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Interaction between delayed visual feedback and secondary cognitive tasks on postural control in older adults

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Abstract. Age-related decline in control mechanisms and sensory information detection adversely affect balance in older adults. This effect is particularly pronounced during the performance of a concurrent cognitive task. The purpose of this experiment was to determine the effects of cognitive load and the temporal salience of delayed visual feedback (DVF) on the stability of upright stance in older individuals. Fifteen healthy young and fifteen healthy older subjects participated. Participants were required to position their centre of pressure (COP) as close to a fixed-target as possible on an LCD monitor. In a set of experimental conditions the delay with which the visual feedback was made available to the participants was systematically varied. The cognitive dual-task involved the performance of a simple serial arithmetic operation. Visual feedback conditions consisted of eyes-open (no COP feedback) and DVF conditions (0, 300, 600, 900 ms). While sway variability increased with visual delay in both groups, older participants exhibited greater sway variability across all DVF conditions. Young adults showed a reduction in AP COP variability in the dual DVF-cognitive task performance conditions Older adults, in contrast, did not benefit from cognitive dual-task performance. We argue that this reflects insufficient or inappropriate modulation of attention resulting in compromised balance control in older individuals.

Key words: Postural stability, aging, delayed visual feedback, dual-task, attention

Résumé. Interaction entre un feedback visuel retardé et une tâche cognitive ajoutée sur le contrôle postural chez des personnes âgées.

Le déclin lié à l'âge des mécanismes de contrôle et de la détection des informations sensorielles affecte l'équilibre chez les personnes âgées. Cet effet est particulièrement prononcé lorsque les sujets doivent réaliser une tâche cognitive concurrente. L'objectif de cette expérimentation était de déterminer les effets de la charge mentale et du délai de feedback visuel sur la stabilité de l'équilibre postural chez des personnes âgées. Quinze sujets jeunes et quinze sujets âgés, tous en bonne santé, ont participé à cette expérimentation. Les sujets devaient maintenir la position de leur centre des pressions aussi proche que possible d'une cible présentée sur un moniteur LCD. Dans un ensemble de conditions expérimentales le délai avec lequel le feedback visuel était rendu disponible a été systématiquement manipulé. La tâche cognitive ajoutée était une tâche sérielle d'opérations arithmétiques simples. Les conditions de feedback visuel comprenaient une condition sans feedback, et des conditions de feedback retardé (0, 300, 600, 900 ms). Les résultats montrent que la variabilité posturale augmente avec le délai de feedback dans les deux groupes, mais que les sujets âgés présentent une variabilité plus élevée dans toutes les conditions avec feedback retardé. Les sujets jeunes présentent une diminution de la variabilité des déplacements du centre des pressions dans les conditions de double tâche, alors que les sujets âgés ne bénéficient pas de cet effet double tâche. Nous pensons que ceci reflète une modulation insuffisante ou inappropriée de l'attention chez les sujets âgés, débouchant sur un contrôle déficient de l'équilibre.

Mots clés : Stabilité posturale, vieillissement, feedback visuel retardé, double tâche, attention

Introduction

The effort involved in maintaining balance while simultaneously engaging in various daily activities is often overlooked due to the perceived simplicity of the pedestrian tasks that one engages in while maintaining upright stance. Although the task of standing upright may appear to be deceptively simple, maintaining posture is often accompanied by the performance of concurrent perceptual, cognitive and motor tasks. Following the work of Stoffregen, Smart, Bardy, and Pagulayan (1999), such tasks, super-ordinate to the maintenance of posture itself, are commonly referred to as supra-postural tasks. In this article, we address the interaction between the performance of a cognitive and perceptual supra-postural task in the maintenance of balance in young and older adults.

Posture, defined as the geometric relation between two or more body segments (Balasubramaniam & Wing, 2002), must be actively maintained in the context of varying task and environmental factors. Due to the interaction of a number of neuromuscular and perceptual processes taking place in concert, active standing is never truly "steady". The neuromuscular system is continually effecting minor adjustments at various frequencies and time-scales to maintain balance, specifically to counter forces acting on various joints to disturb the equilibrium in standing (Balasubramaniam & Wing, 2002).

