Université de Montréal

Interaction Between Attentional and Proprioceptive Demands in Postural Control in Cervical Dystonia

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Résumé

La dystonie cervicale (DC) est un trouble du mouvement caractérisé par des postures et des mouvements anormaux du cou et de la tête. Dans la DC, les instabilités posturales ont été associées à une altération des sensations proprioceptives. La présente étude explore l'interaction entre les exigences proprioceptives et attentionnelles du contrôle postural dynamique dans la DC. Des participants sains et atteints de la DC ont effectué une tâche de limite de la stabilité posturale avec et sans vision, ainsi qu'une tâche secondaire cognitive de soustraction. Ces deux tâches ont été effectuées seules (tâche unique) ou simultanément (tâche double). La force de réaction au sol a été recueillie à l'aide d'une plateforme de force AMTI. Les limites fonctionnelles de la stabilité ont été quantifiées comme étant l'excursion maximale du centre de pression (COP) pendant l'inclinaison volontaire du corps dans quatre directions différentes. Les limites de la stabilité des patients DC étaient, en moyenne, plus petites que celles des témoins sains dans toutes les conditions. Cependant, leurs limites antéropostérieures étaient significativement réduites par rapport aux témoins dans la condition de tâche unique sans vision. De plus, les coûts attentionnels de la posture des patients étaient significativement plus élevés que ceux des sujets témoins dans la condition visuelle. Nos résultats soutiennent la théorie selon laquelle l'intégration sensorimotrice et les déficiences proprioceptives affectent le contrôle postural dynamique dans la DC. En outre, nos résultats suggèrent que les patients utilisent diverses stratégies pour s’adapter aux défis posturaux complexes imposés par la vie quotidienne.

Mots-clés: proprioception, attention, tâche double, trouble du mouvement neurologique, troubles d’équilibres

Abstract

Cervical dystonia (CD) is a movement disorder characterized by abnormal postures and movements of the neck and head. Postural instabilities in CD have been associated with impaired proprioceptive processing. The present study used a dual task paradigm to explore the interaction between the proprioceptive and attentional demands of dynamic postural control in CD. Healthy and CD participants performed a postural stability limit task with and without vision as well as a secondary cognitive subtraction task. These two tasks were performed alone (single task) or simultaneously (dual-task). Ground reaction force was collected using an AMTI force platform and center of pressure (COP) displacements were analysed. The functional limits of stability were quantified as the maximum COP excursion during voluntary leaning in four different directions. CD patients achieved, on average, smaller mean postural stability limits compared to healthy controls in all sensory-attentional conditions. However, their anteroposterior stability limits were significantly smaller compared to controls when vision was removed, particularly in the single task condition. Additionally, patients with CD decreased their stability limits relative to healthy controls when concurrently performing the attentional task under the visual condition. Thus, the attentional postural cost of CD patients was greater than the controls. Our results support the theory that sensorimotor integration and proprioceptive impairments affect dynamic postural control in CD. Furthermore, our findings suggest that CD patients use various adaptive strategies to cope with the sensory-attentional challenges imposed by complex postural situations in daily life.

Keywords: proprioception, attention, dual-task, neurological movement disorder, balance difficulties

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CHAPTER 1 - Literature Review

The following literature review will be organized around four major questions: 1) What is cervical dystonia?, 2) Does cervical dystonia influence proprioceptive processing?, 3) What is the impact of cervical dystonia on postural control?, 4) Does cervical dystonia interfere with attentional functions?

1.1 - What is cervical dystonia?

Cervical dystonia (CD), also known as *Spasmodic Torticollis*, represents the third most common chronic neurological movement disorder (Prudente et al, 2018). It is also the most common form of focal dystonia (Defazio et al, 2013) with an underestimated prevalence rate of 16.43 per 100,000 persons (Steeves et al., 2012). According to the *Dystonia Medical Research Foundation Canada (DMRFC)*, no less than 4000 people in Canada are affected by cervical dystonia. Furthermore, women are 3.5 times more likely to be affected by CD than men (LaHue et al., 2019). However, these figures only represent the tip of the iceberg, given that 50% of individuals with CD risk being misdiagnosed (Defazio et al., 2013).

Dystonia is a complex neurological movement disorder classified based on its clinical characteristics and etiology (Desrochers, 2019). In the context of this thesis, we will be concentrating on a form of focal dystonia, known as *cervical dystonia*, whose origin story remains idiopathic (Albanese et al., 2013; Avanzino and Fiorio, 2014; Desrochers et al., 2019). CD typically has an onset in adulthood between the ages of 21 to 65 years old. Many cases suggest a genetic component, though, acquired cases of CD have also been documented by brain injuries, viral infections, and neurodegenerative diseases, such as Parkinson's disease (Albanese et al., 2013). The main clinical symptoms associated with CD are abnormal intermittent and/or fixed painful postures of the head due to involuntary muscle contractions located at the neck. Scientists believe that the neural mechanism behind the relaxation of cervical muscles is altered in CD (Conte et al., 2019). Consequently, antagonistic muscles are often contracted as if to compete with the agonistic muscles for control of the neck (Cloud and Jinnah, 2012). However, the impaired neurological mechanisms causing these abnormal muscle contractions are not yet fully understood.

Dystonia is frequently initiated or worsened by voluntary movements and accompanied by tremor and pain (Charles et al., 2014; Patel et al., 2014).

The most effective and main treatment option for CD is localised injections of botulinum neurotoxin (BoNT) (Cloud and Jinnah, 2010; Albanese et al., 2015). The injection of BoNT into the affected cervical muscles induces a flaccid paralysis of the targeted muscles, consequently reducing spindle afferent activity (Albanese et al., 2010). As a result, the injections alleviate a great deal of pain that 75% of individuals with CD live with daily. Although injections with BoNT are the treatment of choice to reduce the overflow of muscle activation, they have limited efficacy on functional health (Charles et al; 2014; Patel et al., 2014; Klingelhoefer et al., 2021). The pain associated with CD has reduced the quality of life of many patients (Werle et al., 2014). More so that CD is now associated with several non-motor symptoms such as anxiety, depression, sleep disorders and sensory abnormalities (Contarino et al; 2016; Poliziani et al., 2016). Therefore, research dedicated to understanding the behavioural and/or the somatosensory mechanisms underlying the functional impairments in CD are of paramount importance.

1.2 - Does cervical dystonia influence proprioceptive processing?

Over several decades, numerous studies have suggested that a functional disturbance of communication, between the basal ganglia and cortical areas, can justify the presence of clinical motor symptoms, as well as deficits in movement planning and execution in dystonia (Berardelli et al., 1998; Gregori et al., 2008). However, a very limited number of studies assessed motor functions of patients with dystonia using motor tasks that are highly basal ganglia dependant (Desrochers et al., 2019). Therefore, the exact contribution of the basal ganglia in the symptomatology of patients with CD is not fully understood.

Over the last several years, the pathophysiology of dystonia has been re-evaluated. Researchers have recently proposed that dystonia is linked to the dysfunction of a complex neural network that includes not only, the basal ganglia-thalamic-frontal cortex and the inferior parietal cortex, but more importantly, the cerebellum (Avanzino and Fiorio, 2014; Conte et al., 2019). It is worth mentioning, in the context of this thesis, that the cerebellum receives massive somatosensory information; this input, is largely used for movement regulation and postural control (Avanzino and Fiorio, 2014; Patel et al., 2014; Conte et al., 2019; Desrochers et al., 2019).

While traditionally CD was considered a motor output disorder, it is now widely connected to sensorimotor dysfunctions; more specially, proprioceptive deficits (Desrochers et al., 2019). Proprioception is defined as the sense of position and/or movement of body segments one from the other, without aid of vision (Goble et al., 2009; Proske and Gandevia, 2012). Proprioception is a critical source of information used in everyday motor activities such as: maintaining posture, balance, and walking (Horak, 2006; Doumas et al., 2008; Pettorossi and Schieppati, 2014; Henry and Baudry, 2019). Both cutaneous and joint mechanoreceptors are sources of proprioceptive information. They are imperative for perceiving the position of distal body segments, as well as for signaling extremities in a range of motion. However, the proprioceptive feedback mediating the perception of movement and limb position arises mainly from the primary and the secondary endings of muscle spindles (Goble et al., 2009; Proske and Gandevia, 2012).

A plethora of studies using behavioral and neurophysiological methods have reported sensorimotor integration deficits in CD (Bove et al., 2007; De Pauw et al., 2017; Desrochers et al., 2019). Moreover, numerous studies have shown impaired neck proprioceptive processing in the pathophysiology of CD (Anastasopoulos et al., 2014; Popa et al., 2017). These reports highlighted the reduced acuity of both position and motion senses in patients with CD (Bove et al., 2004; Pelosin et al., 2009; Pettorossi and Schieppati, 2014). For instance, in a recent study by De Pauw and colleagues (2018), cervical sensorimotor control was assessed using a standard head repositioning task (joint position error). Blindfolded participants were asked to relocate their head as accurately as possible to a self-determined neutral position after performing an active movement (flexion or extension and left or right rotation of the neck). Their results stipulated strong evidence that cervical sensorimotor control, more specifically, proprioceptive integration was altered in CD patients compared to asymptomatic healthy controls.

