). Psychophysiology and psychopathology: a motivational approach. Psychophysiology, 25(4):373-91.

Geurts ACH and Mulder TW (1994). Attention demands in balance recovery following lower limb amputation. Journal of Motor Behavior, 26(2): 162-170.

Jeong BY (1991). Respiration effect on standing balance. Archives of Physical Medicine and Rehabilitation, 72:642-5

Maki BE and McIlroy WE (1996). Influence of arousal and attention on the control of postural sway. Journal of Vestibular Research, 6(1): 53-59.

Mulder G, Mulder LJ (1981) Information processing and cardiovascular control Psychophysiology, 18(4):392-402

Rimmer KP, Ford GT, Whitelaw WA (1995). Interaction between postural and respiratory control of human intercostal muscles. Journal of Applied Physiology, 79(5): 1556-1561.

Shumway-Cook A, Woollacott M (2000). Attentional demands and postural control: the effect of sensory context.. Journal of Gerontology, 55(1): M10-6.

Winter DA, Patla AE, Prince F, Ishac M and Gielo-Perczark K (1998). Stiffness control of balance in quiet standing. Journal of Neurophysiology, 80:1211-1221.

Yardley L., Gardner M., Leadbetter A. and Lavie N (1999). Effect of articulation and mental tasks on postural control. Neuroreport, 10(2): 215-219.

Yates BJ and Miller AD (1998). Physiological evidence that the vestibular system participates in autonomic and respiratory control. Journal of vestibular research, 8(1): 17-25.

Table 4.1: Postural sway measures for each standing surface with or without vision.

Standing surface	Vision	Sway Path (mm)	AP RMS (mm)	AP MPF (Hz)	ML RMS (mm)	ML MPF (Hz)
Stable	YES	507.70 ±112.64	3.92±1.44	0.23±0.08	1.76±0.68	0.32±0.13
	NO	570.71± 140.19	4.36±1.47	0.23±0.12	8.07±2.35	0.22±0.09
Unstable	YES	1260.77± 371.64	9.36±3.10	0.23±0.08	1.83±0.87	0.33±0.15
	NO	2829.86±1011.41	12.93±3.62	0.41±0.12	11.94±3.25	0.29±0.10

Figure 4.1: Digital photograph of the motor task. Participants were instructed to bite in the plastic tubing to simulate the movement of the jaw when articulating.

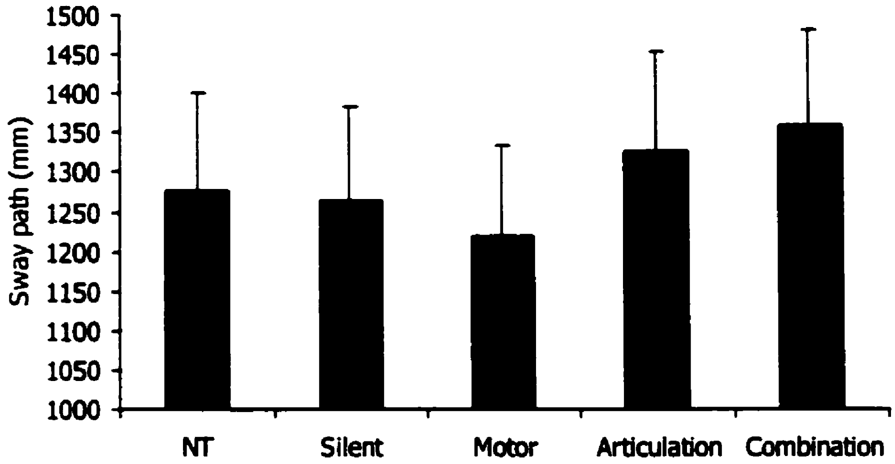

Figure 4.2: Mean and standard error values for sway path for each secondary task.

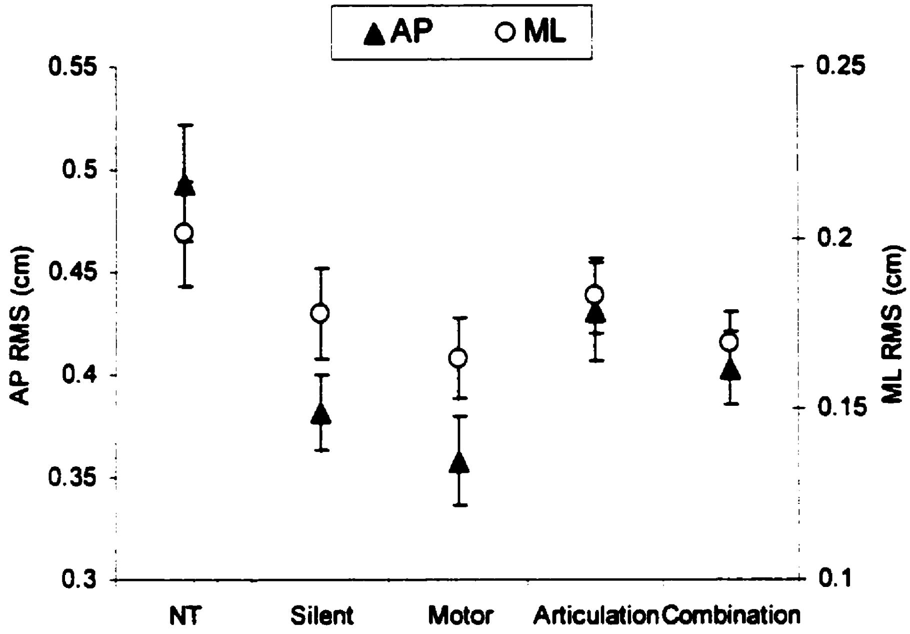

Figure 4.3: Mean and standard error values for RMS in AP and ML direction for each secondary task for eyes open and eyes closed combined when standing on the stable surface.

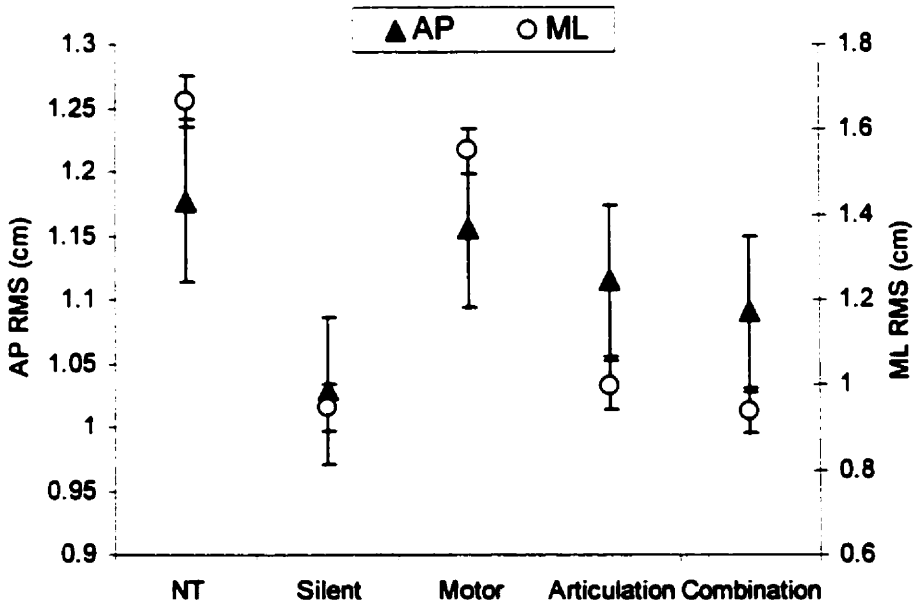

Figure 4.4: Mean and standard error values for RMS in AP and ML direction for each secondary task for eyes open and eyes closed combined when standing on the unstable surface.

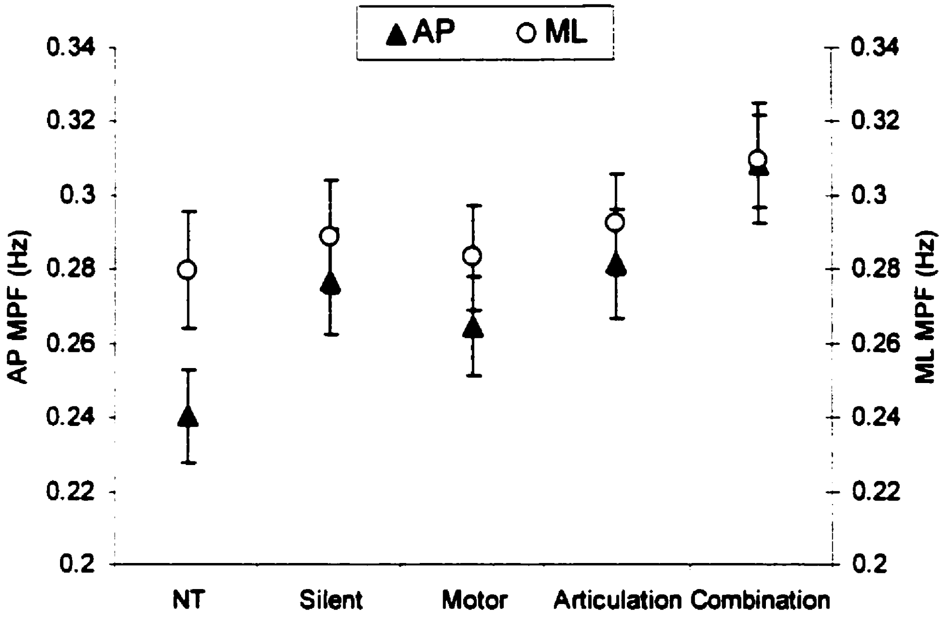

Figure 4.5: Mean and standard error values for MPF in AP and ML direction for each secondary task for eyes open and eyes closed combined and for stable and unstable standing surface combined.

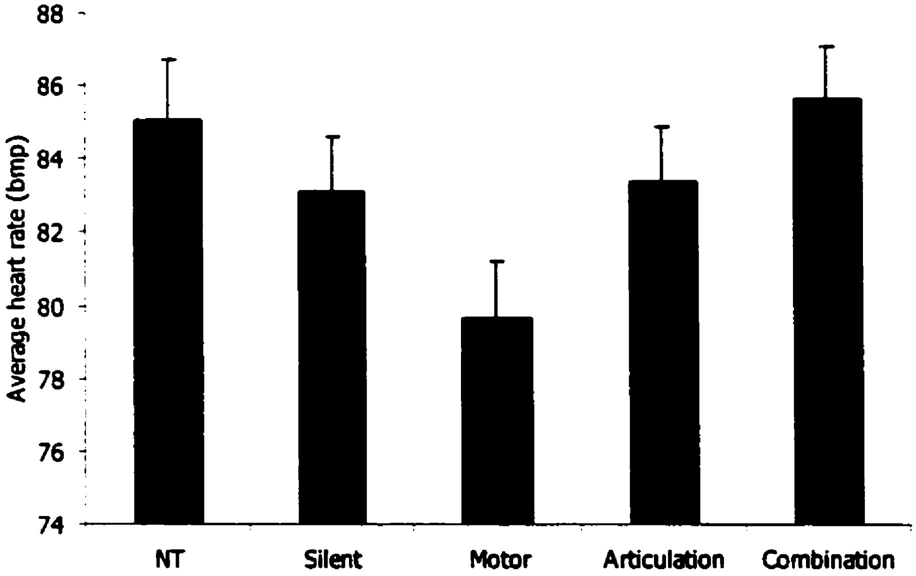

Figure 4.6: Mean and standard error values for average heart rate for each secondary task for eyes open and eyes closed combined and for all postural tasks combined.

CHAPTER 5

DOES EXECUTING A COGNITIVE TASK INCREASE ANKLE STIFFNESS WHILE STANDING?

Mylène C. Dault and James S. Frank

ABSTRACT

Many studies have suggested that increased frequency and decreased amplitude of centre of pressure (COP) displacement demonstrates increased ankle stiffness. In this study, it was investigated whether or not the changes seen in postural sway with the addition of a cognitive task were related to increased ankle stiffness. COP and centre of mass (COM) displacements were recorded and stiffness was calculated using a model proposed by Winter et al. (2001). Results showed that when young individuals were asked to perform a cognitive task, they significantly increased the frequency of COP and COM and decreased the amplitude of COP and COM. Results also indicated that ankle stiffness significantly increased by 5.63% in AP direction. It is hypothesized that by increasing stiffness during quiet standing, the operational demands on the higher centres of the CNS are reduced hence young individuals are able to perform a cognitive without any difficulty.

INTRODUCTION

In recent years, researchers have attempted to understand how tasks involving cognitive processes influence postural control and if postural control requires some degree of attention. Many studies have used dual-task paradigms in which participants are asked to perform a cognitive task while standing on a force platform. These studies have found either an increase (Shumway-Cook et al., 1997; Shumway-Cook and Woollacott, 2000) or a decrease in centre of pressure (COP) displacement (Dault et al., 2001; Hunter and Hoffman, 2001; Vuillerme et al., 2000) with the addition of a secondary task; other studies have not found any changes in postural control but a decline in the performance of the secondary task when comparing a seated to a standing posture or to walking (Lajoie et al., 1996; Teasdale et al., 1993). Dault et al. (2001) observed that independent of the type of task, participants modified postural control by increasing the frequency and decreasing the amplitude of COP displacements. If postural control is controlled as an inverted pendulum, these observations suggest an increased stiffness at the ankle joint (Carpenter et al., 2001).