Postural fluctuations are adaptive in the sense that they show changes that are both predictive and compensatory in nature. These changes are observed in temporal correlations in the short and long term (Van den Heuvel, Balasubramaniam, Daffertshofer, Longtin & Beek, 2009). Many distributed systems must be integrated appropriately to exhibit such anticipatory and compensatory adaptive mechanisms (Torres-Oviedo, Macpherson & Ting, 2009). Commonly studied among those include three sensory systems that provide relevant information regarding the position and movement of the body's centre of pressure (COP). They are visual (Balasubramaniam & Wing, 2002; Lee & Lishman, 1975), vestibular (Fitzpatrick & McCloskey, 1994) and somatosensory (Horak, Nashner & Diener, 1990; Jeka, Schöner, Dijkstra, Ribeiro & Lackner, 1997). Lack of perceptual information, or inaccurate perceptual information from these modalities, results in a decrease in the individual's ability to exhibit postural control. Of the three sensory modalities, support has shown that vision appears to be the dominant source of information used for postural control and balance (Balasubramaniam & Wing, 2002; Nashner & Berthoz, 1978). Recent work by Rougier (2000) and from our own laboratory (van den Heuvel *et al.*, 2009; Boulet, Balasubramaniam, Daffertshofer, & Longtin, 2010; Yeh, Boulet, Cluff, & Balasubramaniam, 2010), has looked at modifying the integrity of visual information by using a delayed visual feedback paradigm. Delays in the visual feedback affect postural performance significantly resulting in increased variability. However, the performance of a concurrent simple cognitive task manages to reduce this variability to a large extent (Yeh *et al.*, 2010). From our previous work it appears that the addition of the moderately demanding cognitive task facilitates postural control in the presence of visual feedback. Facilitatory effects of cognitive tasks on postural sway have been noted in the literature, most clearly by Riley, Baker and Schmit (2003). In this paper, we ask if this added cognitive task would also serve to benefit older adults. It is important to note that balance control is not purely a spinal or subcortical process since there is evidence of cortical involvement in postural reflexes. In addition, cognition cannot be concluded to be purely cortical since the cerebellum has been implicated in cognition (Balasubramaniam & Wing, 2002).

Control of posture can be a demanding task especially for older individuals and this is especially true when attention is shared with the performance of a secondary cognitive task. The interaction between maintaining balance and performance of cognitive activity is typically investigated in dual-task designs, in which subjects perform a secondary task (cognitive or physical) and a postural task simultaneously. The literature regarding the effects of cognitive tasks on balance performance shows fairly consistently that the balance of older subjects is more affected than that of younger subjects when they concurrently perform a cognitive task (Maylor & Wing, 2001; Rankin, Woollacott, Shumway-Cook & Brown, 2000; Lacour, Bernard-Demanze & Dumitrescu, 2008). Aging reduces the efficacy of various systems involved in postural control and this includes sensory and neuromuscular systems. In turn, this affects the reliability of cutaneous and proprioceptive information that older adults detect from their support surface. In addition, aging adversely affects the ability for the systems to integrate feedback (Torres-Oviedo *et al.*, 2006) from multiple modalities (Yeh *et al.*, 2010). These losses are hypothesized to result in older individuals relying more heavily on cognitive mechanisms in sensorimotor control (Huxhold, Li, Schmiedek, & Lindenberger, 2006), which results in slowing down in most motor tasks. Consequently, older individuals engage in trade-off behaviour in prioritizing one task over another to actively maintain postural control (Lacour *et al.*, 2008). The question that arises is: does the requirement of a secondary task in the older people hinder postural control by acting as resource competition thus requiring them to trade-off the completion of the task for postural stability.