Pelosin and colleagues (2009) requested participants to perform reaching movements with their upper limbs towards a given target. In the absence of vision, the accuracy of the reaching movements increasingly relied on proprioception. Interestingly, this study ultimately demonstrated that patients with CD have impaired proprioceptively-guided reaching movements. Cervical dystonia patients showed impaired trajectory formations during the reaching task. This finding suggested that proprioceptive sensation can also be impaired in body parts distant from the affected region (i.e., the neck). Such evidence supports the concept that proprioceptive dysfunction in CD may result from a failure in the central processing of somatosensory information (Avanzino and Fiorio, 2014). In addition, neurophysiological studies using transcranial magnetic stimulation (TMS) concur that there is a failure in the central processing of proprioceptive information in CD (Avanzino and Fiorio, 2014; Popa et al., 2018). CD patients, compared to healthy controls, displayed a reduction in the inhibition of the motor cortex excitability when stimulated by TMS. Altogether, these abnormalities provide substantiating evidence that cervical dystonia, is not only a motor, but also, a sensory disorder. In this perspective, it is important to understand how proprioceptive deficits in CD impair the efficiency and the safety of everyday interactions with the environment.

1.3 - What is the impact of cervical dystonia on postural control?

Postural control is essential for effective execution of countless postures and voluntary movements (Ivanenko and Gurfinkel, 2018). The perception of body sways and limits of postural stability are crucial for effective postural control and, notably, to avoid falls. This complex neural mechanism requires the integration of information from visual, vestibular, and proprioceptive systems (Horak et al. 1989). Thus, postural control is not only imperative for efficient day to day motor activities, but it is also an appropriate model to investigate sensorimotor integration (Peterka, 2002).

Proprioception has been suggested to be the sensory modality with the greatest contribution to postural control (Peterka, 2002). As such, numerous studies have demonstrated a strong association between proprioceptive acuity and performance on movement and balance tasks in aging and neurological disorders (Messier et al., 2003; Mancini et al., 2008; Blanchet et al., 2014). Additionally, the proprioceptive sense is the best predictor of postural instability (Henry and Baudry, 2019). Surprisingly, very few studies have investigated how proprioceptive loss affects postural stability in CD. Yet, reduced proprioceptive sensation may explain, in part, the postural instabilities in CD and thus, may be a key-contributing factor to the increased likelihood of falls.

Several studies suggested, that altered neck proprioceptive sensitivity in CD may lead to disturbances in posture and balance (Pettorossi and Schieppati, 2014; De Pauw et al., 2018). Experimentally-induced neck muscle fatigue as well as neck muscle vibration, both of which stimulate the muscle spindles, resulted in greater postural instabilities (Bove et al. 2007; Vuillerme and Pinsault, 2009). Additionally, in a study by Anastasopoulos and colleagues (2014), patients with CD exhibited difficulties in producing appropriate postural reactions to head-trunk rotations, presumably due to deficient proprioceptive feedback. Such corroboration supports the notion that proprioceptive feedback from the neck plays a primordial role in maintaining postural control (Popa et al., 2018).

Instabilities and fear of falls are frequently reported in CD (Zetterberg et al., 2015; Barr et al., 2017). However, only a few quantitatively investigated postural stability in patients with CD (Bove et al., 2007; Vuillerme and Pinsault, 2009; Barr et al., 2017). These previous studies reported contradictory findings, with some displaying enlarged antero-posterior and medio-lateral postural sways in quiet stance (Bove et al., 2007, De Pauw et al., 2018), while others reported no differences between healthy controls and CD patients (Moreau et al., 1999).

Of particular interest, De Pauw and colleagues (2018) investigated postural control during a quiet seated stance in CD patients. They measured the displacement of center of pressures (COP) of the body in CD patients and were compared to an age-matched control group. They found that the COP displacements were four times larger in CD patients when compared to the control group. These findings demonstrate a correlation between cervical sensorimotor impairments and postural control.

In summary, the previous studies have demonstrated the importance of the neck afferents in postural control. Although these findings are relevant, it is important to mention that decreased proprioception in the lower limbs contribute significantly to loss of stability and falls (Horak et al., 1990, Henry and Baudry, 2019). Likewise, maintaining one’s balance while standing relies on ankle strategy (Gatev et al. 1999). For instance, Warnica and colleagues (2014) demonstrated that active co-contraction of the ankle musculature increases postural sways observed during quiet standing. Consequently, ankle stiffness is one of many ankle strategy contributors that may influence one's balance (Sasagawa et al., 2009; Warnica et al., 2014). Therefore, while assessing the contribution of proprioception during standing, it is crucial to acquire a complete portrait of postural skills of CD patients. Relatedly, one study by Moreau and colleagues (1999) compared patients with CD in static and dynamic conditions, using an external perturbation paradigm (rocking platform) under eyes open and eyes closed conditions. CD patients showed greatest increases in body sway in the dynamic eyes closed condition. This study revealed that a complex postural task is more sensitive for the detection of postural control impairments in patients with CD.

It is noteworthy that most postural control studies in CD, were conducted in static stance and in the eyes open condition, when all exteroceptive information about the surrounding environment was available. Dynamic postural control is a major aspect of daily motor action. To our knowledge, no previous study has assessed dynamic postural control in the absence of external perturbation in different sensory conditions. Therefore, whether the postural abnormalities of patients with CD are exacerbated in more natural dynamic everyday life situations and whether, these postural deficits are linked to impaired proprioceptive processing and/or proprioceptive integration remains unclear.

1.4 - Does cervical dystonia interfere with attentional functions for postural control?

The ability to independently maintain postural stability and interact with the environment often requires the simultaneous performance of multiple cognitive and/or motor tasks. Successful performance on these concurrent tasks greatly depends on attentional functions (Yogev et al., 2008). Traditionally, postural control was considered an automatic or reflex controlled task requiring only minimal attentional resources (Woolacott and Shumway-Cook; 2000; Reilly et al., 2008). However, the past several of years have provided evidence against such assumption (Boisgontier et al., 2012).

Attention is a cognitive process that allows an individual to choose and to concentrate on a stimulus, while excluding other stimuli in its environment. An individual's capacity to process the information is limited by its attentional resources (Marois and Ivanoff, 2005; Wahn and König, 2017). Consequently, performing any task requires a given portion of that capacity to process the information to execute an outcome (Shumway-Cook and Woollacott; 2000). For instance, imagine you are at the beginning of a crosswalk and wish to cross the street. There are no lights present and no cross guards. It is up to you to look both ways before and while crossing the street, until you have reached the sidewalk on the other side. In this situation, your attentional resources are shared between walking while maintaining a stable posture and looking both ways for oncoming cars. Both tasks must be done concomitantly and effectively to cross the street safely. Now, if these simultaneous tasks require more than your total information processing capacity, then these two tasks compete for the same attentional resources and the performance on either or both tasks may deteriorate (Wickens, 1989; Pashler, 1994; Shumway-Cook and Woollacott, 2000). For instance, using the previous example, if one is using more attentional resources to look for oncoming cars because they fear getting hit by a car, they might trip over their own feet and fall. This real-world situation underscores the importance of understanding factors affecting simultaneous actions and attentional functions in different populations.

1.5 - Dual Task Paradigm to Investigate Postural Control

Research for studying the interaction between attention and postural control has extensively used the dual task paradigm, in which postural control (considered the primary task) and a secondary attentional task are performed simultaneously (Doumas et al., 2009; Brustio et al., 2017; Potvin-Desrochers et al., 2017). According to Baione and colleagues (2021), if the enactment of performing both tasks simultaneously is worse than when performing only one task at a time, it may be assumed that the process controlling the two tasks is impeded from exceeded neural processing resources. From this perspective, the extent of deteriorated performance may reflect the degree to which the two tasks shared attentional resources. That is, the degree to which postural control depends on lower-level automatic processing or substantially involved higher level-controlled processing requiring attentional resources (Talelli et al., 2008; Demir et al., 2020).

The maintenance of postural stability and its associated attentional demand or ‘cost’ has been extensively assessed using a wide range of dual-task designs (Doumas et al., 2009; Boisgontier et al., 2012; Montero-Odasso et al., 2012; Brustio et al., 2017). The dual task paradigm is therefore an effective way to assess the interaction between motor and attentional resources. Additionally, dual task performance relies on several executive functions involved in the planning, monitoring, and execution of compound tasks (Hausdorff et al., 2008; Hazeltine et al., 2006; Masquestiaux et al., 2018).

Although several studies have largely presented impaired postural control in CD, in relation to dystonic postures and/or abnormalities in sensorimotor integration, we know very little on the contribution of attentional factors on postural control in CD. Several studies assessed patients suffering from varying neurological movement disorders, such as: Parkinson’s disease (Raffegeau et al., 2019), Huntington’s disease (Purcell et al., 2019), essential tremor (Rao et al., 2013) and Tourette syndrome (Lemay et al., 2010). Their findings suggest that executive functioning deficits were present and consequently, severely reduced the dual task performance and increased their risk of falls.

The clinical representation of CD does not include cognitive abnormalities. However, some studies have shown various altered aspects in cognition. Romano and colleagues (2014) underlined the difficulties in working memory, processing speed, visual motor ability and short-term memory in patients with CD. These findings may suggest the presence of an alteration in the availability of the functional resources and potentially, a modification of the cognitive-motor interactions in CD. Given that dual tasking requires the modulation of activities of many specialized information-processing systems, one may question whether CD alters the ability to perform a postural task concurrently with a cognitive subtraction task.

