

The Effects from Stair Climbing on Postural Control during Sit-to-Stands

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Abstract

Rising up from a chair (sit-to-stand; STS) and stair climbing are both activities of daily living (ADLs) done throughout our lives. The ability to complete ADLs is crucial for independent living. The goal of this thesis was to research how two ADLs interact with each other and affect postural control. It was hypothesized that an increased number of flights of stairs climbed would lead to a decline in postural control during/after a STS in older more than younger adults. Fourteen older adults and fourteen young adults were tested by completing three STSs before and after climbing 1, 3 and 5 flights of stairs, chosen at random. Movements of the center of pressure (COP) for each STS were obtained from a force platform. Only an age effect was found for COP velocity (left-right and anterior-posterior directions) during the momentum transfer phase, during stabilization and after stabilization. Therefore, contrary to our hypothesis, stair climbing did not lead to significant changes in COP movements during and following a STS.

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Chapter 1: General Introduction

Activities of daily living (ADLs) are vital for independent living. ADLs can be defined as routine activities done optimally with little, to no assistance. To break down ADLs further, there are two types, basic activities and instrumental activities. Common basic ADLs consist of: transferring, toileting, bathing and dressing. These activities are more self-care oriented. In contrast, instrumental daily activities include: shopping, housework and managing money. These activities are not necessary for living; however, they give more independence in older adults' lives. This thesis is concerned with basic ADLs.

Basic ADLs are completed throughout life, however as we age, we begin to lose some of the postural control and strength we once had. Because of a decline in strength and postural control throughout aging, falls are likely to occur more often during ADLs (Robinovitch et al., 2012). In long-term care facilities, falls tend to occur more during standing and transferring of body weight, commonly seen when rising from a seated position (also referred to as the sit-to-stand (STS) movement or task) and stair climbing (Robinovitch et al., 2012). This is likely due to the fact that older adults shift their body weight incorrectly, causing their centre of mass (COM) to go outside their base of support (BOS) (Robinovitch et al., 2012). The control of the COM involves efficient integration of sensory information and contractions of the appropriate muscles, both of which are affected by neuromuscular fatigue. It is extremely important to be able to control the COM when rising from a chair as well due to the speed at which it is travelling forward (Akram & McIlroy, 2011). If the COM travels too far anteriorly, the person may fall forward after losing balance.

The question addressed in this thesis concerns whether repeating a common activity related to mobility, that is stair climbing, may affect the performance of community dwelling older adults during the STS compared with that of young adults. Community dwelling older adults tend to live independent lifestyle and having the knowledge of how one common daily activity may affect performance on an important ADL may potentially help in the prevention of falls and loss of independence.

Chapter 2: Review of Literature

2.1 Mobility and Aging

Mobility limitation can be defined as difficulty walking up one flight of stairs or walking 400 meters (Richardson et al.,2014). This decrease in mobility may be due to joint or limb replacement, obesity, osteoarthritis, or neuromuscular dysfunction (Lee and Chou, 2007). The neuromuscular changes that commonly occur during aging include: decreased size and number of muscle fibers, slower muscle fibres and a decrease of muscle twitch velocity (Hasson, Caldwell & Van Emmerik, 2009). These changes can lead to overall slower movements in older adults during different ADLs (Hasson, Caldwell & Van Emmerik, 2009). For example, walking patterns change as we age because of decreased muscle activation, in addition to impaired balance and loss of co-ordination (Nagano et al., 2014). When it comes to STSs, older adults with knee extensors weakness show an increase in flexion of the trunk, to help reduce the load onto the knee extensors (Hortobagyi et al.,2003). Furthermore, older adults also respond differently to perturbations because of the neuromuscular changes. During sudden platform movements, such as riding on a bus, an older adult takes longer to activate the appropriate muscles, responding with a smaller burst of muscle activity and show larger COM acceleration in the direction of the perturbation, as opposed to young adults (Hasson, Caldwell & Van Emmerik, 2009). Moreover, proper mobility is very important while aging because the majority of falls occur during locomotion (Lee and Chou, 2007). If older adults are moving more slowly, or have difficulty moving in general, their ADLs may be disrupted and ADLs are vital for independent living and are completed throughout life. As adults age, they tend to lose some of their independence due to muscle

weakness, decrease in proprioception, loss of vision, vestibular disorders and change of posture, and may require assistance from a caregiver (Miller et al., 2013; Sturnieks, St.George & Lord.,2008).