There is a large body of evidence suggesting that the decline in sensorimotor and cognitive function in older people adversely affects postural control (Balasubramaniam & Wing, 2002; Brauer, Woolacott & Shumway-Cook, 2001; Huxhold *et al.*, 2006; Shumway-Cook & Woolacott, 2000). However, the type of cognitive task and its effect has been a topic of much contention. Some argue that since visual feedback is an integral part of maintaining postural control, this thus implies that secondary visual-spatial tasks are more likely to disturb balance (Huxhold *et al.*, 2006; Kerr, Condon & McDonald, 1985; Maylor & Wing, 2001). In contrast, some studies have shown that a secondary task requiring verbal articulation is the main cause of increased postural sway (Conrad & Schönle, 1979; Mulder & Mulder, 1981; Yardley, Gardner, Leadbetter & Lavie, 1999; Maki & McIlory, 1996; Dault, Yardley & Frank, 2003). Production of speech requires coordination between articulatory, phonatory and respiratory processes. Yardley *et al.* (1999) and Dault *et al.* (2003) have 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. Lastly, 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, for example, heart rate and respiratory changes relating to increased arousal or increased task difficulty (Mulder & Mulder, 1981).

There are two theories that have been used to explain the different effects of a secondary task on postural control. First is the classic Yerkes-Dodson law, which simply states that arousal affects performance in a U-shaped fashion (Yerkes & Dodson, 1908; Nagano, Yoshioka, Hay, Himeno & Fukashiro, 2006) where extremely low and high levels of arousal adversely affect performance. When optimal arousal is achieved via some means, performance will be at its best. It is believed that low cognitive demands increase the level of arousal in a way that triggers optimal postural sway control (Huxhold *et al.*, 2006; Pellecchia, 2003; Yerkes & Dodson, 1908; Nagano *et al.*, 2006). This is because an easy secondary cognitive task may increase the individual's ability to control their posture since it provides them with an "external" focus (McNevin & Wulf, 2002; Wulf, Mercer, McNevin, & Guadagnoli, 2004). Similar results have been noted by Riley *et al.* (2003), who showed an inverse relationship between postural stability and task-difficulty. It is possible that tasks with high cognitive demand increase the level of arousal that is beyond an optimal level and performance on postural control deteriorates.

It can also be argued that difficult secondary tasks exhaust the limited cognitive resources, detracting from the attention given to standing (Pellecchia, 2003). Following this it has been proposed that older individuals with a limited or reduced cognitive capacity would engage in the "posture first principle" (Pellecchia, 2003; Redfern, Jennings, Martin & Furman, 2001) by dedicating all their attention towards postural stability thus minimizing sway. Pelecchia (2003) has argued that selective attention mechanisms would prioritize tasks in such a manner that attention would be directed in a hierarchical fashion. This has now been demonstrated in other complex problem-solving situations where an individual copes by prioritizing balance over other concurrent tasks (Holmes, Jenkins, Johnson, Adams & Spaulding, 2010).

Other findings include asking subjects to visually fixate on a presented object, which resulted in improved postural control (Huxhold *et al.*, 2006). Interestingly these studies seem to present an unexpected confound. Individuals asked to divert their attention toward maintaining balance resulted in them exhibiting relatively worse performance (McNevin & Wulf, 2002; Wulf *et al.*, 2004). Wulf and colleagues have posited that this pattern of results arise from the fact that subjects adopt an internal attentional focus, which in turn results in standing postural control to be processed in an overt conscious manner. Whereas, directing attention onto an external focus allows the postural control system to organize automatically, thus improved postural control.

It is important to note that most of the literature contends that posture is controlled exclusively for the purpose of maintaining stance – sensory information serves to reduce postural fluctuations (Lee & Lishman, 1975; Dijkstra, 2000; Riley Balasubramaniam, Mitra, & Turvey 1998). Autonomous reduction of optic flow that minimizes sway is interpreted as the utilization of perceptual information to increase, maintain or regain postural stability. We refer to this as the "*Autonomous control*" viewpoint. On the contrary following Stoffregen *et al.* (1999), there have been several papers that have shown that postural sway explicitly facilitates supra-postural task performance (Balasubramaniam & Wing, 2002). We refer to this as the "facilitatory" point of view.