Presently, only two recent studies have investigated the effect of dual tasking on postural stability in CD patients. Demir and colleagues (2020), aimed to evaluate postural stability in CD patients and the effect of an attentional task on postural stability, in eyes open and in eyes closed conditions. They discovered that the effect of dual tasking and performing a demanding postural task (i.e., tandem stance) was highly detrimental to postural stability in CD patients. However, it is important to note that the cognitive performance of the participants in this study was not evaluated. Additionally, the attentional task was only performed simultaneously with the postural task in the eyes open condition. Thus, it is not possible to estimate the extent to which participants with CD continuously mobilized their attentional resources when performing the postural task and whether the mobilisation of their attentional resources is altered in a demanding proprioceptive context.

Furthermore, Baione and colleagues (2021) evaluated whether the addition of a cognitive-attentional task negatively affects postural control and balance in cervical dystonia patients. Their findings revealed that CD patients, compared to healthy controls, were less stable while performing simultaneously the postural task and the very demanding cognitive-attentional task. Hence, postural instabilities increased with the complexity of the cognitive-attentional task.

The findings from Demir et al., (2020) and Baione et al., (2021) substantiate the susceptibility of a dual tasking protocol in the context of postural control in CD patients. Both studies, used a quiet standing task in eyes open condition to perform their dual task protocol. Over the last two decades, numerous studies have demonstrated the interaction between cognitive processes and postural control. However, one critical study provided evidence that proprioceptive processing is associated to an attentional cost (Yasuda et al. 2014). The authors used a dual task paradigm which included an ankle position-matching task and a cognitive subtraction task. As a result, they observed that allocating resources towards the challenging cognitive task, compromised the ankle proprioceptive performance. This finding is essential, as ankle proprioception is critical for postural control in most daily activities (i.e., standing and walking). It is therefore plausible, that the increased attentional demand of postural control in CD, may in part, be explained by the increased attentional resources directed to the processing of proprioceptive information. This inquiry might be clarified by evaluating the performance of a dual task paradigm in CD patients, with and without vision to increase the reliance on proprioceptive sensations.

Moreover, none of these previous studies have evaluated the cognitive performance in a control condition (i.e., sitting) and compared it to the dual task cognitive performance (i.e., postural, and cognitive tasks performed concurrently) in CD. Consequently, the attentional cost of introducing a secondary attentional task has yet to be calculated in CD patients. This information is essential to evaluate the mechanisms and strategies used by CD patients when they are faced with dual tasks in everyday life situations.

Recently, our colleagues assessed the interaction between proprioception and attention in postural control of healthy seniors (Vermette et al., 2021). Participants performed a dynamic postural stability limit task and a cognitive subtraction task separately and simultaneously, in eyes open and in eyes closed conditions. Expectedly, the cognitive performance of seniors significantly declined when simultaneously performing the postural task. This effect was exacerbated in the eyes closed condition when proprioceptive demand was greater. These findings highlight the modification of proprioceptive sensitivity and the reduced efficacy of automated processing in seniors; thereby increasing the cognitive load associated to postural control.

Very few studies have evaluated natural perturbations that occur in a functional task, such as standing and leaning in CD. Since decline in proprioceptive and attentional resources have been both associated with risk of falls, investigating the link between attention, proprioception and postural control in CD is of essential clinical value. Such knowledge would be advantageous to develop specialized interventions to preserve proprioceptive function and postural control in CD patients, with the objective of increasing their quality of life.

CHAPTER 2: Objective and Hypotheses

2.1 – Objective

A major innovative aim of this project is to investigate the interaction between the proprioceptive and attentional demands of dynamic postural control in patients with cervical dystonia (CD). We will use a dual-task paradigm, involving a dynamic postural stability limit task and a cognitive subtraction task. These tasks will be performed separately and simultaneously. The postural task will be assessed in eyes open and in eyes closed conditions, to manipulate proprioceptive demands. This is essential to dissociate between disturbances in proprioception from potential deficits in visual processing, in visuo-proprioceptive integration or in the motor component of postural control that may occur in CD. Moreover, the addition of the cognitive task to each of these sensory conditions, will allow the dissociating between impairments in proprioceptive processing, from anomalies in allocation of attentional resources of postural control in CD.

2.2 – Hypotheses

1. First, we hypothesize that patients with CD will display smaller postural stability limits than healthy participants in absence of vision in the single and dual task conditions, due to an increase demand for proprioceptive processing.

2. Secondly, since processing proprioception also has an attentional demand, we hypothesize that the effect of removing vision on postural stability limits of patients with CD will be greater than healthy participants when performing the postural and cognitive tasks simultaneously (dual task), due to their difficulty to concurrently cope with high proprioceptive and cognitive demands.

3. Thirdly, we hypothesize that the performance of participants with CD in the cognitive subtraction task will be most affected when concurrently performing the postural and

cognitive task in the absence of vision (dual task), due to their reduced functional attentional reserve.

CHAPTER 3: Methodology

3.1 - Participants

Ten participants with primary cervical dystonia (CD) (mean age: 59.4; range 31-73 years of age) and seventeen healthy aged-matched adults (control group) (mean age: 55.2; range 31-63 years of age) participated in this study after providing informed consent, approved by the institutional ethics review board of both, the Université de Montréal, and the Institute of Geriatric's Research Centre (CRIUGM) (Approved number: CER VN 2021-21-46).

Participants were included if they were classified as sedentary, according to the *CSEP-Questionnaire on physical activity and sedentary behaviour*, had normal or corrected-to-normal vision and normal hearing. Participants were then asked to complete a general questionnaire disclosing age, sex, and education status. They were also screened for mild cognitive impairments using the *Montreal Cognitive Assessment Form* (MoCA) (Nasreddine et al., 2015). Participants with CD were included if they had been showing typical clinical symptoms (i.e., anterocollis, retrocollis, laterocollis and head tremors), received regular Botulinum Toxin injections, and were followed by a CD specialized Neurologist (Dr. Sylvain Chouinard) for at least three prior years. All participants were excluded if they suffered from musculoskeletal injuries affecting their ability to maintain an upright posture, and or scored less than 26/30 on the MoCA. In addition, controls were excluded if they possessed a history of neurological conditions.

The participants in the control group were recruited through word of mouth and tested at the *Centre de recherche de l'Institut universitaire de gériatrie de Montréal (CRIUGM),* while the participants with CD were recruited by Dr. Sylvain Chouinard and tested at the *Centre de traitement neurologique Montréal*, the largest clinic for the diagnosis and management of Dystonia in Montreal. All participants were evaluated in a single experimental session.

3.2 – Experimental Set Up and Conditions

3.2.1 – Dynamic Postural Stability Limit Task

The experimental set up and the dynamic postural stability limit task used in this study, were inspired by, the various visual conditions used in a previous study conducted by Blanchet and colleagues (2014). During each trial, participants stood barefoot on a force plate, with their arms crossed on their chests while maintaining an upright quiet standing position. The standard stance position used was that established by Maki and Mcllroy (1997). Prior to the experiment, participants performed a practice trial to ensure that the protocol and tasks were well understood. During the experiment, no performance feedback was given to the participants once the testing began.

The total duration of each trial was 100 seconds. Participants were instructed to maintain an upright standing position for 60 seconds, then upon hearing an auditory signal (from the application "multi-Timer", version 6.12.1 by the developer Sergey Astakhov) they were instructed to lean maximally in one of four directions (forward, backward, leftward, or rightward), as far as possible while keeping their firmly fixed feet on the force plate and avoiding any compensatory hip flexion movements. Each participant was asked to maintain their maximum leaning position for 10 seconds, until they heard a second auditory signal (from the application "multi-Timer"), to subsequently return to their initial quiet standing position for an additional 30 seconds.

3.2.2 - Sensory Condition

Participants were asked to perform the dynamic postural stability limit task in eyes open and eyes closed conditions. In the visual condition (i.e., eyes open), participants were instructed to fixate on a target (measuring 2 cm diameter) displayed in front of them (2 m distance) at eye level to ensure that there was a consensus of the head position during all trials, for each participant. In the non-visual condition (i.e., eyes closed), participants were instructed to keep their eyes closed during the data collection but were allowed to open their eyes in between trials. Participants were encouraged to remember the target's position during the eyes closed condition, to keep their head in the same position across all trials.

3.2.3 – Attentional Condition

The secondary attentional task consisted of a continuous randomized mathematical subtraction of minus three (n-3) from a list of 17 randomized two-digit numbers, set at an automatized continuous speed of 2.0 seconds. Participants were asked to give their response to each automated number out loud.

Prior to the experiment, a preview of three random two-digit numbers was presented to participants to allow them to familiarize themselves with the speed of the attentional task. A bank of ten varying sequences of two-digit numbers was created and used for each experimental session to avoid repetition of the same sequence. Throughout the experiment, no performance feedback was given to the participants once the testing had begun.

Once the consent form was signed and the protocol was explained, the participants were asked to perform the attentional task, while sitting down on a chair and eyes opened. The trial served as a control condition.

Following the control trial acquisition, participants were asked during certain trials to perform the dynamic postural stability limit task and the attentional task simultaneously. During the initial quiet standing stance of the protocol (60s), an automated sequence of two-digit numbers were manually initiated after the first initial 30 seconds of the quiet standing stance. The sequenced randomized numbers were timed to stop once the participants had to return to their initial quiet standing stance position (last 30s of the trial).