All studies investigating postural control modifications with the addition of a secondary task have focused mainly on changes in COP displacements. COP measures provide information about the distribution of forces under the feet, which can change under different situations. COP is often used to illustrate how balance is maintained because the CNS is able to control centre of mass (COM) by modifying the net motor pattern at the ankle joint, which is reflected by displacement of the COP (Winter et al., 1990). Body sway refers to displacement of the body COM; COM provides information about how the whole body is controlled taking into account the weighted average of the COM of each body segment (Winter, 1995). The COM projection to the ground (often called the centre of gravity) is maintained within the base of support by displacement of the COP under the feet. If the body is controlled as an inverted pendulum, the slope of the linear regression between COM angular displacement versus ankle moment, determined by position of the COP and vertical ground reaction forces, provides information about ankle stiffness (Fitzpatrick et al., 1992; Winter et al., 2001). According to Winter et al. (1998), the CNS controls the body COM by setting the appropriate muscle tone which will determine the joint stiffness needed to maintain upright stance in a particular situation.

Dault et al.(2001) hypothesized that the changes seen in postural sway with the addition of a secondary task, i.e. increased frequency and decreased amplitude, demonstrated a tighter control of posture possibly achieved by increased ankle stiffness. However, this hypothesis was inferred from COP measures only. A similar hypothesis was suggested by Carpenter et al. (1999) when they examined the effects of fear on postural control. When placed at a higher surface height, participants demonstrated a larger frequency and a decreased amplitude of sway; these modifications in COP displacements were associated with an increased ankle stiffness and muscle activation involved in postural control (Carpenter et al., 2001; Winter at al., 1998). Therefore, the trade-off between frequency and amplitude of sway seems to be related to modifications in ankle stiffness. Fitzpatrick et al. (1992) also demonstrated that ankle stiffness can be voluntarily increased by asking participants to consciously stand as still as possible.

This goal of this study was to examine if the same changes found in COP measures with the addition of a secondary task seen in previous studies also occurred in COM measures (Dault et al., 2001). If posture is controlled as an inverted pendulum, it is important to determine if a change in ankle stiffness also occurs with the addition of a secondary task.

METHODOLOGY

Participants

Twelve university students (mean age=22.0 ± 1.5 years old) voluntarily participated in this study. All procedures were approved by the Office of Human Research, University of Waterloo. Informed consent was obtained from each participant.

Postural measurements

Participants were fitted with 21 infrared emitting diodes (IREDs) at strategic locations on 14 body segments in order to estimate total body centre of mass (COM) (Winter et al.,1998). COM was calculated by taking a weighted average of the COM of each of the 14 segments (see Equation 1)

Equation 1
$$COM(x) = \frac{1}{M}\sum_{i=1}^{14} COM_i(x)\cdot m_i$$

where M is the total body mass, m_i is the mass of the *i*th segment, and $COM_i(x)$ is x coordinate of the *i*th segment.

These IREDs were tracked by a 3D OPTOTRACK imaging system. Participants were asked to stand on an AMTI force platform in order to monitor centre of pressure (COP) displacements. Data from the motion analysis system and from the force platform was sampled at a frequency of 20 Hz and filtered with a dual pass Butterworth filter with a 5 Hz cutoff frequency. Mean position (MPOS) of the COP and COM were recorded in the anterior-posterior (AP) and medio-lateral (ML) direction. Root mean square (RMS) of the COP and COM displacement with bias removed and mean power frequency (MPF) of the COP and COM displacement over 60 s were calculated in the AP and ML direction.

RMS values provide information on the amplitude variability of COP and COM displacement about the mean position (bias) of the COP and COM. MPF was calculated by performing a Fast Fourier Transformation of the COP and COM signals and is an estimate of the average frequency contained within the power spectrum. MPF values provide information on the frequency of the sway control. The stiffness constant was calculated using the direct method proposed by Winter et al. (2001) (see Equation 2).

Equation 2

$$\begin{aligned} M_a &= R \cdot COP = mg \cdot COP \\ \theta_{sw} &= \frac{COM}{h} \\ Stiffness &= K_a = \frac{dM_a}{d\theta_{sw}} \end{aligned}$$

where M_a represents the sum of the left and right ankle moments ,which are calculated by taking into account the body weight (mg) and the vertical reaction force (R). θ_{sw} is the sway angle, which is calculated by taking the COM divided by the height of COM above the ankle joint (see Figure 5.1). The stiffness constant (K_a) is determined by calculating the slope of the linear regression between M_a and θ_{sw} (Winter et al., 2001). This calculation was done for each 15 s bin of the 60 s trial to examine whether level of stiffness varied throughout the trial.

Secondary task

Participants were asked to stand while performing no additional task (NT) and while performing a visuo-spatial task (task). The visuo-spatial task was a modified version of the Manikin test in which participants named in which hand a manikin was holding a black or white circle by saying "left" or "right" (Benson and Gedye, 1963). The manikin was shown on a 19 inch computer monitor placed at eye level in front of the participant. The manikins were displayed in 4 different positions: upright, inverted or lying on their side (Dault et al., 2001). The speed of presentation was determined by the participants; when the answer was given by the participant, the next manikin appeared. Participants were instructed to respond to as many manikins as possible without making any errors during the 60 s trial. Number of items classified and errors were recorded.

Procedures

Participants were asked to perform the secondary task at the beginning of the session to ensure that they understood the requirements of task. Participants then were asked to stand for 60 s periods with or without performing the secondary task. Each condition was repeated 4 times. An average of the 4 trials was used in the statistical analysis. Participants were required to stand at the front edge of the force platform with their preferred stance. A tracing of their feet was taken prior to the first trial to ensure consistency in stance width between trials. During the NT trials, participants were asked to fixate a middle point in the computer monitor. Therefore, the point of visual focus remained the same for all tasks.

Statistical analysis

A one-way repeated measures ANOVA (task) was conducted for the COP and COM measures to determine the effect of task. A two-way repeated measures ANOVA (task x bin) was conducted for the stiffness constant to determine the effects of task and if stiffness varied between the 4 segments of 15 s. in order to examine stability throughout the trial.

RESULTS

Centre of pressure and centre of mass

The addition of the secondary task significantly influenced the COP and COM measurements. A significant main effect of task was found for AP RMS of COM (F(1,11)= 9.47;$p<0.01$) revealing a decreased (24.33%) amplitude of sway with the addition of the secondary task (see Figure 5.2). Changes found in AP RMS of COP were almost significant (F(1,11)=3.97;$p=0.072$) (decrease of 14.88%) (see Figure 5.2). A significant main effect of task was also found for AP MPF of COM (F(1,11)=31.91; $p<0.001$) and AP MPF of COP (F(1,11)=51.60;$p<0.0001$) (see Figure 5.3). MPF was also significantly modified with the addition of the secondary task in ML direction for COM (F(1,11)=10.57;$p<0.01$) and for COP (F(1,11)=20.78;$p<0.001$) (see Figure 5.4). Results revealed a significant increase in frequency of sway in both AP (COM = 57.93%; COP = 76.67%) and ML directions (COM = 23.81%; COP = 37.83%). Figure 5.5 illustrates an example of these modifications. No significant changes were found for MPOS in AP and ML directions.

Stiffness constant

Results revealed a significant main effect of task in AP direction (F(1,11)=4.63;$p<0.05$). The stiffness constant was increased by 5.63% with the addition of the secondary task. This increase in stiffness was the same for all 15 s. segments (see Figure 5.6). No significant changes were found in ML direction.

DISCUSSION

The goal of this study was to verify that the increased frequency and decreased amplitude of COP displacement observed in previous dual-task studies could be interpreted as an increased ankle stiffness (Dault et al., 2001). This was achieved by measuring displacements of the COP and COM in two separate conditions, no task and while performing a visuo-spatial task. Stiffness of the ankle joint was then calculated by using a direct method proposed by Winter et al. (2001).

Results from the COP measurements demonstrated the same results as shown in Dault et al. (2001). Frequency was increased and amplitude of COP displacement was almost significantly decreased in AP direction. Similar results were also found in COM measurements. Frequency was increased and amplitude of COM displacement was decreased in AP direction. Because the COP tracks the COM movement in order to maintain postural stability and because both COP and COM demonstrated increased frequency and decreased amplitude of displacement, we can deduce an increased stiffness. Results from the direct calculation of stiffness supported this hypothesis; stiffness was significantly increased in the AP direction by 5.63% with the addition of the secondary task. The regression between the sway angle and the estimated ankle moment was 0.91 in AP direction and 0.80 in ML direction. This indicates that the estimate of stiffness (regression) resembled a pure spring as the regression was close to 1 which reflects a perfectly linear relation.

These results imply that when individuals are asked to perform a task other than simply standing, they become stiffer in the AP direction. Dault et al. (2001) examined the difference between standing in a shoulder width stance and a tandem stance when executing a variety of secondary tasks. They found that participants increased the frequency and reduced the amplitude of COP displacement in the plane in which the stance was least stable, i.e. AP direction for the shoulder width stance and ML direction for the tandem stance. Hunter and Hoffman (2001) found similar results , in which amplitude of COP displacement was reduced in the ML direction when participants stood in a tandem stance while performing a secondary task. Therefore, it is not surprising to see that the change in stiffness in the present study is in the AP direction, because balance during a shoulder width stance is under the control of ankle plantar and dorsiflexors (Winter, 1995).

Changes found in postural sway cannot be attributed to changes in the visual focus or visual interference with the visuo-spatial task for two main reasons: 1) distance from the force platform to the visual focus point remained the same for all conditions, i.e. participants were asked to focus on a point on the monitor; 2) other studies using secondary tasks that do not require visual processing produced the same changes as seen in this study (Dault et al., 2001; Hunter and Hoffman, 2001).

The modifications in control of posture could, however, be related to changes in concentration (Hunter and Hoffman, 2001; Riley et al., 1999). This hypothesis suggests that postural sway is modified according to what participants are told to focus on (Riley et al., 1999). When standing quietly, partcipants may give more attention to postural control and when performing a secondary task, less attention is given to postural control and more is given to the performance of the task itself. Therefore, by adopting a tighter mode of control, the central nervous system is able to provide more attentional resources to the execution of the secondary task. Loram et al. (2001) recently showed that by asking participants, who were attached to pendulum apparatus, to concentrate or use visual feedback to stand as still as possible, sway size was reduced but was not accompanied by an increased frequency of sway or a change in ankle stiffness. The authors suggest that the reduction in sway size did not result from a change in ankle stiffness or viscosity but was a result of a reduction in torque noise relating to predictive processes that provide damping. Since the study examined the ankle stiffness while participants balanced on a pendulum, the control mechanisms might be different for upright standing.

On the other hand, standing while performing a secondary task may be more "natural" than standing while doing nothing else (Vuillerme et al., 2000). Rarely in real life situations do we ever stand without thinking about something else or without engaging in a discussion. Vuillerme et al. (2000) argued that deliberately controlling posture during the no task condition is less efficient than diverting attention to another task and allowing posture to be controlled at an automatic level.

One question still remains: is less sway better than more sway? Is being stiffer really a good strategy to maintain balance in spite of it being more energy demanding? Is it better to have more sway and a looser control when a perturbation occurs? Loeb and Ghez (2000) explain that if co-contraction is used to maintain balance before a perturbation occurs, the CNS can take advantage of the force-velocity and force-length relationships to respond to a perturbation. Because the muscles surrounding the ankle joint are already activated the forces to counteract the perturbation are larger and instability can be reduced. Therefore, increasing stiffness while performing a secondary task can result in a fast and efficient way to prevent falls if a perturbation should occur. Brown et al. (1999) examined the changes in the recovery strategy following a perturbation when a secondary task is performed. Young adults employed an equal number of in place and stepping responses for both the no task and dual-task condition. However, both young and older adults, when choosing a step response, allowed less displacement of COM during the dual-task compared to the no task condition (Brown et al., 1999). Although COM moved less, time to initiate step did not change from NT to dual-task conditions suggesting that participants were stiffer prior to the perturbation in the dual-task condition. Fitzpatrick et al. (1992) found that when participants significantly increased their stiffness by concentrating on standing as still as possible, EMG activity of the soleus muscle rose faster and had increased activity following a light undetectable pull than when participants were just instructed to stand quietly. This suggests that increased stiffness may be helpful when one is faced with a perturbation.

CONCLUSION

In conclusion, postural control was modified with the execution of a secondary task, indicating that postural control is influenced by changes in cognitive demands.

Increased stiffness in the AP direction was observed when participants were performing the secondary task. It has not yet been established if increased stiffness is a beneficial strategy for controlling posture and if this strategy enables individuals to respond better to a perturbation. Therefore, more research is needed to determine if elderly and pathological populations also adopt a stiffer mode of control when attentional demands are increased.

ACKNOWLEDGEMENT

This research was funded by FCAR and Fondation Baxter et Alma Ricard scholarships to Mylène C. Dault and NSERC grant to James S. Frank.

REFERENCES

Benson AJ. and Gedye JL (1963). Logical processes in the resolution of orientational conflict. RAF Institute of Aviation Medicine Report 259, Farnborough, UK.

Brown LA, Shumway-Cook, A and Woollacott, MH (1999). Attentional demands and postural recovery: The effects of aging. Journal of Gerontology, 54A(4):M165-M171.

Carpenter MG, Frank FS, Silcher CP and Peysar GW (2001). The influence of postural threat on the control of upright stance. Experimental Brain Research.

Carpenter MG, Frank JS and Silcher CP (1999). Surface height effects on postural control: A hypothesis for a stiffness strategy for stance. Journal of Vestibular Research, 9(4): 277-86.