Riley Stoffregen, Grocki, & Turvey (1999) have demonstrated that postural control strategies are varied adaptively to facilitate suprapostural performance. In their seminal paper, participants were placed in one of two experimental groups; "task-relevant" and "task-irrelevant". In the task-relevant group, participants were instructed to minimize deviations of a hanging curtain surround, whereas in the task-irrelevant group, curtain movement was inconsequential to task performance. The results showed support for the facilitatory viewpoint; postural fluctuations were reduced relative to baseline standing only when sway minimization was relevant to suprapostural performance – in the task-relevant condition where participants were explicitly instructed to minimize curtain movement. Postural fluctuations, therefore, are modulated to facilitate suprapostural performance and reflect the precision requirements imposed by conjoint suprapostural performance. This research demonstrated that sensory information does not always result in sway minimization. Several studies have since supported the facilitatory viewpoint by revealing reduced sway magnitude while performing concurrent motor or cognitive performance compared to quiet stance (Balasubramaniam, Riley, & Turvey, 2000, Dault *et al.*, 2001).

In the present study, we are interested in seeing if a simple non-verbal cognitive task, (involving a serial arithmetic problem) while simultaneously receiving delayed visual feedback of COP will exhibit an improvement or deterioration of balance in older adults. The study takes into consideration confounding factors related to cognitive task performance, since neither task requires verbal articulation nor is it not visual-spatial in nature. Specifically, we investigate how providing varying degrees of delayed visual feedback while simultaneously conducting a simple non-verbal cognitive task to the two groups will affect their ability to actively maintain balance. It is proposed that older subjects will exhibit more postural sway when asked to perform the cognitive-dual task relative to younger subjects. However, the younger subjects should exhibit less postural sway in the cognitive-dual task compared to the control conditions (Yeh *et al.*, 2010). We are interested in seeing if the additive beneficial effects seen when performing the cognitive dual task would be observed in older adults also. Finally, we predict that the effect of delayed visual feedback would have a destabilizing effect on postural control on both the younger and older subjects, where the effect of the delay would be proportional to COP variation.

Materials and Methods

Fifteen young healthy subjects (ten female and five male; age = 23.80 ± 3.32 years; height = 167.61 ± 7.89 cm; weight = 60.50 ± 10.59 kg) and fifteen healthy older subjects (five female and ten male; age = 2.13 ± 4.63 years; height = 167.77 ± 8.84 cm; weight = 72.27 ± 11.53 kg) participated in the study. All subjects reported no diagnosed skeleto-muscular disorders or balance impairments of any kind. Participants provided written consent following reading the informed consent form and after they were asked if further clarification regarding their expectations was needed. The Ethics Review Board at McMaster University approved the experimental protocol prior to the experiment. The identities of subjects were protected and any identifying information was kept in a locked office.

The centre of pressure (COP) data were collected by a force platform (OR6-2000, AMTI, Newton, MA, USA) and sampled at 100 Hz. Delayed visual feedback of the COP position was implemented by custom MATLAB$^{\text{TM}}$ code (7.9.0, The Mathworks, Natick, MA, USA) through a 19-inch LCD monitor placed at the subjects eye-level 70 cm away.

Subjects were asked to stand on the force platform with arms placed at their sides with their feet shoulder width apart, maintaining a comfortable position. A red dot (13 mm) at the center of the monitor corresponded to the visual target while a smaller white dot (10 mm) represented the subject's (real-time or delayed) COP position. Subjects were instructed to position their COP (white dot) overlap on to the fixed target (red dot) for visual trials. During the "eyes open" trials (no additional visual feedback provided) subjects were instructed to simply maintain upright balance while looking at a fixed dot. Foot position for individual subjects was determined prior to the experiment during calibration. The position corresponded to the position where the least amount of effort was spent to make COP position overlap onto the visual target. Foot positioning was kept constant for all trials by marking the outline of the subject's feet on the force platform with marking tape.