A decrease in ability to complete these ADLs can partly be due to a decrease in postural control from aging. When comparing older and younger adults' posture, older adults tend to have a hunched back, forward head, increased thoracic kyphosis and a decrease in lumbar flexion (Kuo et al., 2009; Lin et al., 2005). This change in posture has been shown to alter gait, as well as increase sway, therefore altering postural control (Kuo et al., 2009; Lin et al., 2005).

A loss of vision and a vestibular function can also be responsible for the reduced ability to perform ADLs and maintain postural control (Sturnieks, St.George & Lord.,2008). The body uses vision to create a spatial map of its surroundings, while the vestibular system works by detecting the position and motion of the head, assisting with balance through corrective moments (Sturnieks, St.George & Lord.,2008). As humans age, their vision begins to decrease, most notably, after the age of 50, as well as their vestibular function diminishes (Sturnieks, St.George & Lord.,2008). With a decrease in both these systems, it is a common issue that older adults will have a more difficult time controlling their balance.

Another sense that becomes affected with age is proprioception (Sturnieks, St.George & Lord.,2008). Proprioception is sensory information from receptors in the muscles, tendons and joints and give feedback on where the joint is positioned in space (Sturnieks, St.George & Lord.,2008). This is extremely important for walking. Loss of this sensory information can be a result of diabetes mellitus, B12 deficiency and even osteoarthritis in lower limb joints, all common among older adults (Sturnieks, St.George & Lord.,2008).

This lack of peripheral sensory information can lead to less accuracy during weight bearing tasks (Sturnieks, St.George & Lord.,2008).

As described by Bellew et al (2006), changes in the neuromuscular system occur during aging which can also affect postural control, including: motor unit remodelling and a decrease in strength. With aging, a loss of muscle tissue occurs, causing a decrease in type I and type II muscle fibers. Interestingly, the type II muscle fibers, also known as the fatiguable muscle fibers, show greater atrophy (Vandervoot, 2002). Overall, motor unit firing becomes slower with aging which can affect the ability to produce force (Vandervoot, 2002). Furthermore, higher muscle co-activation has also been seen amongst older adults, which is associated with poor postural control and leads to joint stiffness and altered proprioception (Nagai et al., 2012; Ruffieux et al., 2015). Co-activation can result in no net muscle movement because the antagonist and agonist muscle groups are being activated together, leading to a loss of energy and decreased balance control (Nagai et al., 2012). Compared to the younger counterparts, older adults tend to co-contract the dorsiflexors and plantar flexors to maintain postural stability (Shaffer & Harrison, 2007). Co-contraction of the plantar flexors and dorsiflexors could lead to faster fatigue of the muscles, possibly increasing postural sway (Gribble and Hertel, 2004; Lundin et al., 1993). Furthermore, it has been seen with increased age that dorsiflexion range of motion becomes reduced and that range of motion in sagittal and a frontal planes is associated with balance ability (Menz, Morris & Lord, 2006). Also, the plantar flexor and dorsiflexor muscles show a larger and faster initial burst of muscle activity following an upper body perturbation young adults, leading to less sway and greater chance of stabilization compared with older adults (Hasson et al., 2009).