Dault MC, Frank JS and Allard F (2001) Influence of a visuo-spatial and verbal working memory task on postural control. Gait & Posture. 14(2):110-116.

Fitzpatrick RC, Taylor JL and McCloskey DI (1992). Ankle stiffness of standing humans in response to imperceptible perturbation: Reflex and task-dependent components. Journal of Physiology, 454, 533-547.

Hunter MC and Hoffman MA (2001) Postural control: visual and cognitive manipulations. Gait & Posture, 13, 41-48.

Lajoie, Y, Teasdale, N, Bard, C and Fleury, M (1996). Upright standing and gait: Are there changes in attentional requirements related to normal aging? Experimental Aging Research, 22: 185-198.

Loeb GE and Ghez C (2000). The motor unit and muscle action. In Kandel ER, Schwartz JH and Jessell TM (eds). Principles on Neural Science. 4th edition, Chapter 34, New York: McGraw-Hill, pp.674-694.

Loram ID, Kelly SM and Lakie M (2001). Human balancing of an inverted pendulum: is sway size controlled by ankle impedance? Journal of Physiology 532.3:879-891.

Riley MA, Stoffregen TA, Grocki MJ, Turvey MT (1999). Postural stabilization for the control of touching. Human Movement Science 18, 795-817.

Shumway-Cook A, Woollacott M, Kerns A and Baldwin M (1997). The effects of two types of WM tasks on postural stability in older adults with and without a history of falls. Journal of Gerontology, 52 (4): M232-M240.

Shumway-Cook, A, Woollacott, M (2000). Attentional demands and postural control: the effect of sensory context. Journal of Gerontology 55(1): M10-6.

Teasdale N, Bard C, LaRue J and Fleury M (1993). On the cognitive penetrability of posture control. Experimental Aging Research. 19: 1-13.

Vuillerme N, Nougier V and Teasdale N (2000). Effects of a reaction time task on postural control in humans. Neuroscience Letters 291:77-80.

Winter DA, Patla AE and Frank JS (1990). Assessment of balance control in humans. Medical Progress through Technology, 16:31-51.

Winter DA, Patla AE, Rietdyk S and Ishac MG (2001). Ankle muscle stiffness in the control of balance during quiet standing. Journal of Neurophysiology 85:2630-2633.

Winter DA. (1995) A.B.C. of balance during standing and walking. Waterloo, ON: Waterloo Biomechanics.

Winter DA., Patla AE, Prince F, Ishac M and Gielo-Perczak K (1998). Stiffness Control of Balance in Quiet Standing. Journal of Neurophysiology 80:1211-1221.

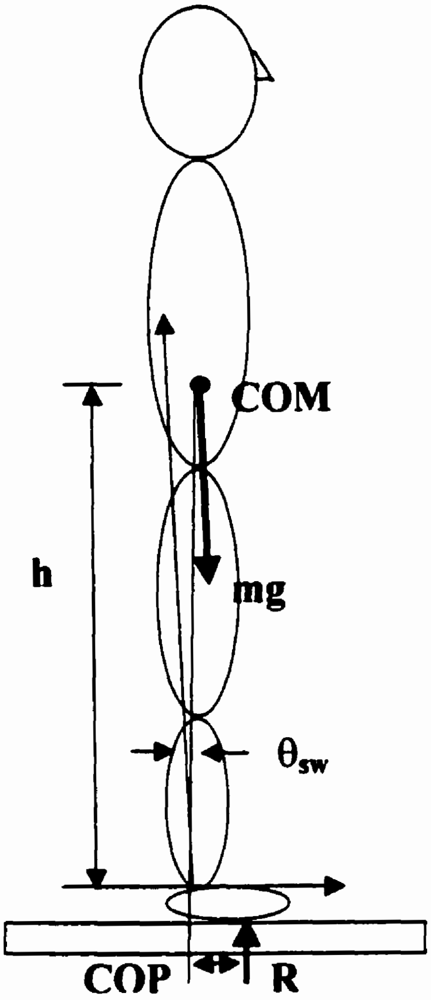

Figure 5.1. Inverted pendulum model (adapted from Winter et al. 2001). COM= center of mass; COP=center of pressure; mg= body weight; h= height of COM above the ankle joint. These variables are used in the equation to estimate muscle stiffness.

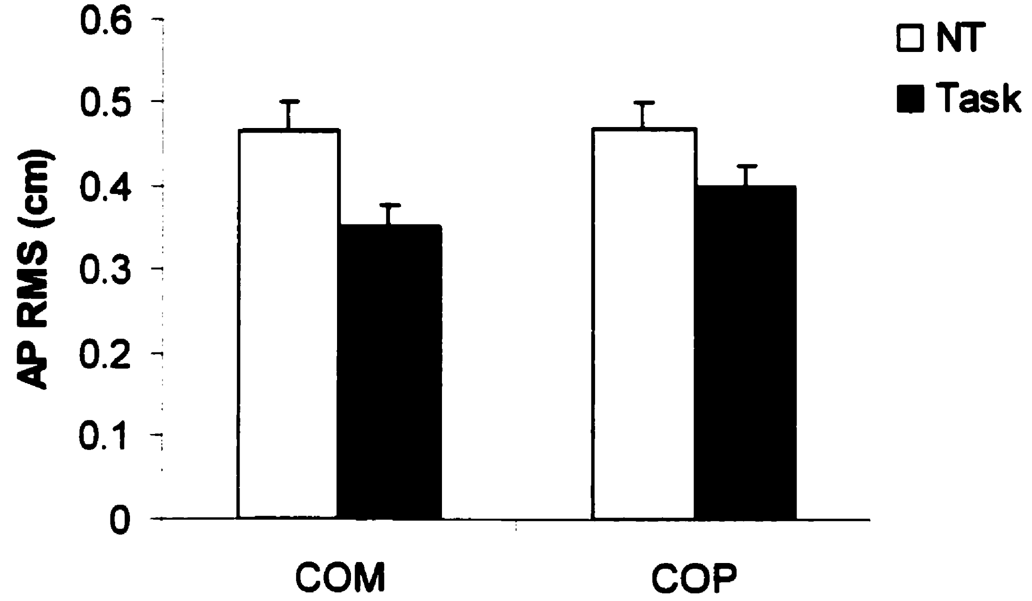

Figure 5.2 Means and standard errors of the RMS in AP direction for the COM and COP during the no task and secondary task conditions.

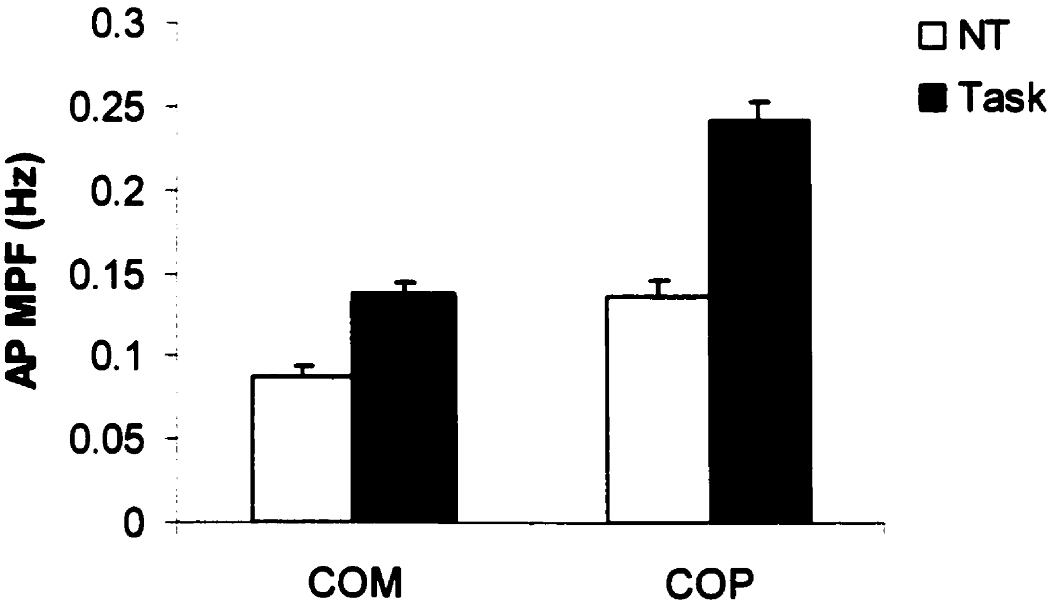

Figure 5.3 Means and standard errors of the MPF in AP direction for the COM and COP during the no task and secondary task conditions.

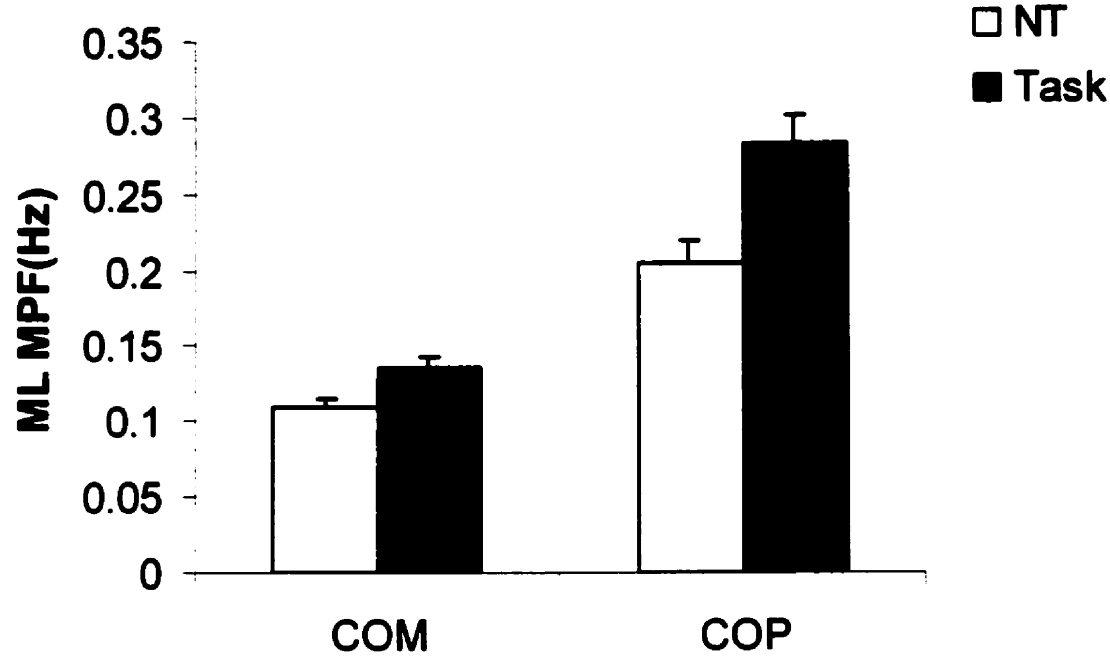

Figure 5.4 Means and standard errors of the MPF in ML direction for the COM and COP during the no task and secondary task conditions.

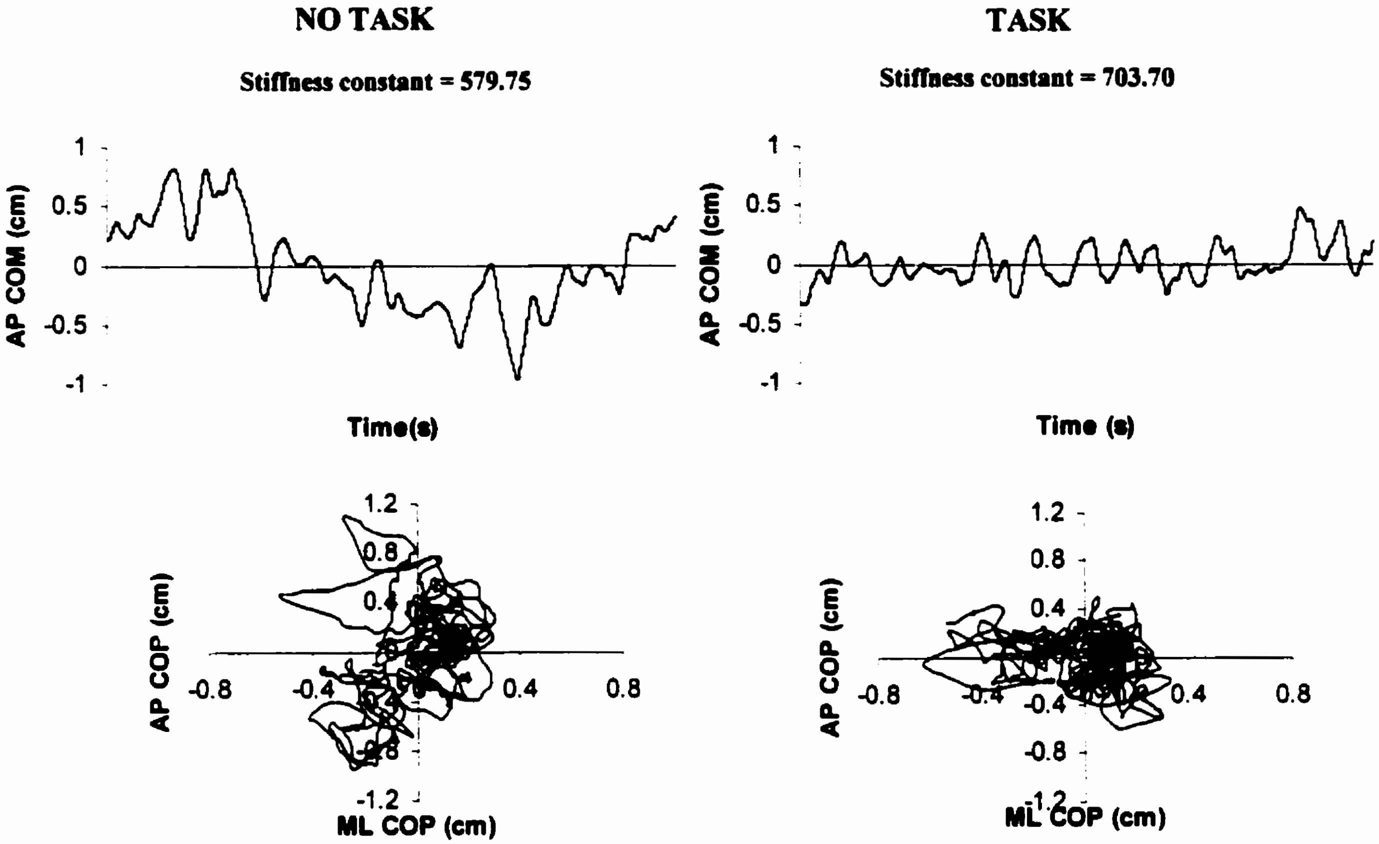

Figure 5.5 Representative data from one participant for a 60 s trial during the no task condition and during the secondary task condition.