3.2.4 – Experimental Sequence

The entire experiment involved four experimental conditions. The order of the experimental conditions was counterbalanced using the following sequence (Figure 1):

<table>
<tr><th colspan="5">EXPERIMENTAL SEQUENCE ORDER</th></tr>
<tr><td colspan="5">A</td></tr>
<tr><td colspan="5">→</td></tr>
<tr><td>SECONDARY ATTENTIONAL TASK (SITTING)</td><td>EO</td><td>EO + 2nd</td><td>EC</td><td>EC + 2nd</td></tr>
<tr><td colspan="5">←</td></tr>
<tr><td colspan="5">B</td></tr>
</table>

Figure 1 A visual representation of the two varying experimental sequence orders used, where eyes open represented EO; eyes closed represented EC; and the secondary attentional task represented 2nd. Participants either underwent sequence A (starting with the attentional control condition and ending with EC + 2nd) or sequence B (starting with EC + 2nd and ending with the attentional control condition).

A complete data set includes one control attentional sitting trial and one maximal leaning movement for each of the four directions, for four experimental conditions (eyes open (EO), eyes closed (EC), eyes opened and closed with cognitive task (EO+2ND and EC+2ND)). As a result, there is a total of 16 trials per experiment and one control trial acquisition for the attentional task.

3.3 - Kinetic Recordings and Data Analysis

3.3.1 – Dynamic Postural Stability Limit Task

An ACG-O (AccuGait-Optimized) force plate (AMTI, Inc.) was used to collect the vertical and horizontal ground reaction force data for the dynamic postural stability limit task. Data collection and processing were performed using AMTI's Balance Clinic software (version 1.5.3). The functional limits of stability were analyzed and derived from the center of pressure (COP) displacements, during the 10s interval of the maximal leaning stance that each participant had to execute while on the force plate for each leaning direction. Moreover, the anterior-posterior and medial-lateral directions were derived from the vertical forces of the total COP displacements (Henry et al., 2001).

The summation of the maximal values for the anterior and posterior leaning directions were combined to represent the total maximum COP excursion along the anteroposterior axis. Similarly, the leftward and rightward maximal leaning direction values were combined to represent the mediolateral axis.

3.3.2 – Secondary Attentional Task

The photobooth video application (version 12.2) on a MacBook Air was used to record, analyze, and compute the mathematical subtraction results for each trial.

3.4 - Performance

3.4.1 – Dynamic Postural Stability Limit Task

Within different sensory conditions, participants with CD were compared to healthy aged-matched controls in each direction (forward, backward, leftward, and rightward). The trials were all recorded on a MacBook Air using the photobooth video application (version 12.2) and were later analyzed to ensure the task parameters were respected. The following variables were computed:

1. The limits of stability (maximal COP excursion in cm): were calculated as the difference between the mean steady state COP position during the initial quiet standing and the maximum COP excursion reached during the maximal leaning position in each direction.
2. The COP RMS (root mean square in cm): represents the standard deviation of the COP displacements during the maximal leaning position in each direction.

3.4.2 - Secondary Attentional Task

3. The percentage of correct answers was computed using the following equation:

$$Performance\ Score\ (\%) = \frac{\#\ of\ total\ correct\ answers}{17}\ X\ 100$$

The total number of correct answers was analyzed for each trial and then divided by the total possible correct answers (seventeen).

3.4.3 - The Dual-Task Cost (DTC)

The DTC was the final variable calculated to evaluate the effects of an additional cost imposed on the single task or performance in the dual-task setting (the dynamic postural stability limit task combined with the attentional task). The postural DTC was calculated using the following equation:

$$Postural\ DTC\ (\%) = \frac{single\ task - dual\ task}{single\ task}\ X\ 100$$

The single task consisted of the dynamic postural stability limit task, either with eyes opened or with eyes closed, and the dual task consisted of performing both postural and attentional tasks simultaneously, with either eyes open or with eyes closed (Li et al., 2018).

The following equation was used to compute the attentional DTC:

$$Attentional\ DTC\ (\%) = \frac{single\ task - dual\ task}{single\ task}\ X\ 100$$

Where the single task consisted of the secondary attentional task in the control sitting condition, and the dual task consisted of performing the postural and attentional tasks simultaneously, either with eyes opened or with eyes closed (Li et al., 2018).

3.5 - Statistical Analysis

3.5.1 - Sensory-Attentional Analysis

To calculate the effect of the sensory and attentional conditions on the postural limits of stability and the variability of the COP displacements of CD participants and healthy controls, two four-way factor repeated measure ANOVAs (2 groups x 2 sensory conditions x 2 attentional conditions x 2 directions) were used. The magnitude of the postural stability limits and the mechanisms involved in postural control, along the anteroposterior (anterior and posterior) and mediolateral (left and right) axes are known to be different (Blanchet et al., 2021). Thus, the limits of stability long these two axes were analyzed sin two separate ANOVAs. Moreover, post-hoc pairwise comparisons were conducted using Bonferroni correction and a two-tailed significant alpha (p) level < 0.05.

3.5.2 - Attentional Performance Analysis

The effect of the secondary attentional task was assessed under single and dual task conditions in CD participants and healthy controls, using a two-factor repeated measure ANOVA (2 groups x 3 sensory-attentional conditions). The three sensory-attentional conditions considered in this analysis are: 1) the attentional task while sitting, 2) the attentional and postural task performed simultaneously in the eyes open condition, and 3) the attentional and postural task performed simultaneously in the eyes closed condition (when proprioceptive demand is greater). The anteroposterior (anterior and posterior) and mediolateral (left and right) directions were assessed using two separate ANOVAs. Moreover, the post-hoc pairwise comparisons were made using Bonferroni correction and a two-tailed significant alpha (p) level < 0.05.

CHAPTER 4: Results

4.1 - Limits of Stability

4.1.1 - Anteroposterior Axis

CD participants achieved systematically smaller mean postural stability limits compared to healthy aged-matched participants, in all sensory-attentional conditions along the anterior and posterior leaning directions (Figure 2AB). However, the group effect did not reach the significance level (F (1,26) = 37.177, $p = 0.054$, ${}_{p}n^{2} = 0.140$). As expected, the stability limits of participants were reduced when leaning posteriorly compared to the anterior direction. In addition, both groups of participants decreased the magnitude of their stability limits in the eyes closed relative to the eyes open conditions. These observations were supported by both a main effect of leaning direction (F (1,26) = 36.390, $p < 0.05$, ${}_{p}n^{2} = 0.593$) as well as a main effect of sensory condition (F (1,26) = 43.288, $p < 0.05$, ${}_{p}n^{2} = 0.634$).

Furthermore, patients with CD and controls often showed a slight decrease in their average stability limits when concurrently performing the attentional task. Accordingly, a main effect of the attentional condition was found (F (1,26) = 4.941, $p < 0.05$, ${}_{p}n^{2} = 0.165$). The ANOVA also revealed a significant interaction between group, sensory conditions, and attentional conditions (F (1,26) = 5.659, $p < 0.05$, ${}_{p}n^{2} = 0.185$). Post hoc analyses indicated that the difference between group only reached the significance level in the eyes closed condition when there were no additional attentional requirements, i.e., in the single task condition ($p < 0.05$, Figure 2AB).

4.1.2 - Mediolateral Axis

In a similar manner as for the anteroposterior axis, CD participants demonstrated smaller mean postural stability limits compared to aged-matched controls, in all sensory-attentional conditions along the mediolateral directions (Figure 2CD). These observations between groups were greater along the mediolateral than the anteroposterior axis. As a result, the ANOVA revealed a significant main effect of group (F (1,26) = 6.273, $p < 0.05$, ${}_{p}n^{2} = 0.201$). Moreover, the limits of stability of both groups of participants also decreased in the eyes closed relative to the eyes open conditions. Accordingly, a main effect of sensory condition was also found ($F(1,26) = 28.651$, $p < 0.05$, ${}_{p}n^2 = 0.534$).