Moreover, the decline in mobility in older adults can be sudden (usually following a traumatic event, such as a fall) or progressive. The early stages of the progressive decline in mobility has been termed “preclinical mobility” (Rantakokko, Mänty & Rantaneni, 2013). Older adults can change the way they do a task during this stage (slowing pace, use of an aid), without perception of increased difficulty. Preventative physical activity programs that focus on strengthening the lower extremities and increasing balance can slow down this stage (Rantakokko, Mänty & Rantaneni, 2013).

2.2 Neuromuscular Fatigue and Aging

Another change that occurs with aging is related to how fatigue can affect movements and balance. Neuromuscular fatigue, defined as an acute impairment in the ability to produce force (Enoka & Stewart, 1992), can occur more quickly after exercises and during ADLs in older compared with young adults, possibly leading to a decline in independence. Neuromuscular fatigue can be due to alterations in structures/mechanisms from the central nervous system to the interaction between contractile proteins. The relative contribution of central versus peripheral fatigue mechanisms could change with age (Bilodeau et al., 2001), however, this is beyond the scope of this thesis.

Neuromuscular fatigue can lead to: joint stiffness (Gribble and Hertel, 2004; Lundin et al., 1993), altered proprioception (Ribeiro et al., 2006; Gribble and Hertel, 2004; Lundin et al., 1993), reaction time (Gribble and Hertel, 2004; Lundin et al., 1993) and cause a decrease in muscle strength (Forestier et al., 2002; Vuillerme et al., 2002; Moore et al., 2005; Hatton et al., 2013). It is suggested that older adults experience more susceptibility to neuromuscular fatigue during performance of dynamic tasks at absolute force levels (Allman &

Rice.,2002). However, older adults appear to fatigue less than younger adults under maximum and sub maximum (relative) voluntary contractions (Allman & Rice.,2002; Christie, Snook & Kent-Braun., 2011). During isometric contractions, older adults show less fatigue in the muscles compared to younger adults likely because of the type I muscle fibers predominance, which allow older adults to have more muscle endurance (Christie, Snook & Kent-Braun., 2011). It should be noted that this is only seen during isometric contractions and not dynamic contractions (Christie, Snook & Kent-Braun., 2011).

Blood flow should also be taken into account when discussing muscular fatigue. Overall, blood flow to the muscles is decreased in healthy older adults, as opposed to younger adults (Allman & Rice., 2002). This decrease in blood flow to the muscles can mean a decrease in oxygen getting to the muscles, which may lead to greater fatigue (Allman & Rice., 2002).

Furthermore, work from our group (Bisson et al., 2014) and previous studies (Petrella et al.,2005; Ribeiro, Mota & Oliveira., 2007) has shown that under certain conditions, the effect of fatigue on postural control can be more pronounced in older compared with young adults. These conditions being, in particular, activities involving an open kinematic chain (e.g., isolated knee extension) as opposed to a closed kinematics chain (e.g., sit-to-stands) (Petrella et al., 2005; Ribeiro, Mota & Oliveira., 2007). This is likely due to everyday activities, such as STSs, being very common repeated movements for all age groups (Petrella et al., 2005). Open kinematic chain activities are those where the distal segment of a chain (combination of multiple joints working together) is free to move and typically is used to isolate a muscle or muscle group. In contrast, closed kinetic chain activities occur

when the distal segment of chain is fixed and the motion occurs proximally, such as with weight-bearing activities.

Isolating muscles to fatigue is adequate when testing postural sway in a highly controlled manner. However, it may not represent real world situations because muscles do not typically get fatigued in isolation (Granacher et al., 2010). Interestingly, it has been shown that older adults have an increased sense of fatigue during ADL and less fatiguability during voluntary, isometric contractions (Allman & Rice.,2002; Eldadah, 2010; Christie, Snok & Kent-Braun., 2011).