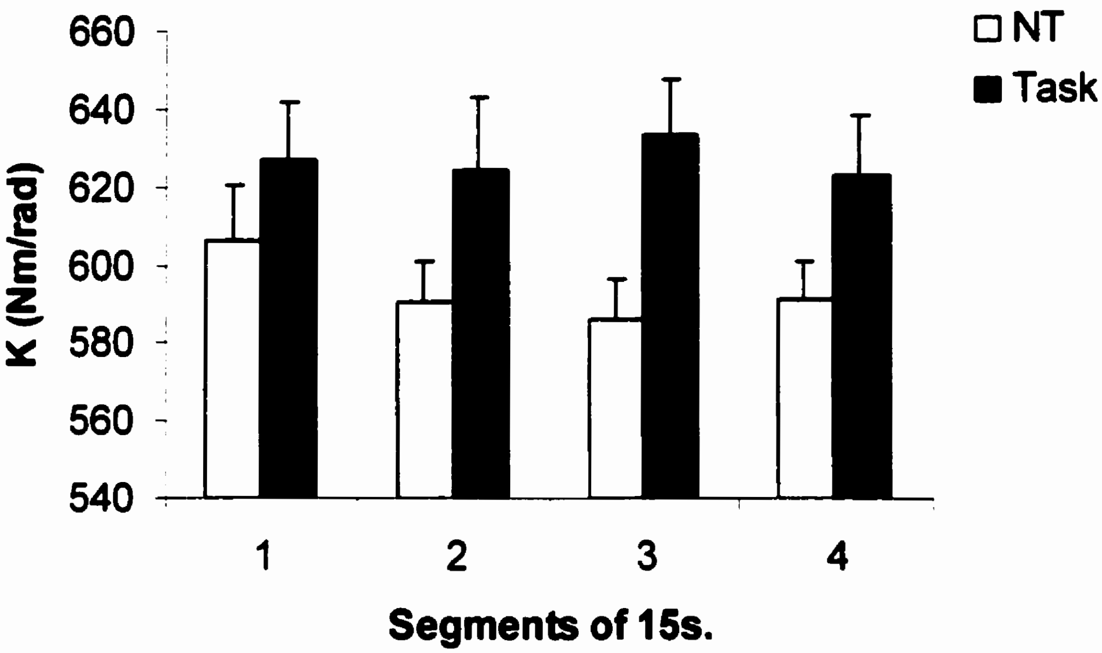

Figure 5.6 Means and standard errors of the stiffness constant (K) for every 15s segment of the 60 s. trials for the no task and secondary task conditions.

CHAPTER 6

DOES PRACTICE MODIFY THE INTERACTION BETWEEN POSTURAL CONTROL AND THE EXECUTION OF A COGNITIVE TASK IN YOUNG AND ELDERLY INDIVIDUALS?

Mylène C. Dault and James S. Frank

ABSTRACT

The goal of this study was to examine if practice could modify the changes seen in postural sway when individuals are asked to perform a cognitive task while maintaining upright stance. Young and elderly individuals were asked to stand on a force platform while performing a cognitive task or no task. The cognitive task condition was repeated 6 times to examine the effects of practice. The number of responses given to the cognitive task was significantly increased from the first to sixth trial indicating a practice effect of the cognitive task. In young participants, amplitude of sway was decreased and frequency of sway was increased indicating an increased stiffness when performing the cognitive task. Elderly participants showed increased amplitude of sway and increased frequency of sway in the medio-lateral direction only. Postural control modifications with the addition of the cognitive task did not change with increased practice. The influence of cognitive processing on postural control is not affected by the characteristics of the cognitive task but may be dependent on the integrity of the CNS.

INTRODUCTION

Many daily activities require performing more than one task simultaneously, such as standing while engaging in a conversion. By using dual-task paradigms researchers have examined the interaction between postural control and cognitive processes. When engaging in this type of protocol, participants are asked to perform a cognitive task while maintaining upright stance. The main goal of dual-task paradigms is to evaluate how two tasks can share the same capacity and how their performance is affected (Pashler, 1994). When participants are asked to perform more than one task at once, less capacity is available and performance of one or of both tasks is impaired (Pashler, 1994). The cognitive tasks used in the previous dual-task studies in postural control are often novel to the participants. Novel tasks require more attention therefore may cause greater interference if performed with another task. The more automatic the task becomes the less attention is required to perform it (Magill, 1993; Wickens, 1989; Abernethy, 1988). Research in motor learning has shown that when executing a primary task that is well learned thus, requires less attentional resources. For example when asking University level hockey players to ice skate at the same time as performing a cognitive secondary task, no interference occurs with the primary task indicating that attentional capacity is not exceeded. However, when novice players are asked to perform a secondary task, execution of the primary task is greatly affected since the level of attention needed to perform both tasks may exceed the attentional capacity (Magill, 1993).

Many researchers have argued that the dual-task effects found in postural control are due to increased attentional loading caused by the performance of the cognitive task. Most studies have only repeated the dual-task condition between 1 and 3 times (Teasdale et al., 1993; Shumway-Cook and Woollacott, 2000, Maylor and Wing, 1996; Dault et al., 2001). Hence, the changes observed in dual-task paradigms may be due to the novelty of the situation and could consequently diminish with practice. Because practice is known to result in decreased attentional demand of a given task (Wickens, 1989; Magill, 1993; Pashler et al., 2001) and that repeated testing is related to decreased arousal and anxiety (Maki and Whitelaw, 1993), could practice of a dual-task condition also result in modifications of the interaction between postural control and a secondary task?

Dual-task studies in postural control have showed that postural sway is either increased (Andersson et al.,1998; Shumway-Cook et al., 1997; Shumway-Cook and Woollacott, 2000) or decreased (Dault et al., 2001; Fearing, 1925; Hunter and Hoffman, 2001; Kerr et al., 1985) with the addition of a secondary task. Other studies have shown that postural sway is not affected but performance of the secondary task is decreased when comparing various postures (Redfern and Jennings, 1998; Teasdale et al., 1993;). Geurts and Mulder (1994) found that individuals who were just starting the rehabilitation process following an amputation of the lower limb showed increased postural sway with the addition of a secondary task. At the end of the rehabilitation process this interference had almost disappeared, indicating that the novelty of the situation may play a role and that practice could possibly minimize this interference. Mulder et al. (1993) also found that when asking elderly individuals to walk while wearing scuba diving flippers and performing a mathematical task, interference caused by these concurrent novel tasks was similar to that seen in individuals with a recent amputation, once again suggesting that novelty may be part of the equation.

Dual-task interference seems to be more pronounced in older adults (March and Geel, 2000; Maylor and Wing, 1996; Teasdale et al.,1993; Shumway-Cook and Woollacott, 2000). This is not surprising, because with aging the ability of dual-tasking is reduced (Groth and Allen, 2000; Salthouse et al., 1991; Vanneste and Pouthas, 1999; Wright, 1981;). Elderly individuals often show reaction times (RT) that are higher than young people and these increased RT are more pronounced when participants are asked to stand when proprioceptive or visual information is modified as compared to when sitting (Teasdale et al., 1993; Shumway-Cook and Woollacott, 2000). Maylor and Wing (1996) found that age differences in postural sway between young and old people become more apparent when participants are asked to perform a task requiring the involvement of the visuo-spatial sketchpad from Baddeley's working memory model (Baddeley, 1986). This might suggest that elderly individuals are not able to share attentional resources and adapt to increased attentional demands as quickly as young individuals. It is also thought that imbalance and falls that occur in the elderly could be related to the inability to allocate sufficient attention to postural control when they are asked to perform more than one task at once (Shumway-Cook and Woolacott, 2000). A recent study has shown that, with practice, individuals can become better at time sharing in dual-task situations (Schumacher et al., 2001). Thus, with practice elderly individuals might learn to cope with dual-task situations, which may result in a reduced interference between postural control and the execution of a secondary task.

The goal of this study was to determine if novelty could explain the changes seen in previous studies and if practice can affect the relationship between postural control and cognitive processing. Also, we wanted to examine if elderly individuals would benefit more than the young from the repetition of the dual-task condition.

METHODOLOGY

Participants

Fifteen university students (mean age=22.0 ± 1.5 years old) and fifteen older adults (mean age= 79.1 ± 4.9 years old) from a retirement home participated in this study. All procedures were approved by the Office of Human Research, University of Waterloo.

For the elderly group, cognitive function was assessed by using the Mini-Mental State Examination (MMSE) to ensure that all participants were able to follow the instructions (Folstein et al., 1975). Average score for the MMSE was of 28/30 ± 1.6. A medical history questionnaire was completed by the elderly participants at the beginning of the testing session to assess the presence of any neurological disease or orthopaedic problems that could affect postural control. Occurrence of falls in the past year was recorded. The "Timed Get Up and Go"(TUG) was conducted at the beginning of the testing session to determine if the elderly participants showed susceptibility to falls, as as the TUG is a good indicator of this susceptibility (Podsiadlo and Richardson, 1991; Shumway-Cook et al., 2000). Results indicated an average of 13.58 ± 5.03 seconds. Shumway-Cook et al. (2000) reported that non-fallers were able to perform the TUG in 8.4±1.7 seconds and fallers performed it in 22.2±9.3 seconds. Podsiadlo and Richardson (1991) report that patients who performed the test in less than 20 seconds tended to be more independent, had reasonable balance and functional gait speed. Therefore, according to the TUG time, elderly participants in this study did not show a large susceptibility to falling.

Postural task

Participants were required to stand on a force plate while either performing no task (NT) or a secondary task. When standing, participants were asked to align their toes to the front edge of the force plate with their preferred stance width. A trace of their feet was taken before the first trial to ensure that participants always placed their feet at the same place for every trial. Participants were instructed to stand quietly with arms at their side.

Centre of pressure (COP) displacement was obtained from force and moment of force measures using an AMTI force plate. Data was sampled at a frequency of 20 Hz and filtered with a dual pass Butterworth filter with a 5 Hz cutoff frequency. Root mean square (RMS) of the COP displacement with bias removed and mean power frequency (MPF) of the COP displacement over 60 s. were calculated in the AP and ML directions. RMS values provide information on the amplitude variability of COP displacement about the mean position (bias) of the COP. MPF values provide information on the frequency of sway control.

Secondary task

The secondary task was a modified version of the Manikin test in which participants named in which hand a manikin was holding a black or white circle by saying "left" or "right" (Benson and Gedye, 1963). Manikins were displayed in 4 different positions: upright, inverted or lying on their side (Dault et al., 2001). Manikins were shown on a 19 inch computer monitor placed at eye level in front of the participant.

The monitor was placed 150 cm from the participants when they were standing on the force plate and 200 cm from them when they were seated. The monitor was connected to a portable computer that generated the presentation of slides.

The speed of presentation was determined by the participants; when the answer was given by the participant the next manikin appeared. Participants were instructed to respond to as many manikins as possible without making any errors during the 60 s trial. Number of responses given and errors were recorded. Percentage of success was calculated by taking into account the number of correct responses over the total number of responses and converting it to a percentage.

Procedures

The conditions were presented in the same order to investigate the effect of practice. The testing session started and ended with the performance of the secondary task in a seated position. The participants were asked to perform 3 blocks of 3 standing trials. Each block consisted of one NT trial followed by two dual-task trials. Therefore, a total of 9 standing trials were performed. A rest period was provided after each trial to prevent fatigue. The repetition of the dual-task condition allowed us to evaluate learning and the repetition of the NT allowed us to monitor fatigue. During the NT trials, participants were asked to fixate a middle point in the computer monitor. Therefore, the point of visual focus remained the same for all tasks.

Statistical analysis

The postural control measures were subjected to a logarithm transformation in order to ensure a normal distribution. A repeated measures ANOVA (group x task) using the mean of all trials, was conducted on the postural sway measurements to establish the difference between groups when a secondary task is added. The goal of this study was to examine the effect of practice of the secondary task condition, therefore a repeated measures ANOVA (group x trial) was conducted for the dual-task condition only.

Performance of the secondary task (% of correct responses and number of responses) was analysed by conducting a repeated measures ANOVA for group using the means of all trials to look at the difference in performance between the groups. The effects of repetition on the performance of the secondary task were examined by using a linear contrast analysis on the secondary task condition only, to examine if the changes found with practice occurred in a linear fashion.