4.1.3 – Figure 2-AD: The Limits of Stability in CD and Healthy-Aged Matched Adults

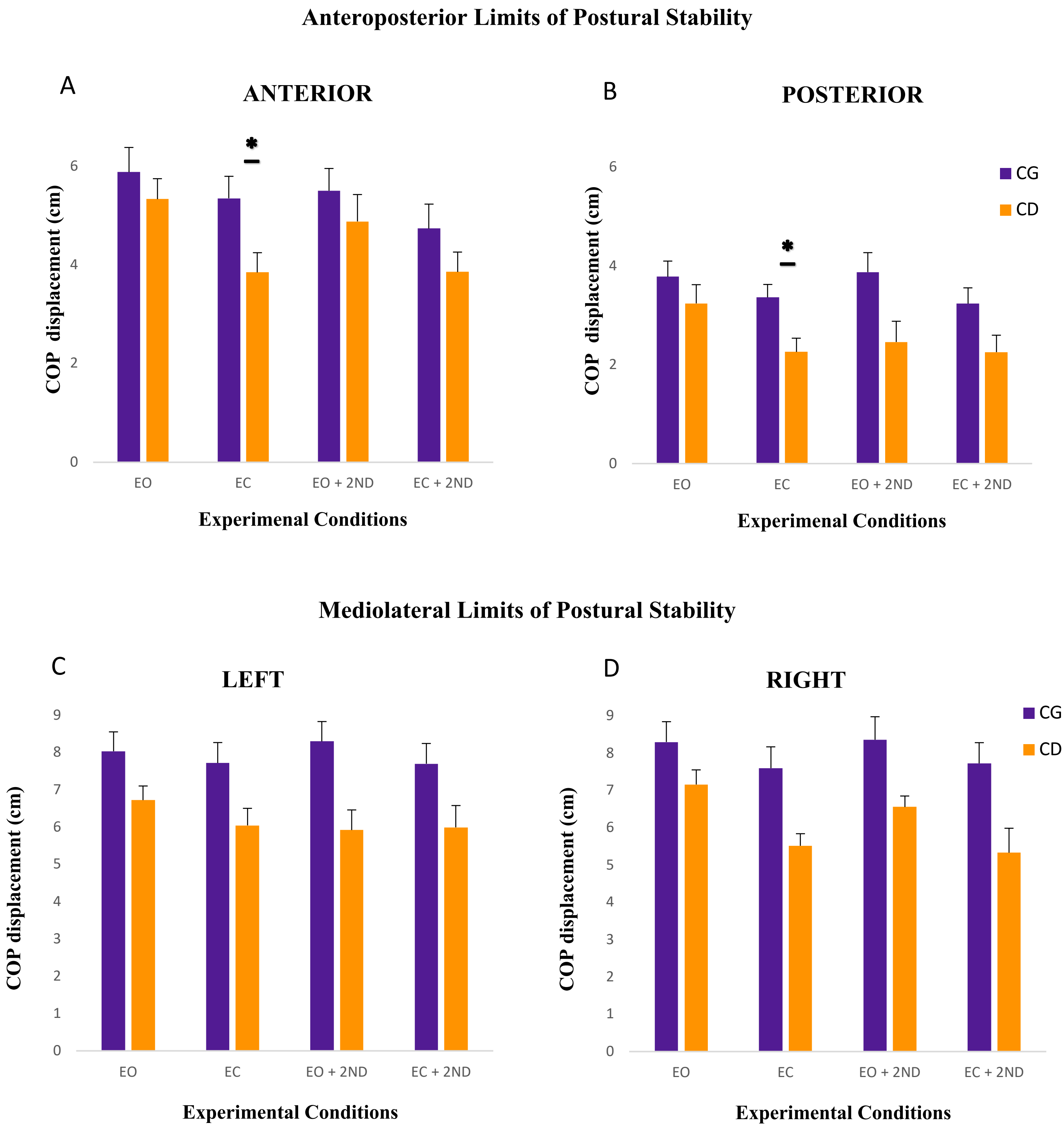


Figure 2A-D Limits of postural stability (LOS) in the anterior (A), posterior (B), left (C) and right (D) leaning directions, measured as the centre of pressure displacement during maximal leaning from quiet standing in the four experimental conditions (EO: eyes open/single task, EC: eyes closed/single-task, EO + 2ND: eyes open + attentional task, EC + 2ND: eyes closed + attentional task) for CD and healthy aged-matched adults along the anteroposterior and mediolateral axes. *Error bars* represent SE of the mean (SE)

4.2 - Root Mean Square

4.2.1 - Anteroposterior Axis

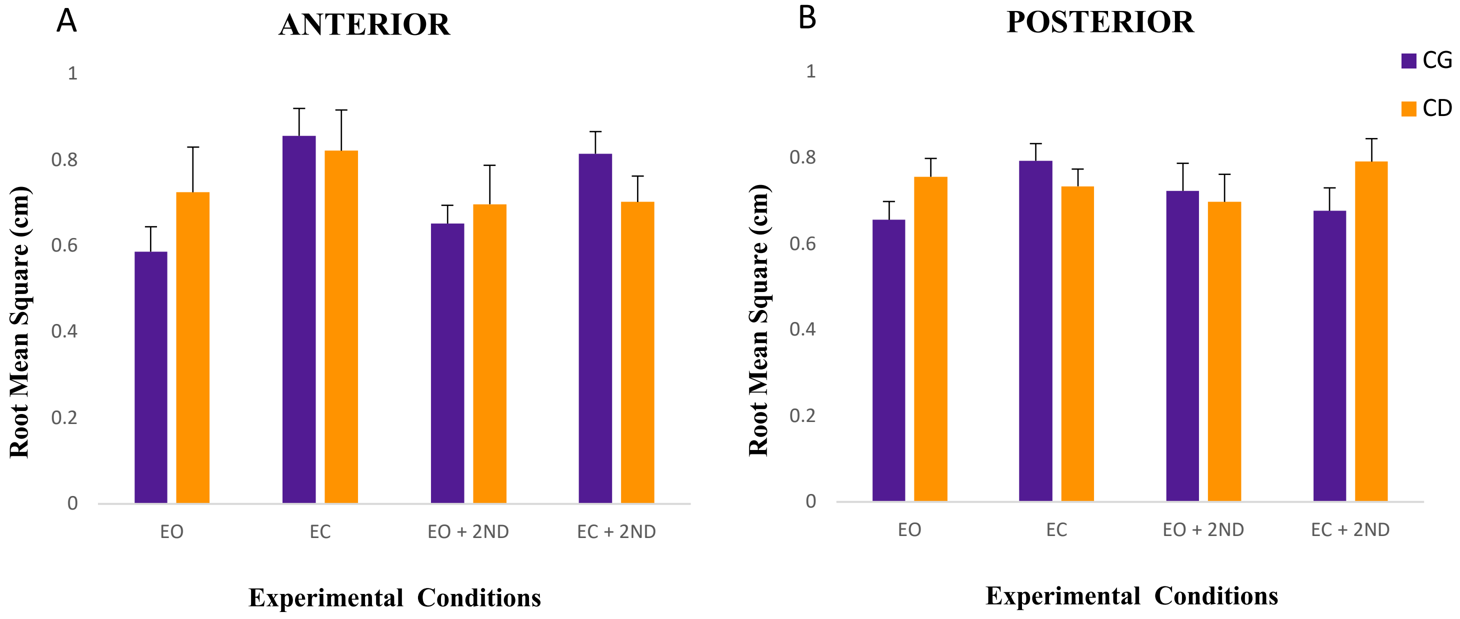
The magnitude of COP variability measured during the maintenance of stability limits was relatively similar between patients with CD and healthy controls, in all sensory-attentional conditions. As such, there was no significant group effect (F (1,26) = 0.005, $p > 0.05$, ${}_{p}n^{2} = 0.000$). However, participants in both groups often exhibited greater COP variability in the eyes closed compared to the eyes open condition. This trend was seen in both attentional conditions as well as along both directions of the anteroposterior axis (Figure 3AB). Accordingly, the ANOVA revealed a main effect of sensory condition (F (1,26) = 7.995, $p < 0.05$, ${}_{p}n^{2} = 0.242$). Furthermore, the COP variability remained unaffected by the addition of the secondary attentional task (F (1,26) = 0.506, $p > 0.05$, ${}_{p}n^{2} = 0.020$).

4.2.2 - Mediolateral Axis

Relative to the anteroposterior axis, there was also no main effect of group on the COP variability measured for patients with CD and healthy controls in the mediolateral axis (F (1,26) = 0.764, $p > 0.05$, ${}_{p}n^{2} = 0.030$). Though, both groups of participants displayed greater COP variability in the eyes closed relative to the eyes open condition in both attentional conditions (Figure 2CD). The ANOVA revealed a main effect of sensory condition (F (1,26) = 10.608, $p < 0.05$, ${}_{p}n^{2} = 0{,}298$), whereas no effect of attentional condition was found (F (1,26) = 0.209, $p > 0.05$, ${}_{p}n^{2} = 0.008$). The variance analysis also revealed an interaction between group, sensory condition, and leaning direction (F (1,26) = 5.201, $p < 0.05$, ${}_{p}n^{2} = 0.172$). However, post hoc analyses did not reveal any between-group difference in COP variability across all conditions ($p > 0.05$).