ADLs include dressing, bathing, transferring from bed to chair and toileting (Garrett et al., 2013). A survey done by Eldadah et al (2010) found that the majority of the 754 non-disabled community dwelling adults over the age of 70 years surveyed said they felt that fatigue (tiredness) was the main reason for restricting activity. For this particular study, fatigue/fatiguability was defined as “a whole-person construct” and “a self-reported sensation”, in contrast to the definition of fatigue in the exercise literature, which describes the endurance characteristics of individual muscles; and although different concepts, they may be interrelated. In older women with osteoarthritis, they stated that fatigue was more restrictive than pain. As well, 49 percent of non-disabled elderly men and 53 percent of non-disabled elderly women reported tiredness associated with more than one daily living activity (Eldadah et al., 2010). Fatiguability, which describes how fatigued a person gets in relation to defined activities, can be reported as a ratio of self-reported fatigue to activity level work performance. The higher the fatiguability, the more likely a person is to terminate their activity before completion (Eldadah et al., 2010). Therefore, “fatigue”(tiredness)

may lead to reduced physical activity (Moore et al., 2005). Fatigue in older adults can affect many aspects of their daily lives, including how STSs are performed.

2.3 Sit-to-Stand: an activity of Daily Living

To begin, a STS can be defined as a movement in which the base of support is transferred from a chair (buttocks, seated) to the floor (feet, standing). There are three phases and two events comprising a STS. They have been defined to help identify changes in body position: flexion momentum, momentum of transfer, and finally, stabilization, with two events occurring, including: seat-off and extension. (Baer et al., 1995; Hennington et al., 2004; Dos Santos et al., 2011). Seat off occurs between the flexion momentum phase and momentum of transfer phase, while extension occurs between momentum of transfer phase and the stabilization phase. Within those three phases, four different challenges present themselves. They include: 1) bringing the COM forward, 2) vertically raising the COM, 3) making the transition from a large BOS to a smaller BOS and 4) controlling the anteriorly moving COM, as to make certain it does not travel outside the BOS while stabilizing (Alexander et al., 1991; Akram & McIlroy, 2011). It is important to note, that during stabilization, the COM is moving at a quick rate, therefore stabilization time may take longer for older compared with younger individuals due to differences in muscle strength (Akram & McIlroy, 2011). This is a reason why the two age groups use different strategies while raising from a chair.

Furthermore, the muscle groups involved in the STS include: erector spinae, rectus abdominus, the quadriceps, hamstrings and ankle dorsiflexors and plantarflexors (Burnett et al., 2011; Cuesta-Vargas & Gonzalez, 2013). Therefore, a STS is a lower limb and body

core activity. During the seat off event, it has been shown that the rectus femoris, hip flexors, gluteus maximus, bicep femoris and tibialis anterior are all activated (Munton et al., 1984). Heading into the first phase of the STS, flexion momentum, all four of the previous muscles remain activated except for the hip flexors. Next, during the momentum-transfer phase, all the previous muscle groups remain activated and the gastrocnemius and soleus begin to activate as well. Finally, during stabilization, only bicep femoris, gastrocnemius and soleus remain activated (Munton et al., 1984).

As mentioned previously, older compared with young adults use different strategies during a STS. A very common strategy seen during STSs amongst the younger adult population has been defined as the momentum-transfer strategy, in which, during the seat-off, the COM is posterior to the heel and outside of the BOS, followed by the horizontal momentum of the COM allowing for the completion of the STS, leading to a more stabilized and smoother rise (Gross et al, 1998). However, because of the age-related decrease in strength of the knee extensor muscles, a stabilization strategy, common among older adults is used. The stabilization strategy differs from the momentum-transfer strategy in that an exaggerated trunk flexion is performed before the moment of the seat-off (Savelberg et al., 2007). This strategy leads to an increase in movement time compared to the momentum-transfer strategy (Savelberg et al., 2007).