RESULTS

Postural sway modifications with the addition of the secondary task

A significant main effect of group was found for AP MPF ($F(1,28)=18.95$; $p<0.001$) and for AP RMS ($F(1,28)=11.88$; $p<0.01$). A significant main effect of task was found for AP MPF ($F(1,27)=15.86$; $p<0.001$) and for ML MPF ($F(1,27)=5.84$; $p<0.05$). A significant interaction between group and task was found for AP MPF($F(1,27)=22.33$; $p<0.0001$), AP RMS ($F(1,27) = 6.98$; $p<0.01$), and ML RMS

($F(1,27)=4.66$; $p<0.05$) . As shown in Figures 6.1 and 6.2, results revealed that the elderly group did not modify frequency and amplitude of sway in the AP direction with the addition of the secondary task whereas the young group significantly increased AP frequency and significantly reduced AP amplitude of sway. Elderly participants demonstrated a significantly higher frequency of sway and significantly lower amplitude of sway for the NT condition in the AP direction when compared to the young group. In the ML direction, both groups significantly increased the frequency of sway with the addition of the task (see Figure 6.3). For ML RMS, the significant interaction was shown by a significant increased amplitude of sway for the elderly group whereas the young group showed a trend towards decreased amplitude with the addition of the secondary task, as shown in Figure 6.4.

Postural sway modifications with repetition of the secondary task

No significant changes were found in postural sway in either group with the repetition of the secondary task. Figures 6.5 and 6.6 illustrate the lack of significant change between trials of the secondary task condition.

Performance of the secondary task

A significant group effect was found for the number of responses given ($F(1,28)=148.11$;$p<0.0001$) and for the percentage of success ($F(1,28)=7.35$;$p<0.01$). The elderly group was only able to answer an average of 16.25±4.99 manikins where as the young group answered to 34.30±6.27 manikins. The elderly group had an 87.44% success rate whereas the young group demonstrated a mean performance of 94.76%.

Performance of the secondary task across trials

A significant linear trend was found for number of responses given for the young group (F(7,91)=435.56; p<0.0001) and for the elderly group (F(7,91)=169.20; p<0.0001). As the repetition of the secondary task increased, the number of responses given also increased (see Figure 6.7). In the elderly group, participants increased an average of 7 responses from the first to the last trial. In the young group, participants increased an average of 17 responses. No significant change across trials was found for the percentage of success. This indicates that even though number of responses increased, participants kept the same success rate.

DISCUSSION

The goal of this study was to examine the interaction between postural control and attention by using a dual-task paradigm and to determine if practice can affect this relationship in young and elderly individuals. Participants were asked to either perform no task or a secondary task while standing. The no task condition was repeated 3 times in order to ensure an adequate baseline measurement. The secondary task condition was repeated 6 times to examine the effects of practice.

Results indicated a significant increase in frequency of sway accompanied by a decrease in amplitude for young participants when performing a secondary task compared to a no task condition in both AP and ML directions. These results are similar to previous studies in young healthy individuals in which participants adopted a tighter control of postural sway with the addition of the secondary task (Dault et al., 2001; Dault et al.,submitted; Dault and Yardley, Chapter 4; Hunter and Hoffman, 2001). Dault and Frank (Chapter 5) found that increased frequency and decreased amplitude of sway with the addition of a secondary task was related to an increase in ankle stiffness. This modification of control strategy could indicate that the central nervous system (CNS) chose to control posture by using a co-contraction mode rather than reciprocal innervation as it requires less attention (Ghez, 1991; Loeb and Ghez, 2000). If attentional resources are limited, by reducing the attentional demand for postural control, more resources remain available for the execution of the secondary task (Abernethy, 1988).

Elderly participants only modified postural sway in ML direction when the secondary task was added. These changes were characterized by an increase in frequency and amplitude of sway, which suggests a larger instability in ML direction. These results are not surprising because Maki and McIlroy (1996) have shown that elderly individuals have greater difficulty in controlling balance in ML direction. The elderly group demonstrated much higher frequency and lower amplitude of sway in the AP direction when compared to the young group for the NT condition. The elderly were stiffer in AP direction during the NT condition and maintained the same strategy when the secondary task was added. When the secondary task was added, the young group increased the frequency and reduced the amplitude of sway to a level similar to the elderly group in AP direction.

Elderly participants responded to a lower number of items indicating that speed of response was much slower than that of the young participants. This finding is not surprising since previous dual-task studies investigating postural control and attention have shown that elderly individuals show increased reaction time and require more processing time when executing a cognitive task (Marsh and Geel, 2000; Maylor and Wing, 1996; Shumway-Cook and Woollacott, 2000; Teasdale et al., 1993). When aging attentional capacities are reduced, elderly individuals are faced with greater difficulties in dual-tasking (Groth and Allen, 2000; Salthouse et al., 1991; Vanneste and Pouthas, 1999; Wright, 1981). In addition, elderly individuals demonstrate difficulties in processing operations that are related to the capacity of the working memory (Salthouse et al., 1991). Elderly participants might have been slower at performing the task as it required the activity of the visuo-spatial component of the working memory (Baddeley, 1986).

Elderly individuals experience deterioration of the sensory systems involved in postural control, hence the CNS might require more attention to maintain appropriate control of posture to compensate for this reduction in sensory information (Alexander, 1994; Shumway-Cook et al., 1997; Stelmach et al., 1990). If attentional resources are limited and more attention is needed to maintain postural control, less attention is left for the execution of a secondary task resulting in impaired secondary task performance (Pashler et al., 2001). Elderly participants in the present study responded to fewer items in the secondary task and made more errors than the young participants. Consequently, the reduction of attentional capacity combined with increased attentional demands of postural control may have prevented elderly participants from performing the secondary task as well as young participants.

Recent studies have shown that increased fear can produce a tighter control of postural sway between first and 6th trial (Adkin et al., 2000; Carpenter et al. 1999; Carpenter et al., 2001). Some elderly participants reported being afraid of standing on the force platform since it was 20 cm above ground level. Testing sessions for the elderly were performed at the retirement home to try to control for laboratory effects. Even though TUG results did not reveal a large susceptibility to falls, elderly individuals are often afraid of falling and perceive themselves as being unstable, therefore, in this dual-task paradigm, they may have chosen to maintain the same tight control to the detriment of the performance of the secondary task. Six participants out of fifteen had fallen in the past year and reported been afraid of falling again, which resulted in them being more cautious. History of falls may be related to increased fear of falling and consequently could modify the choice of postural strategy (Maki et al., 1991, 1994; Tinetti et al., 1988). In fact, the elderly group did demonstrate higher frequency and lower amplitude of sway in AP direction when compared to the young group which, could have resulted from increased stiffness.

Although a learning effect was found in terms of number of responses given for both groups, this was not associated with any changes in postural sway between the first and sixth trial. This finding indicates that the novelty of the secondary task does not play a role in the interaction between postural control and attention. Brown et al. (1997)

showed a habituation of the postural response with repeated perturbations, which resulted in an increased COM displacement indicating that participants became more relaxed and did not feel as threatened by the perturbations. Maki and Whitelaw (1993) also demonstrated a reduction in arousal with increased experience. Because no changes in postural control were found with practice and because participants increased the speed at which they responded to the items with practice, it could be argued that arousal remained the same. The lack of changes in postural control with practice in the present study may indicate that not enough trials were included and that maybe a practice effect would have been seen if the number of testing sessions had also been manipulated. In addition, attentional demand of the task may have remained the same as participants kept improving on the cognitive task.

CONCLUSION

Previous studies have not been able to attribute the changes seen in postural control in dual-task paradigms to the type of secondary task performed, the sensory modalities used in the execution of the secondary task and the motor requirements of the task (Dault et al., 2001; Dault and Yardley, Chapter 4; Hunter and Hoffman, 2001). Therefore, we can only conclude by stating that changes in this dual-task paradigm are dependent on attentional resources available and on the requirements of the postural task as well as the perceptual-motor requirements of the secondary task such as increase respiration needed to vocalize (Dault and Yardley, Chapter 4). Hence, postural control and attention interact with one another and the direction of this relationship may be dependent on psychological factors such as fear and arousal, as well the integrity of the

CNS, and independent of the characteristics of the secondary task and are not modified with practice.

ACKNOWLEDGEMENT

The authors would like to thank Richard TerVrugt for his help for the recruitment of participants and allowing us to conduct part of the testing at Winston Park Retirement Home. In addition, we would like to thank all the participants from Winston Park Retirement Home. This research was funded by FCAR and Fondation Baxter et Alma Ricard scholarships to Mylène C. Dault and NSERC grant to James S. Frank.

REFERENCES

Abernethy B (1988). Dual-task methodology and motor skills research: some applications and methological constraints. Journal of Human Movement Studies. 14: 101-132.

Adkin A, Carpenter M, Frank JS and Peysar G (2000). Postural control is scaled to level of postural threat. Gait & Posture, 12, 87-93.

Alexander NB (1994). Postural control in older adults. Journal of the American Geriartric Society, 42(1): 93-108.

Andersson G, Yardley L and Luxon L. (1998). A dual-task study of interference between mental activity and control of balance. The American Journal of Otology, 19: 632-637.

Baddeley, A. (1986) Working Memory. Oxford: Clarendon Press.

Benson, AJ. and Gedye, JL. Logical processes in the resolution of orientational conflict. RAF Institute of Aviation Medicine Report *259*, Farnborough, UK, 1963.

Brown LA and Frank JS (1997). Postural compensations to the potential consequences of instability: kinematics. Gait & Posture. 6: 89-97.

Carpenter MG, Frank FS, Silcher CP and Peysar GW (2001). The influence of postural threat on the control of upright stance. Experimental Brain Research. 138:210-218.

Carpenter MG, Frank JS and Silcher CP (1999). Surface height effects on postural control: A hypothesis for a stiffness strategy for stance. Journal of Vestibular Research, 9(4): 277-86.

Dault MC and Frank JS (Chapter 5) Does executing a secondary task increase ankle stiffness?

Dault MC and Yardley L (Chapter 4) Can articulation explain the interaction between postural control and attention?

Dault MC, Carpenter MG, Allard F and Frank JS (submitted). Can postural sway be consciously modified? Human Movement Science.

Dault MC, Frank JS and Allard F (in press) Influence of a visuo-spatial and verbal working memory task on postural control. Gait & Posture. 14(2):110-116.

Fearing FS (1925). Factors influencing static equilibrium: An experimental study of the effects of controlled and uncontrolled attention upon way. The Journal of Comparative Psychology, 5: 1-24.

Folstein MF, Folstein SE, McHugh PR.(1975) "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. Journal of Psychiatric Research. 12(3):189-98.

Geurts ACH and Mulder TW (1994). Attention demands in balance recovery following lower limb amputation. Journal of Motor Behavior. 26(2):162-167.

Ghez, C. Muscles: Effectors of the motor system. In Kandel, E, Schwartz, JH and Jessell, TM. Principles of Neural Science, 3rd edition,Chapter 36, 1991:548-563.

Groth KE and Allen PA (2000). Visual attention and aging. Frontier in Bioscience 5:D284-97.

Hunter MC and Hoffman MA (2001) Postural control: visual and cognitive manipulations. Gait & Posture, 13, 41-48.

Loeb GE and Ghez C (2000). The motor unit and muscle action. In Kandel ER, Schwartz JH and Jessell TM (eds). Principles on Neural Science. 4th edition, Chapter 34, New York: McGraw-Hill, pp.674-694.

Magill RA (1993) Motor learning: Concepts and applications. Indianapolis, Indiana: Brown & Benchmark.

Maki BE and McIlroy WE (1996) Postural control in the older adult. Clinical Geriatric Medicine. 12(4):635-58.

Maki BE, Holliday PJ, Topper AK (1991). Fear of falling and postural performance in the elderly. Journal of Gerontology 46(4):M123-31.

Maki BE, Holliday PJ, Topper AK (1994). A prospective study of postural balance and risk of falling in an ambulatory and independent elderly population. Journal of Gerontology 49(2):M72-84.

Maki BE, Whitelaw RS (1993). Influence of expectation and arousal on center-of-pressure responses to transient postural perturbations. Journal of Vestibular Research. 3(1):25-39.

Marsh AP and Geel SE (2000). The effect of age on the attentional demands of postural control. Gait & Posture 12:105-113.

Maylor, EA and Wing, AM Age differences in postural stability are increased by additional cognitive demands. Journal of Gerontology, 1996;51B(3): P143-P154.

Mulder TW, Berndt H, Pauwels J and Nienhuis B (1993). Sensorimotor adaptability in the elderly and disabled. In: Stelmach G, Holberg V, eds. Sensorimotor impairment in the elderly. Dordrecht:Kluwer. pp.413-426.

Pashler H (1994). Dual-task interference in simple tasks: Data and theory. Psychological Bulletin, 16(2):220-244.

Pashler H, Johnston JC and Ruthruff E (2001). Attention and performance. Annual Review of Psychology, 52:629-51.

Podsiadlo D, Richardson S (1991). The timed "Up & Go": a test of basic functional mobility for frail elderly persons. Journal of the American Geriatric Society 39(2):142-8.

Redfern MS and Jennings JR (1998). Influence of attention on standing posture. Proceedings from the Satellite Meeting to the Society for Neuroscience Conference, Los Angeles CA.

Salthouse TA, Babcock RL, Shaw RJ (1991). Effects of adult age on structural and operational capacities in working memory. Psychology and Aging 6(1):118-27.