4.2.3 – Figure 3A-D: Root Mean Square of Stability Limits in CD and Healthy Aged-Matched Adults

Anteroposterior Root Mean Square



Mediolateral Root Mean Square

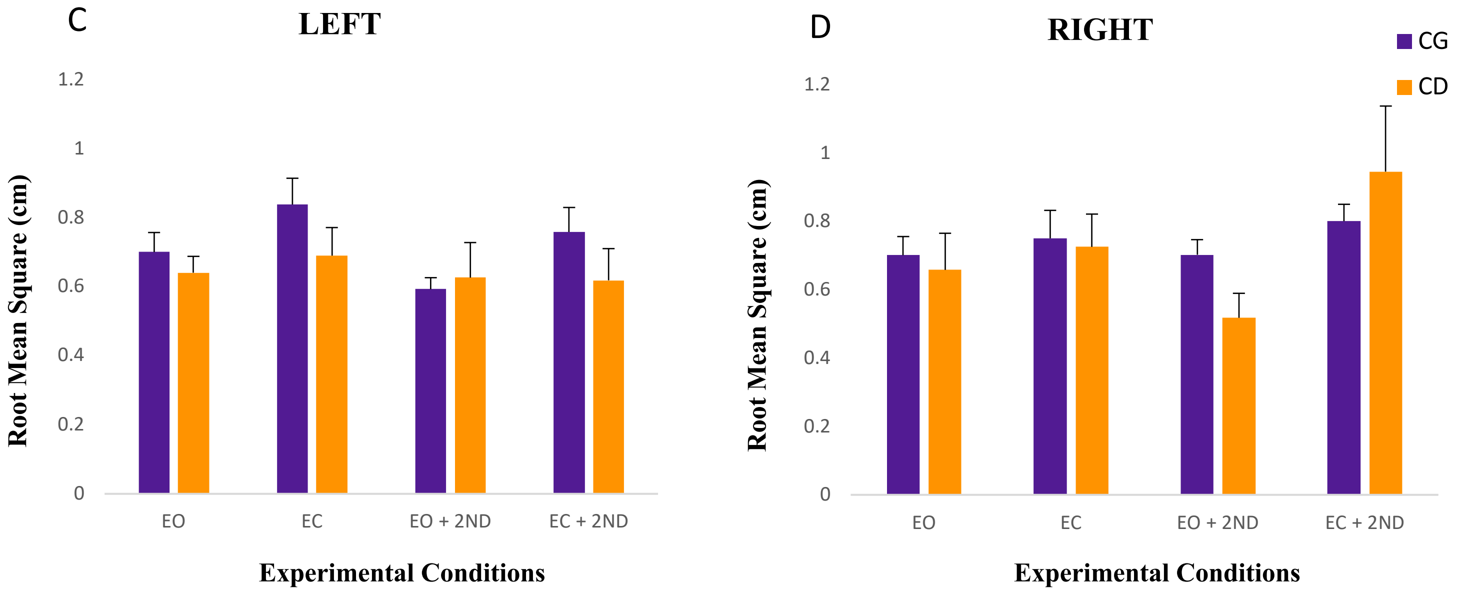


Figure 3A-D Variability in the maintenance of the limits of postural stability in the anterior (A), posterior (B), left (C) and right (D) leaning directions, measured as the root mean square (RMS) during maximal leaning phase in the four experimental conditions (EO: eyes open/single task, EC: eyes closed/single-task, EO + 2ND: eyes open + attentional task, EC + 2ND: eyes closed + attentional task) for CD and healthy aged-matched adults along the anteroposterior and mediolateral axes. *Error bars* represent SE of the mean (SE)

4.3 - Attentional Task Performance

4.3.1 – Overall Attentional Task Performance

Participants with CD made, on average, more errors (i.e., lower performance score) in the attentional task compared to healthy aged-matched adults in all attentional conditions (Figure 4). A variation in the performance scores was also noted in the attentional task among each group of participants. As a result, the ANOVA indicated a non-significant group effect (F (1,26) = 4.786, p = 0.071, $_{p}n^2$ = 0.444).

4.3.2 – Figure 4: Secondary Attentional Task Performance in CD and Healthy Aged-Matched Adults

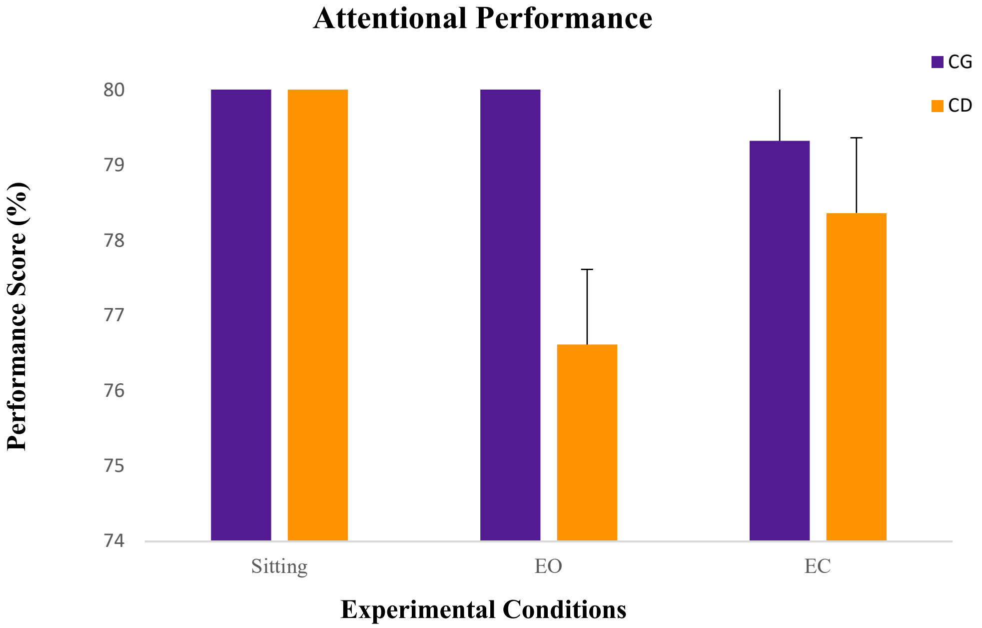


Figure 4 The average attentional task performance of the four leaning directions (anterior, posterior, left and right) measured as a percentage of the correct answers in each trial in the two experimental conditions (EO: eyes open and EC: eyes close) for CD and healthy aged-matched adults along the anteroposterior and mediolateral axes. *Error bars* represent SE of the mean (SE)

4.4 - Dual Task Costs

4.4.1 – Postural Dual Task Cost

The effect of adding the secondary attentional task to the maximal leaning task, did not substantially degrade the limits of stability of healthy aged-matched controls. As a result, they displayed small and similar dual task costs (DTC) of the postural task in the eyes open and eyes closed conditions (Figure 5). By contrast, patients with CD showed a larger deterioration of their stability limits when simultaneously performing the postural and the attentional tasks in the eyes open condition only. Therefore, their mean DTC was greater than that of the controls when vision was available. Consistent with these observations, the ANOVA on DTC values did not find a significant group effect (F (1,26) = 3.364, $p = 0.069$, ${}_{p}n^2 = 0.031$). However, there was a significant group by sensory condition interaction (F (1,26) = 9.176, $p < 0.05$), ${}_{p}n^2 = 0,080$). Post hoc tests confirmed that the DTC of patients with CD are significantly greater than those of healthy controls in the eyes open condition ($p < 0.05$).

4.4.2 – Attentional Dual Task Cost

The performance in the attentional task when concurrently performing the postural task was also assessed in patients with CD and healthy controls. CD patients and healthy aged-matched controls presented a similar small decline in the attentional task in the dual task condition performed with and without vision. Accordingly, the analysis of the DTC of the attentional task did not reveal any significant difference between groups in both sensory conditions (F (1,26) = 0.846, $p > 0.05$, ${}_{p}n^2 = 0.008$).

4.4.3 – Figure 5: The Postural Dual Task Performance in CD and Healthy Aged-Matched Adults

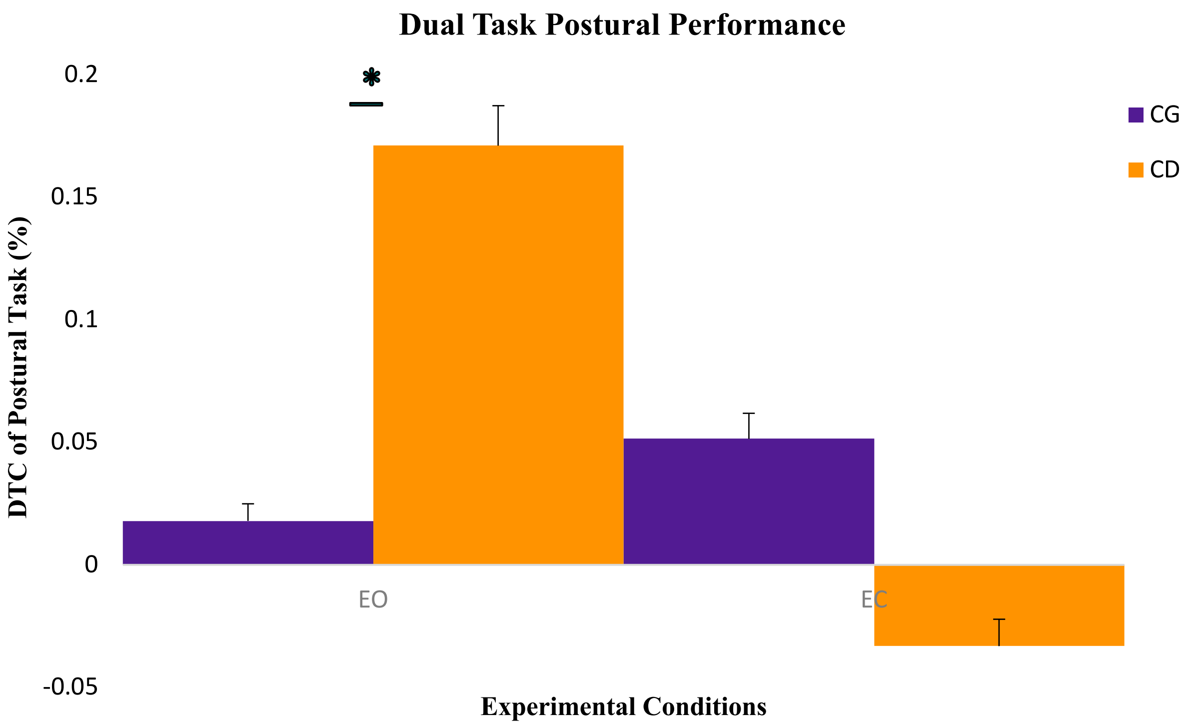


Figure 5 The average dual task costs (DTCs) of the postural stability limit task of the four leaning directions (anterior, posterior, left and right) in the two experimental conditions (EO: eyes open, EC: eyes closed) for CD and healthy aged-matched adults along the anteroposterior and mediolateral axes. *Error bars* represent SE of the mean (SE)