Moreover, since a STS requires significant knee extensor strength and a large range of joint motion, it makes for a good tool to identify functional limitations (Riley et al., 1991; Papa & Cappozza, 2000). For example, older adults tend to rotate their body forward and rise only after bringing their COM over their BOS, while young adults rotate and raise in a synergistic manner (Riley et al., 1991; Ikeda et al., 1991; Papa & Cappozza, 2000).

Because STSs require large knee extensor moments and precise balance control, the height of the seat is very important (i.e. The lower the seat the more effort will be needed to rise)(Doorenbosch et al., 1994; Baer et al., 1995;Hughes et al., 1996). Since muscle strength is important during STSs, older adults perform STSs at a higher relative effort (Papa & Cappozzo, 2000; Lin et al., 2011). It is important to remember that the lower the seat, the more difficulty the participants will have in completing the STS, causing a higher knee extensor moment (Baer et al., 1995; Hughes et al., 1996). Hughes et al (1996) found that the lowest possible chair height than an older adult was able to get up out of used 97 percent more available knee extensor strength as compared to an optimal seat height of 53 cm. While in young adults, at the lowest possible seat height, they only used 39 percent more available knee extensor strength compared to their optimal chair height (of which was the height of participant's knees).

However, a strategy change may occur in young adults as well. It was found amongst healthy, young adults, that an increase in number of repetitions and speed of STSs completed showed an association with an increase of knee extensor load due to fatigue (Roldan-Jimenez et al., 2015). This increase in knee extensor load could then lead to a strategy change during STSs (Hughes et al., 1996). Fatigue of the knee extensors causes both young and older adults to go into a stabilization strategy, therefore more trunk flexion will be seen during seat off compared to a non-fatigued seat off (Hughes et al., 1996; Van der Heijden, et al., 2009). It is believed that the STS strategy is switched during fatigue because it allows the majority of the load to be put on the hip extensors, as opposed to the knee extensors (Van der Heijden et al., 2009). When looking at STSs and fatigue, Hughes et al (1994) found knee extensor strength to be a limiting factor in getting up off the chair,

which is known to cause greater trunk flexion. Similarly, Akram & McIlroy (2011) stated that fatigue caused an increase in anterior-posterior forces, meaning more forward flexion is needed to stand up. Mazza et al (2005) had also found that fatigue had caused older adult participants to take longer to complete STS, as well as produce a lower force production. Therefore, after fatigue of the knee extensors, it will be common to see an increase in overall completion time of a STS, longer stabilization time, and more trunk flexion will be witnessed to decrease the load that would otherwise be placed on the knee extensors.

Completion time is a very good quantitative measurement when looking at functional abilities during a STS (Roldan-Jimenez et al., 2015). In a research setting, a STS is typically studied in the sagittal plane, with the seat adjusted to 75 to 80 percent of the floor to knee height. However, this does not allow the individual to adapt to the environment and is more for normalization in the research environment (Baer et al., 1995). In addition, research has concluded that resulting joint moments are positively correlated with increasing knee flexion at the beginning of the STS position (Doorenbosch et al., 1994; Baer et al., 1995; Hughes et al., 1996). Since a limited number of daily STSs accomplished can be detrimental to the independence of the older adult, they have become integral parts of rehabilitation for older adults and stroke patients (Bohannon et al., 2015).

In the end, older adults show a more exaggerated trunk flexion at seat-off compared to young adults when completing STSs. This exaggerated trunk flexion during the STS increases movement time overall and because it takes a longer time to complete the task, an increase risk of a fall may occur (Savelberg et al., 2007).

2.4 Stair Negotiation

Another mobility-related ADL that can have an impact on many older adults' function and independence is negotiating stairs. Stair negotiation in older adults appears to show a higher foot clearance than the actual stairs (Chiu, et al., 2014). Older adults tend to activate the knee extensors earlier than younger adults and show greater co-contractions of the plantar and dorsiflexors (Chiu et al., 2014). The difference in muscle activation during ADL between these two age groups make it very interesting to research in order to determine how two ADLs can possibly affect each other.