In the dual-task conditions, participants performed a simple, non-verbal serial arithmetic task. Prior to trial onset, participants received a two-digit number. Participants performed a series of six randomized arithmetic operations (addition or subtraction of a number less than 10) at a rate of one computation per 5 s interval. They computed the running sum of operations and verbalized their response following trial completion, thereby eliminating confounding articulation effects on COP displacements. The experiment consisted of ten conditions: eyes-open (EO) and four delayed visual feedback (DVF) conditions: 0, 300, 600, and 900 ms, and with or without a concurrent cognitive arithmetic task (C, NC). In the EO condition, no visual feedback of the subject's COP was provided and a cover was placed over the LCD monitor with a red dot in the middle for fixation. The 0ms condition refers to the participant receiving real-time feedback about their COP location.

Three 31 s trials were performed in each condition, resulting in a total of 30 trials per subject. Trial order was randomized within blocks (all conditions were randomly presented within each block) to minimize learning effects.

The first 0.9 s of collected data accounted for the length of the maximum visual delay. Therefore, only the last 30.1 s of each trial were used for AP COP time series analysis, resulting in a time series of 3010 points. Mean differences in sway variability (standard deviation) were contrasted across DVF and dual-task cognitive conditions using a 2 (Young, Older) $\times$ 2 (C, NC) $\times$ 5 (DVF: EO, 0, 300, 600, 900 ms) mixed factor analysis of variance (ANOVA) with repeated measures on the cognitive task and visual conditions. Greenhouse–Geisser correction factor for statistical degrees of freedom was used to correct sphericity violations (Mauchly's Test, $p < 0.05$). Post hoc analysis was performed with LSD for pair-wise means comparisons. Significance level was set at $p < 0.05$.

Results

The main findings are illustrated in Figure 1. Sway variability was found to be dependent on imposed visual delay (F (2.43, 67.99) = 12.66, $p < 0.0001$) and age (F (1, 28) = 30.37, $p < 0.0001$) but not on cognitive task performance (F (1, 28) = 0.14, $p = 0.71$). It was found that there was no significant interaction between DVF $\times$ cognitive task performance (F (4, 112) = 1.72, $p = 0.15$) and the three-way DVF $\times$ cognitive task $\times$ age (F (4, 112), $p = 0.28$) was also not significant. However there was a significant cognitive task $\times$ age interaction (F (1, 28) = 4.77, $p = 0.037$) and DVF $\times$ age interaction (F (2.43, 67.99) = 3.53, $p = 0.027$).

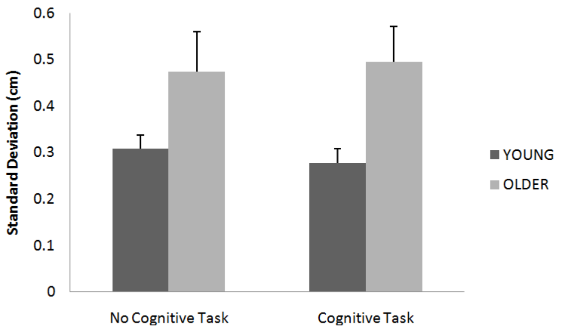

Fig. 1. Mean standard deviation of the AP COP time series in the presence and absence of the cognitive dual-task. The data are ensemble-averages collapsed across all vision conditions. The young group is shown in grey while the older group is shown in black. Error bars represent the standard deviation of the mean.