CHAPTER 5: Discussion

5.1 – Summary of Main Findings

The present study is the first to investigate the interaction between proprioceptive and attentional demands of dynamic postural control in CD. First and foremost, patients with CD showed smaller mean stability limits relative to healthy controls in all sensory-attentional conditions. However, this group effect was only significant in the mediolateral axis. In addition, CD and healthy aged-matched participants decreased their stability limits and increased their COP variability in the absence of vision when their reliance on proprioception was greater. As compared to aged-matched controls, patients with CD significantly reduced their anteroposterior stability limits in the eyes-closed single-task condition. While the addition of the attentional task decreased the anteroposterior stability limits of both subject groups; they were able to maintain relatively similar attentional performance scores in the single and in the dual task conditions. Yet, analysis of dual task costs revealed that patients with CD had a significant decrease in their stability limits relative to healthy controls when concurrently performing the attentional task under the visual condition. These main findings are discussed in the following sections.

5.2 - The Effects of Cervical Dystonia on Dynamic Postural Control

Over the last several years, few studies have investigated postural control of patients with cervical dystonia. Most authors reported decreased stability in patients with CD with no additional attentional task. Moreau et al. (1999) reported significant body sway for the lateral direction and in the dynamic condition in patients with CD compared to healthy aged-matched adults. Moreover, the body sway was considerably greater in the eyes closed condition compared to the eyes open condition. Relatedly, Bove et al., (2004) observed increased sway paths, sway area and anteroposterior and mediolateral enlarged displacements in CD patients compared to healthy controls. Similarly, Barr and colleagues (2017) and De Pauw and colleagues (2018) reported increased postural sway and impairments in postural control in patients with CD. The differences in the study protocols and clinical profiles of patients with CD may explain the divergent findings found in the literature. However, it is worth mentioning that most of these previous studies to assess postural control in patients with CD were conducted in static stance conditions. This suggests that postural mechanisms involved in quiet standing are largely preserved in CD. Thus, patients with CD might be using compensatory sensory and motor function adjustments to maintain their posture in static circumstances.

For instance, Moreau and colleagues (1999) investigated both static and dynamic postural control in patients with CD using an external perturbation. Their findings suggested that CD and control participants displayed similar postural sway in the quiet standing condition with and without vision. However, the greatest body sway in the lateral direction were observed in patients with CD compared to healthy controls in the eyes closed dynamic condition. Together, these results suggest that static stance conditions are often not sufficiently sensitive to detect postural deficits in patients with CD (Lekhel et al., 1997; Demir et al., 2020).

Dynamic postural control is a major aspect of everyday motor activities. To our knowledge, no previous study has used internal postural disturbances to assess dynamic postural control in sensory-attentional conditions in CD. We used a natural, self-initiated maximal leaning task to measure postural stability limits of patients with CD along the anteroposterior and mediolateral axes. This complex task involves the ability to anticipate, to move, and to avoid instabilities caused by centre of mass displacement (internal perturbation). Our results display systematically smaller mean postural stability limits in the mediolateral axis in patients with CD compared to healthy aged-matched subjects, across all sensory-attentional conditions. Unfortunately, no main group effect was found in the anteroposterior axis, most likely due to either a large inter-subject variability in CD dystonic profiles and/or a reduced statistical power associated with our small sample size. Nevertheless, our results corroborate the findings found in the literature (Moreau et al., 1999; Demir et al., 2020) that a challenging dynamic postural task is sufficiently sensitive to alter postural control in CD.

The widespread clinical profile of patients with CD may in part explain the variability observed on postural control across all sensory-attentional conditions. However, recent studies have reported no correlation between disease severity and balance in CD (Moreau et al., 1999; De Pauw et al., 2018; Demir et al., 2020; Baione et al., 2021). Most patients included in this study had a predominant fixed dystonic posture; only three patients had a tonic inclined posture to the right, which potentially could have slightly moved the center of mass to the right. Studies have demonstrated that the anticipated direction of one's gaze reorients the orientation of the head and other body segments through a given movement (Grasso et al., 1996; Bernardin et al., 2012). To reduce such effect, we have asked the participants to fixate their gaze on a sticker (1 cm diameter) on the wall during the experimental trials. The analyses confirmed that the stability limits and the COP variability showed no differences along the left and right leaning direction between patients with CD and their control counterparts. Thus, consistent with the previous studies, it is unlikely that abnormal head posture substantially contributes to greater postural instabilities observed in patients with CD.

Additionally, motor features of our dynamic postural stability task, might in part, justify the altered postural performance observed in CD participants. For instance, diminished muscle strength at the ankle joint could have reduced the magnitude of stability limits and maintenance of maximal leaning in CD subjects. Decreased maximal strength of ankle plantar and dorsal flexor muscles are well-known in normal aging and neurogenerative disorders, such as Parkinson's Disease (Falvo et al., 2008). Additionally, ankle muscle strength is a strong predictor of falls in normal aging (Cattagni et al., 2014). Moreover, a sedentary lifestyle could cause atrophy of muscles and ligaments and thus, interfere with postural stability (Rosengren et al., 1998; Skelton, 2001). However, since both CD participants and controls were considered sedentary and relatively the same age, future studies would be necessary to assess the effect of CD on ankle strength to dissociate this feature from other factors affecting postural stability and to better predict risk of falls.

An alternative compensatory mechanism that might have been used by patients with CD is the co-activation of the muscles surrounding the ankle joint to maximise stability (Baudry and Duchateau, 2012, Donath et al., 2015). Previous studies in seniors showed greater co-activation of the plantar and dorsal flexors of the ankle in a challenging postural task in sensory conditions (Baudry and Duchateau, 2012, Donath et al., 2015). The results of our healthy aged-matched controls support the previous findings. Their COP variability appeared to increase in the eyes closed condition when performing the single and dual tasks. What is noteworthy is that the COP variability of patients with CD patients had a tendency to be lower when performing the dual task, specifically in the anterior direction. Increasing the sample size may help clarify the strategy used by patients with CD to achieve similar postural stability limits in the dual task conditions.

Fear of falling (FOF) is another primordial factor that may have had an impact on the dynamic postural stability limits in CD participants. While this study does not explicitly address falls in cervical dystonia, FOF was favourably present in CD participants compared to their control counterparts. Barr and colleagues (2017) observed that higher FOF in patients with CD relatively correlated with stepping reaction time impairments. No correlations were associated with gait and balance performance. Similarly, we observed no significant reduction of the magnitude of stability limits when CD participants were asked to perform the dual task condition (i.e., postural, and attentional tasks simultaneously). One might hypothesize that CD participants favoured the dynamic postural stability limit task due to their fear of falling. However, our results show no significant reduction in the performance of the attentional task. Consequently, although fear of falling may have played a role in our study, we believe it is unlikely that it solely explains our findings. Nevertheless, future studies using a dynamic postural dual-task paradigm may benefit from including objective measures of FOF.

Cervical dystonia is associated with the dysfunction of a complex neural network that comprises the basal ganglia-thalamic-frontal cortex, as well as the parietal (somatosensory) cortex, and the cerebellum (Avanzino and Fiorio, 2014). For optimal execution of movement or maintaining posture, accurate processing of sensory information from the body (internal) and environment (external) is required (Avanzino et al., 2015). The cerebellum is responsible for receiving sensory and visual information to build an internal representation of the body and send out the motor commands (Avanzino and Fiorio, 2014; Conte et al., 2019). Therefore, one would expect that dysfunction in these circuits alter the integration of multimodal sensory information.

Furthermore, the perception of our maximal leaning limits is crucial for postural control and thus, provides a better understanding of the risk of falls. This complex neural process involves the processing and integration of visual, proprioceptive, and vestibular signals. As such, it is now widely known that patients with CD have abnormal sensorimotor processing deficits (Avanzino et al, 2015; Popa et al., 2017; Avanzino et al., 2018; Conte et al., 2019). Likewise, our results of lower mean postural stability limits in all sensory-attentional conditions in CD participants may largely reflect a global sensorimotor deficit due to aberrant activity in this sensorimotor network. Our results, however, do not permit the dissociation of the aberrant activity in this sensorimotor network. Future studies are required to investigate in greater specificity the corporal segments (i.e., head, waist and ankle) and the inappropriate weighing of visual, proprioceptive, and vestibular information associated to the global sensorimotor deficit in CD.