Schumacher EH, Seymour TL, Glass JM, Fencsik DE, Lauber EJ, Kieras DE, Meyer DE (2001). Virtually perfect time sharing in dual-task performance: uncorking the central cognitive bottleneck. Psychological Science 12(2):101-8.

Shumway-Cook A, Woollacott M (2000). Attentional demands and postural control: the effect of sensory context.. Journal of Gerontology, 55(1): M10-6.

Shumway-Cook A, Woollacott M, Kerns A and Baldwin M (1997). The effects of two types of WM tasks on postural stability in older adults with and without a history of falls. Journal of Gerontology, 52 (4): M232-M240.

Stelmach GE, Zelaznik HN and Lowe D (1990). The influence of aging and attentional demands on recovery from postural instability. Aging, 2(2): 155-161.

Teasdale N, Bard C, LaRue J and Fleury M (1993). On the cognitive penetrability of posture control. Experimental Aging Research. 19: 1-13.

Tinetti ME, Speechley M, Ginter SF (1988). Risk factors for falls among elderly persons living in the community. New England Journal of Medicine. 29;319(26):1701-7.

Vanneste S and Pouthas V (1999). Timing in aging: the role of attention. Experimental Aging Research 25(1):49-67.

Wickens CD. Attention and skilled performance (1989). In: Holding D.H. (Ed.) Human Skills. New York: J. Wiley, pp.71-195.

Wright RE (1981). Aging, divided attention, and processing capacity. Journal of Gerontology 36(5):605-14.

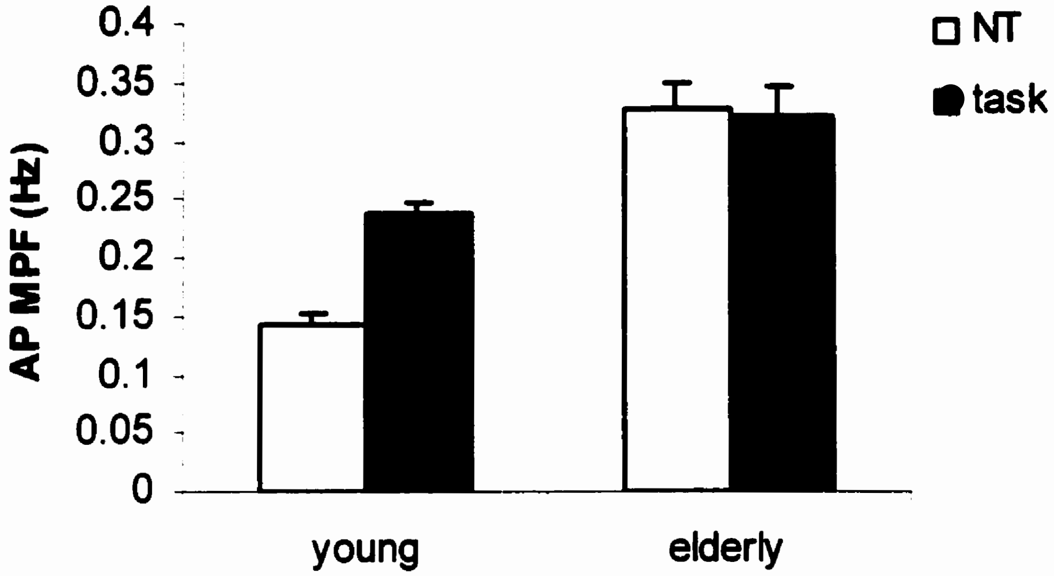

Figure 6.1 Mean and standard error values for MPF in AP direction between the NT and secondary task condition for both groups.

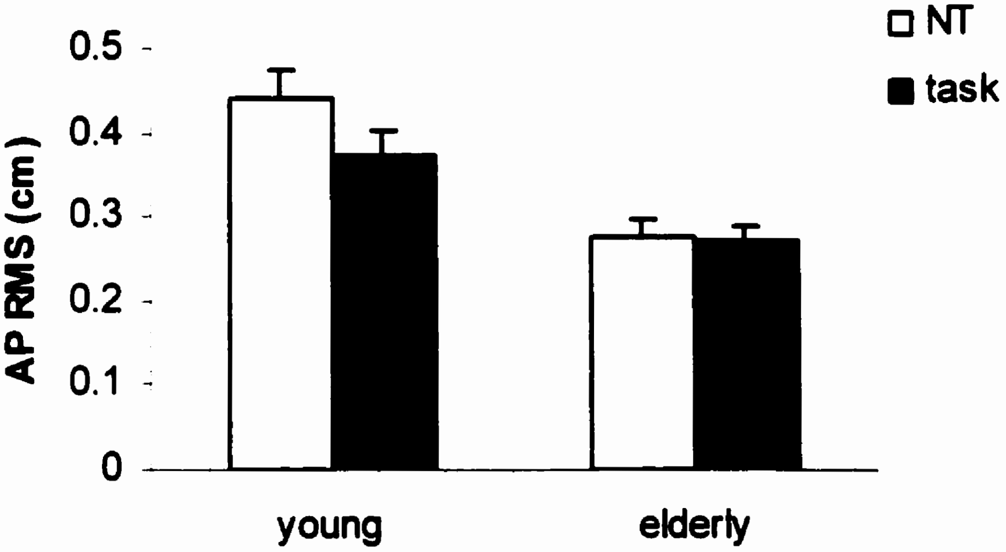

Figure 6.2 Mean and standard error values for RMS in AP direction between the NT and secondary task condition for both groups.

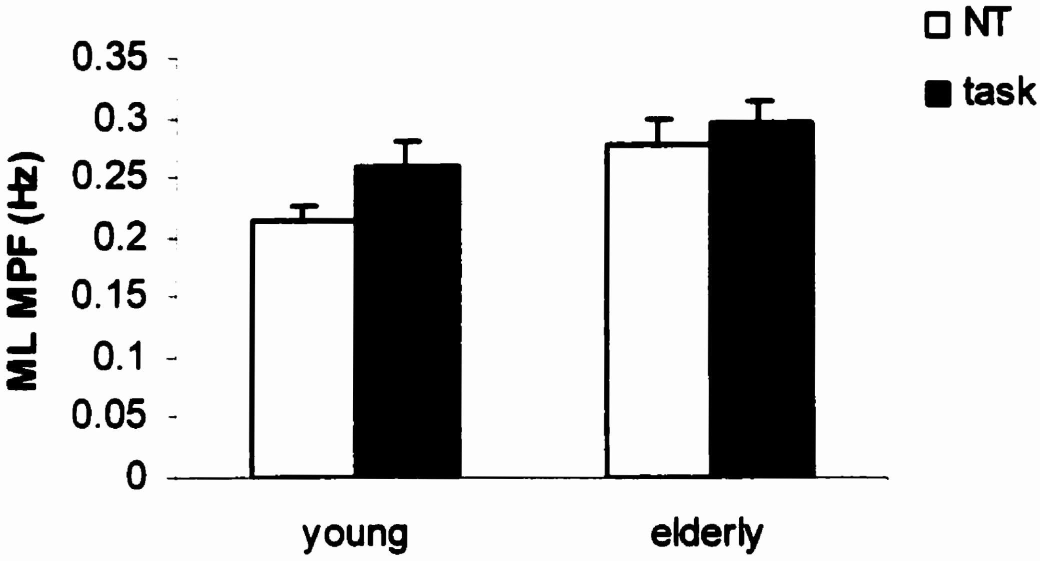

Figure 6.3 Mean and standard error values for MPF in ML direction between the NT and secondary task condition for both groups.

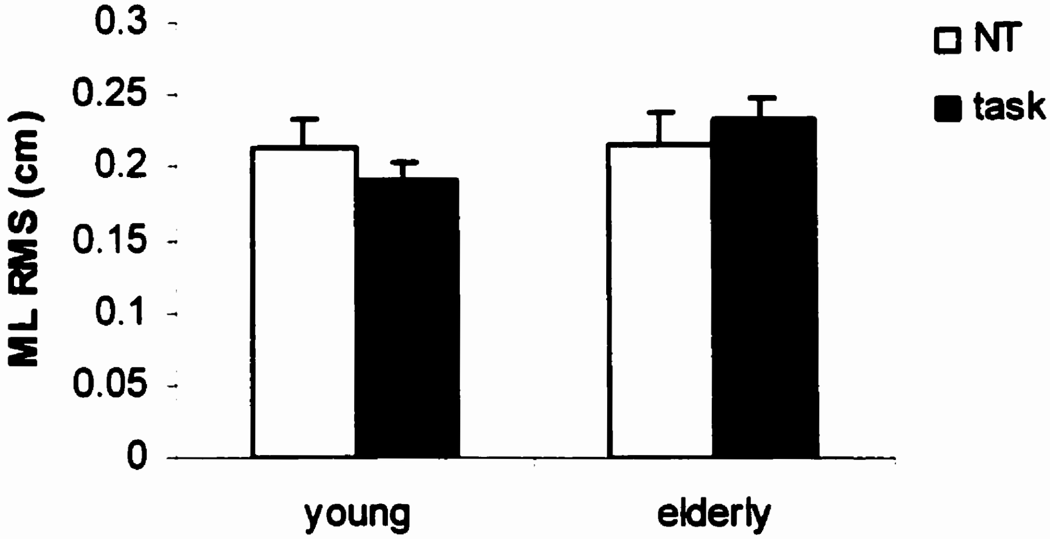

Figure 6.4 Mean and standard error values for RMS in ML direction between the NT and secondary task condition for both groups.

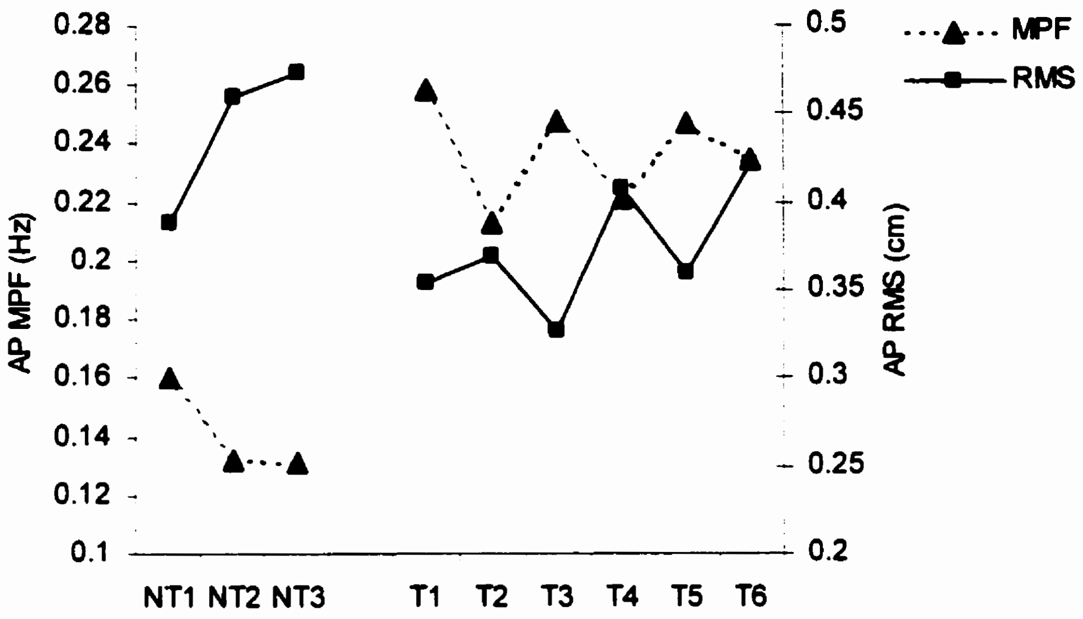

Figure 6.5 Mean MPF and RMS in AP direction for each condition and each trial for the young group.

Legend: NT1 = NT condition/trial 1; NT2 = NT condition/trial 2; NT3 = NT condition/trial 3; T1 = secondary task condition/trial 1; T2 = secondary task condition/trial 2; etc.

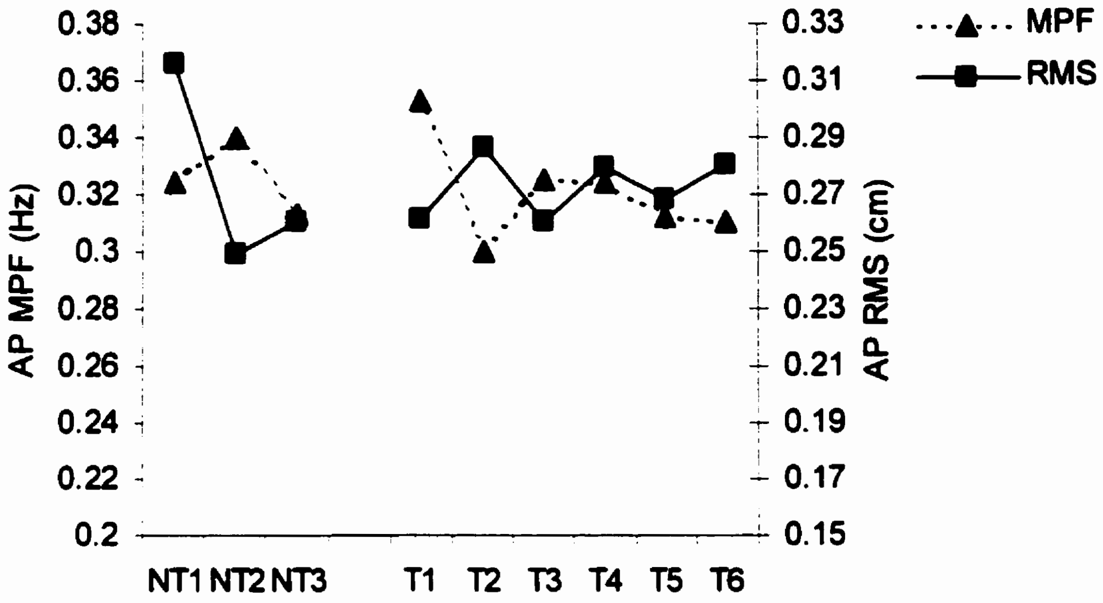

Figure 6.6 Mean MPF and RMS in AP direction for each condition and each trial for the elderly group.