Many community-dwelling older adults live in homes or buildings that require some stair negotiation, however, 45 percent of older adults report they have difficulty with stair climbing (Novak et al., 2010).

Stair ascending and descending can be broken down into phases similar to gait. There are two phases for both stair ascending and stair descending, which are: the stance phase and the swing phase. Since the present study is focusing on the ascending aspect of stair climbing, the following description will be about stair ascending only.

While ascending stairs, 66 percent of the cycle is spent in the stance phase, while 34 percent of the cycle is spent in the swing phase (Abbas et al., 2013). Furthermore, within the stance phase, there are three sub-phases; weight acceptance, followed by pull up and finally, forward continuance. For the swing phase, there are two sub-phases being foot clearance and foot placement (Figure 1)(Novak et al., 2010; Abbas et al., 2013).

During stair ascent in the stance phase, the knee extensors and plantar flexors are activated to exert control in the sagittal plane, while the hip abductors are activated to exert force in the frontal plane (Novak et al., 2010). However, loss of stair climbing ability

with age is associated with loss of these muscle's strength and power, therefore causing quicker fatigue, and increased chance of loss of balance (Bergmann et al., 2012). Novak et al (2010) showed that older adults showed a decrease in plantar flexor moments and knee extensor moments compared to young adults, which is a cause of loss of power. Moreover, to make stair climbing more challenging, it has been shown that there is an increase in range of motion of the lower limbs compared to level walking (Novak et al, 2010).

Although older adults have shown to have a reduction in plantar flexor and knee extensors moments, and have shown to have longer stopping times on each step during stair ambulation compared to younger adults (Ojha et al, 2009), there are no significant differences of COM-COP coordination during stair ascending between the age groups (Lee & Li-Shan, 2007). These researchers found that older adults find it harder to maintain balance during descending more than ascending compared to younger adults, however that was it. Older adults perform stair walking fine, however it is the confidence that this age group lacks (Lee & Li-Shan, 2007). A decrease in confidence has shown to cause an increase in handrail use, or a position closer to the hand rail (Lee & Li-Shan, 2007).

Researchers often tell their participants to descend and ascend at a comfortable pace and then a metronome is used to make sure the participants continue at that pace (Ojha et al., 2009). A comfortable, but brisk pace that can cause fatigue has been shown to be roughly 88 steps per minute in the younger population (Boreham et al., 2000). Boreham et al (2000) also stated that in order for stair climbing to cause fatigue, it is important to keep the pace up for at least two minutes and fifteen seconds.

In the end, stair climbing has been shown to be a relatively difficult task within all age groups, and that the more a person has impaired motor function, balance problem or

reduction in lower-limb function, the more difficulty stair climbing will be (Abbas et al, 2013).

Thus, several laboratory-based studies have documented age-related differences in STS and stair climbing performance. However, very few studies have looked at a more ecological approach when researching these ADLs, therefore making it difficult to apply the findings to daily life. Climbing multiple flights of stairs could have a significant acute impact on function (such as when performing the STS) in both young and older adults.

2.5 Research Purpose and Hypothesis

The aim of this study was to determine whether climbing a set number of flights of stairs affects STS performance in older adults, and whether the effect is different than in young adults. Both stair climbing and STSs are activities of daily living that give older adults freedom and independence in their lives. However, little research has been carried-out into investigating the potential interaction between two such ecological activities.