Abnormal head postures in CD may also impact other sensorimotor systems, such as vestibular function. Very few studies have reported asymmetric vestibular influences in CD (Stell et al., 1989). It is impossible to determine if altered vestibular functions affected postural control in the patients with CD and whether this could have contributed to the observed smaller stability limits along the mediolateral axis. Controlling posture along the anteroposterior and mediolateral axes relies on different mechanisms (Blanchet et al. 2019). Avanzino and colleagues (2018) found no differences between patients with CD with and without head tremors. In other words, the head position cannot entirely explain the deterioration in dynamic postural performance found in cervical dystonia participants. Moreover, such information suggests that it can be a general deficit (Pelosin et al., 2009). Experience may have had more of an influence in the anteroposterior axis. Most functional activities are executed along the anteroposterior axis, such as reaching for an object. It is therefore possible that this created more opportunity for patients with CD to practice and adapt to their functional challenges along the anteroposterior axis. Additionally, the body weight transfer using hip muscles (abductors and adductors) required along the mediolateral axis, might be more demanding and complex than in the anteroposterior axis (Winter et al. 1996). Evaluating a larger group of CD patients with two force platforms may increase the sensitivity for the detection of postural control differences along the mediolateral and anteroposterior axes.

5.3 - Effects of Proprioceptive and Attentional Demands on Postural Stability in CD

The main objective of this study was to use a dual-task paradigm to analyse the impact of proprioceptive and attentional demands on postural control in cervical dystonia. Dual tasking is common in everyday life situations such as, talking on the phone while crossing the street or answering questions while cleaning the dishes. Healthy individuals can perform motor and cognitive tasks simultaneously while maintaining adequate postural control (Tsang et al., 2016).

While few studies (Demir et al., 2020; Baione et al., 2021) have evaluated proprioception and attention in the context of postural control in CD, this study is the first to assess the interaction between proprioceptive and attentional demands of dynamic postural control in CD. Relatedly, one of our main findings is that CD participants decreased their anteroposterior limit of stability in the eyes closed condition, while relying heavily on proprioceptive information. However, this effect only reached significance in the single task postural condition. This finding was anticipated as several studies have attested the presence of sensorimotor integration deficits in CD, which are largely due to impaired neck proprioception that contribute to postural imbalances (Bove et al., 2004; Pettorossi and Schieppati, 2014; Popa et al., 2018). Thus, this supports the notion that neck proprioception plays a fundamental role in body representation (i.e., the coordination of limbs and postural control) (Popa et al., 2018; De Pauw et al., 2018). In summary, our findings are consistent with previous studies and suggest that altered proprioceptive processing in patients with CD has an impact on their dynamic postural control.

Furthermore, supressing a sensory modality that contributes to postural stability allows for an assessment of its functional importance. Along this line, we anticipated that CD participants, in whom there is a proprioceptive deficit would increase their dependency on visual information as a compensatory mechanism to maintain their postural stability. It has been suggested that each sensory source is associated with a weight in accordance with its functional state (Henry and Baudry, 2019). Accordingly, the contribution of the most reliable sensory inputs increase, whereas the less reliable inputs are weakened. Our results are consistent with this report and suggest, that the reduced reliability of proprioceptive information in patients with CD, is compensated by increasing the weight of visual information.

Moreover, studies have demonstrated somatosensory dysfunctions in body parts distant from the affected region (i.e., the neck) (Pelosin et al., 2009; Desrochers et al., 2019). Decreased proprioception in the lower limbs might, in part, explain the loss of stability in the impaired postural performance in CD participants in our current study. Standing predominantly relies on ankle strategy (Gatev et al., 1999; Henry and Baudry, 2019) and ankle proprioception (Duysens et al., 2008; Pasma et al., 2012). To our knowledge, no study has investigated the integrity of proprioceptive function in ankle joints in patients with CD.

Dual-task paradigms are extensively used to evaluate the performance of simultaneous tasks and the additional cost imposed (Brustio et al., 2017). Studies have suggested that postural control consists of a large range between total control and automatic processing (Stins and Beek, 2012; Boisgontier and Nougier, 2013; Henry and Baudry, 2019). Supplementary evidence suggests that altered proprioception reduces the efficacy of the automatic processing of postural control and thereby, increasing the controlled processing. Consequently, the attentional load associated to the increased controlled processing of postural control is also higher (Baudry and Gaillard 2014, Boisgontier and Nougier 2013; Woollacott and Shumway-Cook, 2002). As such, proprioceptive processing is also associated to an attentional cost (Yasuda et al. 2014). These concepts suggest that allocating attentional resources towards a challenging cognitive task may compromise proprioceptive performance.

Based on these previous findings, we predicted that CD participants would reduce their postural stability limits, more specifically, when eyes were closed and performing the second attentional (cognitive) task. On the contrary, our results demonstrate that while healthy subjects slightly decreased their stability limits, those of patients with CD remained very similar. One would hypothesize that, in absence of vision, patients with CD would maintain similar postural stability limits, while performing simultaneously the attentional task, by sacrificing the attentional task to prioritize the postural task. However, our results show that patients with CD did not reduce their attentional performance scores and thus, we cannot corroborate such hypothesis.

Moreover, in contrast to our initial prediction, the analysis of the postural dual task cost, revealed that CD participants significantly deteriorated their limits of stability, only when simultaneously performing the attentional task in the eyes open condition. Our results corroborate the findings of Demir and colleagues (2020) and Baione in colleagues (2021), in which patients with CD decreased their postural performance in the dual task condition with eyes open. In theory, patients with CD known to have proprioceptive impairments, should rely more heavily upon visual information to control their posture. It is plausible that the visual analysis of the surrounding environment could mobilize a substantial proportion of their available attentional resources. Few studies have addressed altered cognitive functions in cervical dystonia (Romano et al., 2014; Loetscher et al., 2015, Ray et al., 2020). Hence, we propose that when attention was directed toward the attentional task, in the eyes open condition, the attentional demand might have exceeded their functional reserve. As a result, CD patients could not appropriately process visuospatial information and consequently, which led to decreased postural performance.

5.4 - Study Limits

In the present study, we used a dual-task paradigm to assess the impact of proprioceptive and attentional demands on postural control in CD. The findings suggest that our dynamic postural stability limit task is a sensitive predictor of impairments in CD. However, several elements may have limited the outcomes of this study.

First and foremost, the major limitation of our study is the small sample of patients with CD. Therefore, our results must be confirmed with a larger population size of patients with CD. The reduced sample size of CD participants did not allow us to create subgroups based on clinical characteristics. For instance, a larger number of patients would have allowed to assess whether CD participants with and without tremors, would produce similar postural control impairments. This is important as it has been recently shown that proprioceptive dysfunctions differentiate in CD with and without tremors (Avanzino et al., 2020). Such information may provide a better understanding of the communication between different areas of the brain in the pathophysiology of CD.

Additionally, the secondary attentional (cognitive) task used in this study might not have been challenging enough to produce a significant decrease in performance scores during the dual task conditions. The cognitive subtraction task in our protocol used seventeen two-digit numbers read at a 2 second interval. The numbers were randomised and ensured that no two-digits were repeated for each trial. Limited combinations may have caused a pattern to emerge and consequently, reduced the difficulty of the task.

Lastly, fatigue is another factor that may have impacted the performance of both CD and aged-matched participants. The protocol was composed of sixteen, one hundred-second trials in which participants were asked to reach and maintain their maximal inclined posture for 10 seconds. Despite breaks being imposed between each condition to reduce the effect of fatigue, the muscles surrounding the ankle were likely highly solicited, which might have reduced the performance of participants. Supplementary studies should use a Borg's rate of perceived exertion scale to quantify the participant's perceived fatigue during the experimental sessions.

5.5 - Future Studies

Future studies will primarily be aimed at understanding how impaired proprioception in cervical dystonia affects postural control. More specifically, we plan to investigate the proprioceptive function at the neck and ankle joints. Ankle proprioception is critical to maintaining one's balance (Duysens et al., 2008; Pasma et al., 2012). Such knowledge would be a great asset to understanding postural control in CD. Furthermore, as there are contradictory findings about the potential effects of the botulinum toxin injections on sensorimotor processes, we also plan to evaluate the impact of this toxin on proprioceptive and attentional demands of postural control.

Moreover, another interest of ours is to evaluate the effects of a proprioceptive intervention program aimed at improving postural control in CD. There is very little literature on the use of physical activity as a complementary treatment to the botulinum toxin injections and more importantly, there is no consensus about the dose, the duration, and the type of exercise that are the most beneficial to patients with CD (Boyce et al., 2013; Counsell et al., 2016; Hu et al., 2019).

CHAPTER 6: Conclusion

To conclude, this is the first study that has investigated the interaction between proprioceptive and attentional demands of dynamic postural control in CD. Our findings demonstrate that CD participants achieved smaller mean postural stability limits compared to aged-matched controls across all sensory-attentional conditions, particularly along the mediolateral axis. The results support the idea that sensorimotor integration and proprioceptive processing might be key factors affecting dynamic postural control in CD. Furthermore, the results suggest that there is a greater reliance on visual information in patients with CD to maintain control of their posture. Such a compensation mechanism has been shown to interfere with dual tasking in patients with CD.

The aging population is rapidly growing worldwide and life expectancy has substantially increased. Cervical dystonia is a chronic neurological movement disorder with a late onset in the fourth decade. Numerous seniors will live with the hindering symptoms of CD. Therefore, a deeper understanding of sensorimotor deficiency in CD is crucial to elucidate the pathophysiology, but also, to develop new strategies to facilitate proprioception and motor control to help these patients live their lives more effortlessly during their advancing age.

CHAPTER 7: Bibliography

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