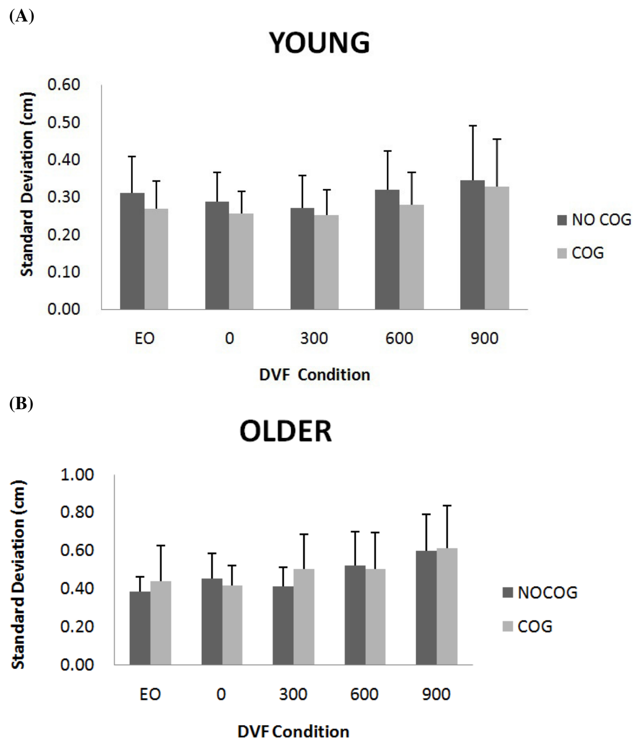

Fig. 2. A-B Mean standard deviation of the AP COP time series for the young (**A**) and older adults (**B**) in eyes open (EO) and DVF conditions (0, 300, 600, 900 ms).Vertical bars denotes the presence (*grey*) and absence (*black*) of the cognitive dual task. Error bars represent the standard deviation of the mean.

An examination of Figure 2 reveals the differences between the two groups as a function of the delayed visual feedback. Pair-wise comparisons revealed that sway variability in the following conditions were reduced relative to the latter condition: EO (M = 0.35, SD = 0.002 mm) and 900 ms ($M = 0.47$, SD = 0.003 mm) ($p < 0.0001$), 0 ms (M = 0.35, SD = 0.002 mm) and 600 ms (M = 0.41, SD = 0.003) ($p = 0.001$), 0 ms and 900 ms ($p < 0.0001$), 300 ms (M = 0.36, SD = 0.002 mm) and 600 ms ($p = 0.005$), 300 ms (M = 0.36, SD = 0.002 mm) and 900 ms ($p < 0.0001$), 600 ms and 900 ms ($p = 0.005$).

As expected, overall sway variability measured by AP COP variability in older subjects was greater than the young subjects. In addition, cognitive load had a significant effect on AP COP variability between the two age groups: DVF-cognitive task performance decreased AP COP sway variability in the young group whereas it increased AP COP variability in older subjects. It is thus suggested that older adults, in contrast, do not benefit from cognitive dual-task performance. This can be seen in Figure 1. Sway variability increased with increasing visual delay in both groups. However, older participants exhibited greater sway variability across all DVF conditions than young, which is summarized in Figure 2A-B.

Discussion

The study examined the extent to which sway variability was influenced by the interplay between delayed visual feedback and cognitive task performance in an upright postural stance. We examined whether the magnitude of sway variability attributable to imposed visual delay and cognitive load combined interactively or independently to influence postural control in both young and older adults. Results showed that DVF affected both the young and older subjects alike, whereas imposition of a cognitive task had showed differences between the two groups.

Upright balance control with the provision of delayed visual feedback (DVF) and the demand to attend to attentional dual tasks is of particular interest in the study of aging. It has been suggested that there is an increased likelihood of destabilization during the performance of cognitive dual tasks in older adults (Maylor & Wing, 2001; Rankin *et al.*, 2000; Lacour *et al.*, 2008), particularly when attention is directed to a cognitive activity. The general suggestion from this line of work is that engaging in cognitive tasks has a greater effect in older subjects than younger subjects since aging reduces the efficacy of the systems involved in postural control. This is because many different systems are integrated and work together to demonstrate the adaptive mechanisms involved in balance (Torres-Oviedo *et al.*, 2006). This decline has been attributed to reduced lower limb muscle strength, diminished information processing capacity, and most importantly, the age-related decline in multisensory integration (Huxhold *et al.*, 2006; Rankin *et al.*, 2000) Therefore it has been proposed that older individuals will need to trade-off performance in certain tasks to maintain postural control (Lacour *et al.*, 2008).