I hypothesize that an increase in number of flights of stairs will cause a greater decline in postural control and alterations in the movement strategy during a STS, and that alterations will be more pronounced in older adults for a given number of flights of stairs. For example, the COP may become more forward in both age groups during the STS flexion-momentum phase to allow for the participants to feel more stabilized before standing up. Both groups may also show a stabilization strategy during the STSs after they have completed the maximum number of flights of stairs. The change towards the stabilization strategy occurs when the knee extensors begin to fatigue, leading to the hip extensors being activated to a greater extent, allowing the load of the knee extensors to be lessened, thus

changing into the stabilization strategy (Hughes et al., 1996). Since stair ascending involves knee extensors, it can be assumed that this muscle group will become fatigued, therefore leading to forward flexion of the trunk and hip extensor activation during STS performance. This may be seen as an increase in the antero-posterior (A/P) COP velocity during the momentum transfer phase and longer stabilization times. Furthermore, I also expect to see an increase in time to stabilize with the more flights of stairs that have been climbed, due to muscular fatigue. This is because the dorsiflexors in older adults have a typically reduced range of motion, resulting in poorer balance (Spink et al, 2011). As older adults use their dorsiflexors and plantarflexors more from the stair climbing, the more fatigued they will become, which may lead to an increase in postural sway (Gribble and Hertel, 2004).

Chapter 3: Methodology

3.1 Participants

Participants consisted of one group of fourteen active, older adults (65 to 80 years, average \pm SD, 71 ± 6 ; 7 men, 7 women) and one group of fourteen younger adult participants (18-30 years, 24.18 ± 2 ; 8 men, 6 women) who deem themselves healthy. A power analysis for the calculation of sample size adequate to detect group differences based on an effect size obtained from previous studies from our laboratory looking at the same task and dependent variables (alpha level = 0.05, power = 0.80; Bryanton 2016) led to a result of eleven participants per group. An additional 3 participants per group were tested to compensate for unusable data in a few participants. The testing was done in the Aging and Movement Lab at Elisabeth Bruyere Hospital.

Participants first filled out a “List of Exclusion Criteria” survey to give insight into medical history (Appendix 1). If two or more of the exclusion criteria were checked off, they were excluded from participating in concern for their safety. The older adults then were asked to complete a Mini-Mental State Examination (MMSE, Appendix 2) in order to assess whether the participants had adequate cognitive abilities (score of 24/30 or greater). Finally, both age groups filled out the Godin Leisure-Time activity questionnaire, allowing for a better understanding and comparison of the participants’ fitness levels (Appendix 3).

3.2 Materials

The STSs were performed on an AMTI Accugait force platform placed on the ground anterior to a bench (AMTI AccutGait, Watertown, MA) and center of pressure (COP) data was collected at a sampling rate of 100 Hz using a 1401 plus analog to digital board using spike2 v.7 *(CED, Cambridge, UK). The bench included a switch located beneath the cushion of the seat. The switch would be pressed on when sat upon, and turn off when the participant stood up. This permitted accurate identification of seat-off. As well, this allowed for the COP movement path to be documented as soon as seat off occurred. Furthermore, an electrogoniometer (models, SG150 Biometrics Ltd, DataLINK DLK900, Gwent, UK; accuracy of ± 2 degrees) was placed on the lateral ankle, with the lateral malleolus used as reference, of the dominant foot. This was used to monitor the angle of the ankle joint of the participant’s dominant leg to show change in joint angle during the beginning of the STS and the beginning of the stabilization event. Joint angle profiles during the STSs were collected at a sampling rate of 100 Hz using a 1401 plus analog to digital board using spike 2v.7* (CED, Cambridge, UK). Furthermore, a Biodex dynamometer was used to quantify muscle force of

the knee extensors throughout the study (Biodex Medical System, Inc., Shirley, NY; resolution: $\sim 0.3 \text{ N}\cdot\text{m}$).

The participants were instructed on the stair climbing and STS protocol, along with how to use the Borg Scale of Perceived Exertion (Appendix 4). This is an important scale rating system that was used during the stair climbing protocol to assess the level of perceived exertion. Heart rate was also collected at the end of the stair climbing as another indicator of exertion. A heart rate monitor strap was placed across the participant's chest to provide a reading to a watch the participant was also wearing.