Legend: NT1 = NT condition/trial 1; NT2 = NT condition/trial 2; NT3 = NT condition/trial 3; T1 = secondary task condition/trial 1; T2 = secondary task condition/trial 2; etc.

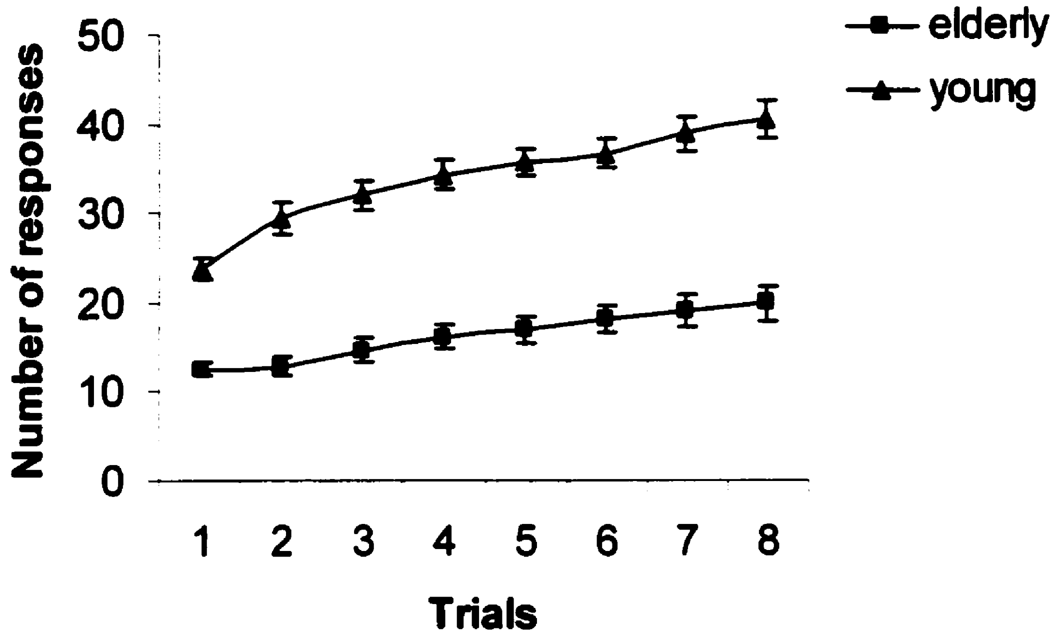

Figure 6.7 Representation of the linear increase in number of response from trial 1 to trial 8 for the young and elderly groups. Please note that trial 1 and 8 were done in a seated position.

CHAPTER 7

DISCUSSION

In recent years, a greater number of studies have been interested in understanding the role of cognitive processes in postural control. Many of our daily activities require performance of two tasks simultaneously. Therefore, it is critical to determine how the control of posture and cognitive processes interact since distractions may be a contributing factor to falls. The goal of this thesis was to investigate how and why postural control and cognitive processes influence each other.

Five studies were conducted to address this goal. Three variables were controlled across all studies: 1) all participants were young healthy individuals; 2) all trials were at least 60s duration; and 3) postural sway measures were the same across all studies. By maintaining the age group constant throughout the studies we are able to compare results without having the confounding effects of age. The last study examined the differences between an elderly and young healthy groups. All trials were 60s or longer (120 s in study 2), which provided reliable measures of COP displacement and a full representation of the frequencies across the spectrum (Carpenter et al., 2001). In all studies, both displacement (RMS) and frequency (MPF) measures were used to fully represent changes in COP. Instructions given to participants also remained the same across all studies; participants were instructed to stand quietly with arms at their side and to perform the secondary task as best they could without making any errors. By giving these instructions, we hoped to not bias participants by giving more importance to either postural control or the cognitive task.

All studies presented in this thesis reported changes in postural control while performance on the cognitive tasks remained the same. Previous studies which have reported changes in the cognitive task while the postural task was unchanged may have provided instructions that placed greater importance on the postural performance (Redfern and Jennings, 1998; Lajoie et al., 1993-1996). The lack of changes in postural sway may be related to short duration trials that did not capture the high amplitude, low frequency changes in COP displacement, which are represented better in longer trial lengths (Carpenter et al., 2001). In addition, most studies only examined displacement measures without taking into account the frequency changes.

All cognitive tasks modify postural control in the same manner

Chapter 2 of this thesis examined the influence of task type and difficulty on the interaction between postural control and working memory (WM). Participants were asked to perform various tasks involving each component of Baddeley's WM model while maintaining balance in shoulder width stance or tandem stance (Baddeley, 1986). The type of the WM task did not modify the results. Results indicated that the performance of all WM tasks resulted in an increased frequency and decreased amplitude of sway. The subsequent studies presented in this thesis also used various types of tasks such as a verbal shadowing task (Chapter 3), memorizing letters that form words (Chapter 4), repeating random letters (Chapter 4) and even biting on a plastic tube (Chapter 4). Interestingly, modifications of postural control, i.e. increased frequency and decreased amplitude of sway, were the same for all studies independent of the type of task. Hence, regardless of the type of tasks, when participants were asked to perform a secondary task, modifications in postural control resulted in increased stiffness.

In Chapter 2 we manipulated the difficulty of the visuo-spatial task in order to examine the effects of task difficulty. Postural control was the same between the two levels of difficulty of the visuo-spatial task; however, participants responded much more slowly when the visuo-spatial task was made more difficult. These results are similar to Dault et al. (in press b). By reducing the speed of responding, participants might have reduced the difficulty of the task in order to preserve postural control. Yardley et al. (2001) showed that tasks that required "high mental loading" produced greater changes in postural sway than a "low mental loading task". Therefore, the differences between the levels of difficulty of the visuo-spatial task may not have been challenging enough to cause further changes in postural sway in young healthy individuals.

The difficulty of the postural stance, presented in Chapter 2, did not influence the interaction between postural control and the WM tasks. The only change observed was that postural control was most affected by the addition of a WM task in the direction that the particular stance was least stable. For example, postural control was modified in the AP direction when participants were standing in a shoulder width stance whereas postural control was modified in ML direction when they were standing in tandem stance. However, the same modifications occurred in both directions, i.e. increased frequency of sway and decreased amplitude of sway. Similar results were found in Chapter 4, when we compared a stable standing surface to an unstable surface. Dault et al. (2001b) demonstrated that when young healthy participants performed a secondary task while standing on a seesaw in a tandem position they became less stable and swayed more when compared to the NT condition. Results from previous studies also have shown that reaction time increased as the difficulty of the postural task increased, such as from seated to standing or from standing on a stable surface to standing on an unstable surface (Lajoie et al., 1993-1996; Redfern and Jennings, 1998; Yardley et al., 2001). In this thesis, no changes were found in the performance of the secondary tasks between sitting, standing at shoulder width or tandem stance (Chapter 2) and between sitting, standing on a stable or unstable surface (Chapter 4). The tandem stance and the unstable surface used in Chapters 2 and 4 may not have been challenging enough for young healthy adults to require increased attentional demand and result in a larger interference. Therefore, postural task difficulty requires further investigation.

Consciously focusing on postural control does not modify the interaction between postural control and the performance of a cognitive task.

Chapter 3 examined how consciously focusing on remaining as still as possible and using visual feedback to reduce postural sway can modify the relationship between postural control and attention while one is standing in a normal and a fearful environment. Participants responded to the addition of the secondary task in the same manner whether they were asked to consciously focus on standing as still as possible or simply to stand quietly. The group that stood quietly and the group that consciously focused on standing as still as possible demonstrated increased frequency of sway and decreased amplitude with the addition of the secondary task. With addition of visual feedback, participants increased frequency and decreased amplitude of sway regardless of the addition of the secondary task or the change in environment. When using visual feedback participants may have reached a plateau at which postural sway could not be reduced further with the addition of a secondary task. However, when placed in a fearful situation (high standing surface height), participants who consciously focused on postural sway showed increased sway whereas participants who simply stood quietly displayed tighter control. Because both the addition of the visual feedback and the addition of the secondary task resulted in a tighter control, it appears that the addition of any task requiring cognitive processes results in reduced postural sway in young healthy individuals.

Vocalization can explain only part of the modifications seen in postural control

Yardley et al. (1999) suggested that articulation, and not attentional interference as suggested by many researchers may be at the source of the modifications seen in postural control during dual-task paradigms. This hypothesis was further investigated in the study presented in Chapter 4. Participants were asked to perform five different tasks while either standing on a stable surface or on an unstable surface with eyes open or closed. Each task was either aimed at increasing attentional demand only (silent task), motor coordination only (motor task), articulation with low attention demands (articulation task), articulation with high attention demands (combination task) or there was no task at all. Results revealed that the performance of all tasks resulted in increased frequency and decreased amplitude of sway when compared to the NT condition. Motor coordination is not the cause of the modifications seen in postural control during dual-task paradigms since the motor task resulted in the same changes as the silent task, which required no movement. Interference was greater in the ML direction for the unstable surface and in AP for the stable surface, indicating that dual-tasking provides interference in the same plane in which the stance is least stable. The tasks that required vocalization, i.e. the articulation and the combination, resulted in greater increase in frequency of sway, which caused the sway path to be longer. Therefore, the changes in respiration needed to vocalize may be related to the increased frequency and sway path. Nevertheless, tasks that did not require any vocalization still caused postural control to become tighter.

Ankle stiffness is increased in dual-task conditions

Many studies have argued that an increase in frequency and a decrease in amplitude of sway indicates an increased ankle stiffness (Carpenter et al., 1999; Adkin et al., 2000; Dault et al., 2001 a; Dault et al., 2001 b). Chapter 5 investigated whether an increase in frequency and a decrease in amplitude of sway found during dual-task conditions can indicate an increased stiffness. Results of Chapter 5 confirm that the addition of a secondary task increases ankle stiffness in the AP direction. Therefore, when a task requiring cognitive processes is performed while participants are maintaining upright stance, they become stiffer. This may indicate that the CNS adopts a stiffer mode of control to free more attentional resources for performance of the cognitive task.

Practice of the dual-task condition did not modify the changes seen in postural control

The study presented in Chapter 6 examined whether the novelty of the secondary task could explain the changes seen in postural control and whether practice of the dual-task condition could modify this interaction. Considering that attentional capacity is reduced with aging, we also investigated if elderly individuals would benefit more from practice than young individuals. Results of Chapter 6 demonstrated that young participants showed the same results as in all the previous studies, i.e. increased frequency and decreased amplitude of sway with the execution of the secondary task. Elderly only showed changes in ML direction which were characterized by an increased frequency and amplitude of sway. No changes occurred with practice. Both groups demonstrated the same mode of control the first time they execute the dual-task condition to the 6th trial although they were able to respond faster to the secondary task. Therefore, results indicate that practice over 6 trials does not modify postural.

Why does the addition of a cognitive task result in modification of postural control in healthy young individuals?

All studies demonstrated the same results: increased frequency and decreased amplitude of sway regardless of secondary task type, consciously focusing on minimizing postural sway, sensory and motor requirements or practice of the secondary task. These modifications in frequency and amplitude are related to an increased joint stiffness, as reported in Chapter 5. If standing posture control is controlled as an inverted pendulum and joint stiffness is used to regulate upright posture, as suggested by Winter et al. (1998-2001), increasing joint stiffness may reduce the operating demands of the CNS (Winter et al., 1998). When a secondary task is performed, the CNS may simply increase the gain of the stiffness control. Because young healthy individuals may be able to control posture at a lower level of the CNS, more attentional resources remain for the execution of the secondary task and no large interference becomes apparent. However, when the postural task is made more difficult when standing on a sway referenced platform, such as in Redfern and Jennings (1998), participants have greater difficulty performing the secondary task. When a postural task is more difficult, even young healthy individuals may experience greater difficulties with the execution of a cognitive task.

Stiffness at the ankle joint can be increased in several ways. Stiffness can be increased by leaning forward, which causes an increase in passive stiffness because of muscle lengthening. However, we did not see a forward shifts of the COP mean position with the addition of a secondary task suggesting that this did not occur. Widening the base of support can also result in increased stiffness, however stance width was kept constant through the various experimental conditions examined in all 5 studies (Winter et al., 1998). Loeb and Ghez (2000) argue that co-contracting the muscles surrounding the ankle joint during quiet standing increases joint stiffness. When controlling posture through co-contraction the CNS can adjust the force-velocity and force-length relations and thereby, modify the response to a perturbation. Therefore, it is possible that participants used this method of increasing stiffness when performing a secondary task as it can result in a faster and more efficient way to prevent falls if a perturbation should occur. One of the disadvantages of using a co-contraction mode of control is that it requires muscles to be constantly activated, which results in fatigue (Loeb and Ghez, 2000). This might be one of the reasons why this mode of control is not adopted by elderly individuals Also, participants may have increased muscle stiffness in order to increase the monitoring of sensory feedback. Future research is needed to determine why healthy young individuals choose to increase stiffness when conducting a secondary task and what are the neuromuscular mechanisms involved in this increased stiffness.