Our results showed that older individuals do not benefit from the cognitive-dual task. Rather, their performance and postural stability is adversely affected by the addition of a cognitive task. If simultaneous tasks can be performed without the integrity of either being compromised then neither task will suffer in performance. However, with increased difficulty, compromised control is seen in either the physical task of controlling posture or reduced performance is seen in cognitive task performance. The question of how this trade-off is organized remains unanswered to date. It has been suggested that mechanisms have evolved over time and been selected for to select information and allocate attention according to their importance (Pellecchia, 2003). Thus, from an ecological point of view, attention should be directed so that balance would be prioritized over other concurrent tasks (Holmes *et al.*, 2010) in the case of any perturbation or threat to stability.

As predicted, our results show increased DVF resulted in a proportional increase in sway variability in both groups (Dault *et al.*, 2003; Van de Heuvel *et al.*, 2009; Yeh *et al.*, 2010). In addition, this effect was more pronounced in the older subjects. The younger subjects exhibited decreased AP-COP variability and this is in agreement with our original hypothesis. These results offer some support for the idea that there is an optimal level of arousal where performance in a task will peak. As predicted by the Yerkes-Dodson Law (Huxhold *et al.*, 2006; Nagano *et al.*, 2006; Pellecchia, 2003; Yerkes & Dodson, 1908) extreme levels of arousal, at either end of the scale, would adversely affect motor performance. The level of attentional activity in the moderate cognitive-dual task is thus optimal for successful performance of both the physical task of balancing and the serial arithmetic task

It can be argued that when individuals are asked to focus their attention on maintaining balance, performance is worse since they are adopting an internal attentional focus (McNevin & Wulf, 2002; Wulf *et al.*, 2004). A relatively simple cognitive task increases the individual's ability to control their posture since it in a sense provides them with an external focus. This is in line with previous work from our group, where subjects engaged in the performance of physical supra-postural task (pole balancing) while engaged in a serial arithmetic task (Cluff, Gharib & Balasubramaniam, 2010). Interestingly, in this study, the manipulation of the focus of attention did not have any effect on the variability of postural sway and pole position. However, when participants performed an additional cognitive task while concurrently pole-balancing and standing, there was a significant decrease in overall variability in postural sway and pole displacement.

Within the pool of older subjects an observable dichotomy is apparent. There are individuals that are able to complete the cognitive task whereas there are subjects that display a lack of accuracy. Half of the older subjects had very poor accuracy with the non-verbal serial arithmetic task, where they made more than seven errors out of fifteen questions. This observation raises the concern that this group is either not capable of completing the serial arithmetic task or that they are engaging in trade-off behaviour. It would be interesting to investigate the two groups that emerged within the older subjects separately. Individuals who were not able to perform the cognitive task may exhibit decreased sway variability, thus providing further support for trade-off behaviour in favour of the "posture-first principle". In addition, older subjects were recruited from a gym where the members often engaged in physical activity a minimum of two times per week. This may present a potential confound, since these individuals are in a better physical condition than their non-active counterparts. Therefore, the individuals in the study may not be a true reflection of the abilities of the demographic.

In the present study, we limited our analyses to the AP axis. In future work, it would be interesting to apply this method to radial sway and fluctuations specific to the mediolateral (ML) axis (Maki & McIlory, 2005). The influence of a dual-cognitive task on ML fluctuations and lower-limb dynamics needs to be explored. Important questions regarding the independence of the control processes governing AP and ML sway could also be tested using this paradigm.

Overall, the main findings in this study is that sway variability increased with visual delay in both groups, however older participants exhibited greater sway variability across all DVF conditions. DVF-cognitive task performance decreased AP COP sway variability in the young group; however, older adults did not benefit from cognitive dual-task performance These results provide further support to the current literature that the insufficient or inappropriate attention allocation with aging and therefore compromised balance control. This observation is an interesting platform to further explore to see if the differences influence postural sway variability in older adults.

We are presently engaged in modeling efforts using a stochastic delay-differential model developed by Boulet *et al.* (2010) to study the role of priority switching between the various processes that go into the complex control of postural fluctuations. We are also presently engaged in collaborative efforts to look at the structure of long-range correlations observed in postural fluctuations to arrive at a model of how posture is controlled in the context of delayed visual feedback in general (Delignières, Torre, & Bernard, 2011).

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