Individuals with pathologies of the CNS respond differently than young healthy individuals when asked to perform a secondary task. Recent research has shown that individuals with Parkinson's disease reduce gait speed and show deterioration in balance control during dual-task conditions (Morris et al., 2000; Camicioli et al., 1998). Morris et al. (1996) showed that patients with Parkinson's disease decreased mean stride length and velocity when asked to repeat days of the week backwards while walking. O'Shea et al. (1999) found that both the Parkinson patients and age matched controls showed a decline in gait speed, cadence and step length when asked to perform a secondary task. However, the magnitude of change was larger for Parkinson patients. Individuals with Alzheimer's disease also demonstrate reduced gait speed when walking while executing a verbal fluency task (Camicioli et al., 1997). A case study by Sandyk (1997) revealed that talking while walking produced an increase in spasticity in the legs and trunk and impaired balance and gait which resulted in occasional falls in patients with multiple sclerosis. These studies suggest that deterioration of the CNS because of pathology and aging results in a greater attention demand to maintain postural control and that the CNS may not be able to adapt to dual-task demands as efficiently as young healthy individuals. A large number of studies conducted with pathological populations during dual-task performance have looked at gait modifications during the performance of a secondary task. These studies have attributed the interference to an increased attentional demand of postural control; however, the interference could be due to the production of the voluntary movement of walking and not due to the demands for balance control.

The greater interference with dual-tasking seen in elderly and pathological populations also may reflect the fact that these populations are not able to time-share attentional capacities but must adopt a time-switching strategy because of the reduced attentional capacities found with aging. This is demonstrated in the "Stops walking while talking test" in which certain elderly literally stopped walking to be able to respond to the cognitive demand of the secondary task (Lundin-Olsson et al., 1997). The time-switching strategy also may be the strategy that elderly individuals adopted in the last study of this thesis as they were much slower in performing the secondary task when compared to young individuals. However, there is a need for more research investigating time-switching versus time-sharing strategies.

In the presence of pathology, aging and/or a difficult postural task, postural control may shift from a more lower level stiffness control to a more attention demanding control by the higher centres of the CNS resulting in larger dual-task interference. Consequently, individuals might be at a higher risk of falling because performing another task while maintaining balance may result in increased instability (see Chapter 6). Increasing joint stiffness seems to be an advantageous strategy to control posture when in a dual-task situation; however it has not yet been investigated in older adults and individuals with various pathologies.

Neurophysiology of postural control and attention

Many brain structures have been shown to be involved in the control of posture (Horak and Macpherson, 1996). One important area involved in postural control seems to be the vestibular nuclear complex located in the medulla and pons area. This center is involved in the integration of vestibular, proprioceptive and visual information through the vestibulospinal and reticulospinal pathways, which terminate in the neck, axial and limb motoneurones and interneurones. Horak and Frank (1995) have suggested that the basal ganglia play an important role in three separate postural pathways: tonic postural tone because they project to the brainstem, centrally initiated postural adjustments because they are involved in the corticobasal ganglia loop and externally triggered reactions as these automatic reactions are influenced by the basal ganglia control of the centers involved in muscle tone, gain and set (Horak and Macpherson, 1996). The cerebellum is thought to be implicated in postural coordination as it receives projections from many cortical area and projects to the spinal cord. Individuals with cerebellar lesions demonstrate very hypermetric responses to perturbations. Lesions of the frontal lobes seem to result in oscillations of the COP that are correlated with respiration frequency. Therefore, the frontal lobe secondary motor areas may play a role in the coordination of postural adjustments with the destabilizing influences of respiration (Horak and Macpherson, 1996).

Attentional processes have projections in the frontal, parietal and thalamus brain regions (Coull et al., 1999). More precisely, the noradrenergic system in the prefrontal cortex, which is implicated in the control of attention and working memory, seems to modulate the activity of the cells found in the locus coeruleus. The locus coeruleus then projects to the cerebral cortex, hippocampus, thalamus, midbrain, brainstem, cerebellum and spinal cord (Aston-Jones et al., 1999). Interestingly, the locus coeruleus contains noradrenergic neurons that project to the spinal cord and are involved in the control of posture (Andre et al., 1995). Hence, the interaction between postural control and attention may take place in this area. Clonidine, a mixed 1α & 2α adrenoceptor agonist, has been shown to alter attentional capacities (Coull et al., 1999). It would, therefore, be interesting to investigate if the use of clonidine also has an impact on postural control.

CONCLUSION

Dual-tasking is required by many of our daily activities. Previous studies have found different results; some have shown increased sway (Andersson et al., 1998; Shumway-Cook et al., 1997; Shumway-Cook and Woollacott, 2000), others have found decreased sway (Vuillerme et al. 2000; Hunter and Hoffman, 2001; Dault et al., 2001 a), while others only observed modification in the performance of the secondary task with various postural tasks (Redfern and Jennings, 1998; Teasdale et al., 1993; Lajoie et al., 1996). The strength of our results lies in the fact that all studies used the same population (young healthy adults), length of trial (60s) and COP displacement measures (RMS and MPF). This resulted in the observation of the same modifications in postural sway with the addition of a secondary task and no changes in the performance of the secondary task for all studies. Healthy young individuals performed two concurrent tasks by simply becoming stiffer regardless of the characteristics of the secondary task. By increasing stiffness the CNS may be able to allocate a larger proportion of attentional resources to the performance of the secondary task without putting the individual at greater risk of falling. On the other hand, elderly individuals seem to have greater difficulty coordinating two tasks as they showed larger instability in the ML direction in a dual-tasking situation. This increased instability could be related to reduced attentional capacity due to aging as well as an inability to regulate posture by only using joint stiffness. Hence, the different results found in previous studies could lie in the fact that various populations, trial lengths and COP displacement measures were used. Future research needs to use the same trial length and the same COP displacement measures as in this thesis in order to adequately compare populations.

FUTURE DIRECTION

Very few studies have examined whether or not dual-tasking influences the development of balance control in children. How do children develop the ability to dual-task? Recent research demonstrated that children with dyslexia showed deficits in balance control (Nicolson and Fawcett , 1990; Moe-Nilssen et al., 2001). Nicolson and Fawcett (1990) and Yap and van der Leij (1994) found that children with dyslexia demonstrated greater difficulty dual-tasking while maintaining upright stance than age-matched healthy children. The same research group further suggests that dyslexia may be linked to abnormal cerebellar activation (Nicolson et al., 1999). Children with dyslexia may have greater difficulty dual-tasking while standing due to an inability to automatize postural control (Fawcett and Nicolson, 1992; Yap and van der Leij, 1994). Further investigations of dual-task performance during postural control in dyslexic children might provide some insight to the role of the cerebellum in dual-task situations.

REFERENCES

Adkin A, Carpenter M, Frank JS and Peysar G (2000). Postural control is scaled to level of postural threat. Gait & Posture, 12, 87-93.

Andersson G, Yardley L and Luxon L. (1998). A dual-task study of interference between mental activity and control of balance. The American Journal of Otology, 19: 632-637.

Andre P, Horn E and Pompeiano O (1995). Microinjections of *GABA*ergic agents in the locus coeruleus modify the gain of vestibulospinal reflexes in decebrate cats. Archives Italiennes de biologie 133 :47-75.

Aston-Jones G, Rajkowski J and Cohen J (1999). Role of locus coeruleus in attention and behavioral flexibility. Biological Psychiatry 46: 1309-1320.

Baddeley A (1986). Working Memory. Oxford: Clarendon Press.

Camicioli R, Howieson D, Lehman S and Kaye J (1997). Talking while walking: the effects of a dual-task in aging and Alzheimer's disease. Neurology 48(4):955-958.

Camicioli R, Oken BS, Sexton G, Kaye JA, Nutt JG (1998). Verbal fluency task affects gait in Parkinson's disease with motor freezing. Journal of Geriartric Psychiatry Neurology, 11: 181-185.

Carpenter MG, Frank JS and Silcher CP (1999). Surface height effects on postural control: A hypothesis for a stiffness strategy for stance. Journal of Vestibular Research, 9(4): 277-86.

Carpenter MG, Frank JS and Winter DA and Peysar GW (2001). Sample duration influences center of pressure summary measures. Gait & Posture 13: 35-40.

Coull JT, Buchel C, Friston KJ and Frith (1999). Noradrenergically mediated plasticity in a human attentional neuronal network. NeuroImage 10:705-715.

Dault MC, Frank JS and Allard F (2001 a) Influence of a visuo-spatial and verbal working memory task on postural control. Gait & Posture. 14(2): 110-116

Dault MC, Geurts ACH, Mulder T W and Duysens J (2001 b) Postural control and cognitive task performance in healthy participants while balancing on different support-surface configurations. Gait & Posture. 14(3):178-185.

Fawcett AJ and Nicolson RI (1992). Automatisation deficits in balance for dyslexic children. Perceptual and Motor Skills 75:507-529.

Horak FB and Frank JS. (1995) Three separate postural systems affected in parkinsonism. In: Motor Control VII, edited by DG Stuart, Gurfinkel VS and Wiesendanger. Tucson: Motor Control Press.

Horak FB and MacPherson JM (1996). Postural orientation and equilibrium. In Handbook of Physiology, Section 12, Chapter 7 (pp.255-292).

Hunter MC and Hoffman MA (2001) Postural control: visual and cognitive manipulations. Gait & Posture, 13, 41-48.

Lajoie Y, Teasdale N, Bard C and Fleury M (1996). Upright standing and gait: Are there changes in attentional requirements related to normal aging? Experimental Aing Research, 22:185-198.

Lajoie Y, Teasdale N, Bard C and Fleury M (1996). Attentional demands for static and dynamic equilibrium. Experimental Brain Research. 97:139-144.

Loeb GE and Ghez C (2000). The motor unit and muscle action. In Kandel ER, Schwartz JH and Jessell TM (eds). Principles on Neural Science. 4th edition, Chapter 34, New York: McGraw-Hill, pp.674-694.

Lundin-Olsson, L., Nyberg, L. and Gustafson, Y. (1997). "Stops walking when talking" as a predictor of falls in elderly people. Lancet 349(9052): 617.

Moe-Nilssen R, Helbostad JL, Tonnesen FE (2001). How children with dyslexia utilize a visual cue in balance control. In Duysens J, Smits-Engelsman BCM and Kingma H (Eds). Control of posture and gait: Proceedings from the Symposium of the International Society for Postural and Gait research (pp.469-472).

Morris M, Iansek R, Smithson F and Huxham F (2000). Postural instability in Parkinson's disease: a comparison with and without a concurrent task. Gait & Posture 12(3):205-16.

Morris ME, Iansek R, Matyas TA, Summers JJ (1996). Stride length regulation in Parkinson's disease. Normalization strategies and underlying mechanisms. Brain, 119: 551-568.

Nicolson RI and Fawcett AJ (1990). Automaticity: A new framework for dyslexia research? Cognition 35:159-182.

Nicolson RI, Fawcett AJ, Berry EL, Jenkins IH, Dean P and Brooks DJ (1999). Association of abnormal cerebellar activation with motor learning difficulties in dyslexic adults. Lancet 353:1662-67.

O'Shea S, Morris ME, Iansek R (1999). The effect of secondary cognitive and motor tasks on gait in Parkinson's disease. Book of Abstracts from the International Symposium on Gait Disorders. (pp.198-199).

Redfern MS and Jennings JR (1998). Influence of attention on standing posture. Proceedings from the Satellite Meeting to the Society for Neuroscience Conference, Los Angeles CA.

Sandyk R (1997) Treatment with electromagnetic fields improves dual-task performance (talking while walking) in multiple sclerosis. The International journal of neuroscience 92 (1-2):95-102.

Shumway-Cook A and Woollacott M (2000). Attentional demands and postural control: the effect of sensory context.. Journal of Gerontology 55A(1): M10-6.

Shumway-Cook A, Woollacott M, Kerns A and Baldwin M (1997). The effects of two types of cognitive tasks on postural stability in older adults with and without a history of falls. Journal of Gerontology, 52A(4): M232-M240.

Teasdale N, Bard C, LaRue J and Fleury M (1993). On the cognitive penetrability of posture control. Experimental Aging Research. 19: 1-13.

Vuillerme N, Nougier V and Teasdale N (2000). Effects of a reaction time task on postural control in humans. Neuroscience Letters 291:77-80.

Winter DA, Patla AE, Prince F, Ishac M and Gielo-Perczak K (1998). Stiffness Control of Balance in Quiet Standing. Journal of Neuropysiology, 80:211-1221.

Winter DA, Patla AE, Rietdyk S and Ishac MG (2001). Ankle muscle stiffness in the control of balance during quiet standing. Journal of Neurophysiology 85:2630-2633.

Yap RL and van der Leij A (1994). Testing the automatization deficit hypothesis of dyslexia via a dual-task paradigm. Journal of Learning Disability 27(10):660-665.

Yardley L, Gardner M, Bronstein R, Buckwell D and Luxon L (2001). Interference between postural control and secondary task performance in patients with peripheral vestibular disorder and healthy controls. Journal of Neurology, Neurosurgery and Psychiatry . 71: 48-52

Yardley L, Gardner M, Leadbetter A and Lavie N (1999). Effect of articulation and mental tasks on postural control. Neuroreport, 10(2):215-219.