3.3 Experimental Overview

The study began with the participants sitting on a backless bench with feet placed on the force platform, located in front of the bench. Participants were asked to sit in the middle of the bench, with shoes on and with their feet in a comfortable position on the force plate. Shoes were left on for faster collection of data after stair climbing. Foot position was then traced on a paper, allowing them to go to the same position on the platform throughout the process. The participants were asked to cross their arms over their chest in order to prevent upper limb use. They then completed three STSs. A verbal cue was provided to allow the participants to know when to stand up. After a given STS, participants remained standing for 10 s following seat off, thus allowing for the stabilization phase to be completely collected. After the 10 s, another verbal cue was given for them to sit down, where they sat and remained seated for 5 s before being asked to stand up again. It was found that normal stabilization time following seat off is in a range of 1.8 to 3.3 s (Baer et al., 1995). However, because the participants were performing stair climbing prior to the

STSs, the stabilization time may have increased. Thus a 10 s wait was used before sitting again.

Following the three initial STSs, the participants transferred over to the Biodex dynamometer where they were asked to perform three maximum isometric voluntary contractions (MVCs) of the knee extensors. The participants were seated in the Biodex dynamometer, with their knees bent at approximately 60 degrees. Their legs were then strapped into the machine at this angle. On the count of 3, the participants were asked to push against the padded arm of the dynamometer at full force. They were asked to hold on to the handles of the dynamometer as well. One reading was collected after every round of three STSs. The force output of the knee extensors (highest of the 3 MVCs) was used to quantify any fatigue due to stair climbing between the different participants and different age groups.

Then, the stair climbing activity was performed. Older adults began by walking up one flight, three flights or five flights of stairs, with the end goal of ending on the seventh floor, where STS measurements were repeated. The order of the number of flights to climb (1-3-5) was counter-balanced in order to take into account a potential order effect. The older adults were asked to climb stairs at a pace of 65 steps/min. Once on the seventh floor, the participants gave a rating using the Borg Scale of Perceived Exertion and heart rate was recorded. The participants then immediately perform three STSs as described above. After this, they performed one MVC and finally rested for five minutes to allow heart rate to go back to resting levels. After the five minutes, if the participant's heart rate was still elevated, they were provided an additional five minutes of rest until heart rate returned to resting values. Once rested, the older adults performed the three STSs the same as before, al-

ternating with 10 s standing and 5 s seating. They then performed the next bout of stair climbing, with the next number of flights of stairs, according to the counter-balanced order determined. This was again followed by the documentation of the level of perceived exertion (Borg Scale) and heart rate, three STSs, MVC, and five minutes of rest. This sequence was repeated one last time for the last number of flights of stairs.

For the younger adult participants, they were asked to complete the same protocol with the exceptions that they walked up one, three, five and seven flights of stairs, and at a pace of 90 steps/min, which was a brisk but manageable pace. The younger adults were asked to walk up more flights of stairs, as well as use a quicker pace because our pilot work found that five floors was manageable for older adults, but seven floors was too demanding, but not for young adults. As well, 65 steps/minute was a quick pace for the older adults, but again, manageable; whereas young adults could manage 90 steps/min.

3.4 Data Processing

Three phases of the STS were analyzed, which included: 1) the momentum transfer phase (moment of seat-off to the moment of extension), 2) the stabilization phase and 3) a post-stabilization phase. (Figure 1). The moment of seat-off was determined from the switch placed on the bench. The moment of extension was determined visually from the ankle angle signal (electrogoniometer) as the moment in time when the ankle returned to a $\sim 90^\circ$ stable angle following a dorsiflexion motion after seat-off. The stabilization phase was delimited from the moment of extension to the moment when COP movements returned to within 2 standard deviations around the mean position (in the X and Y planes) calculated for the last 5-s (stable period) of a given 10-s period after a STS. The post-

stabilization phase comprised the period between the end of the stabilization phase until the moment when participants initiated the movement to sit back down on the bench; as determined visually from COP and ankle angle data.

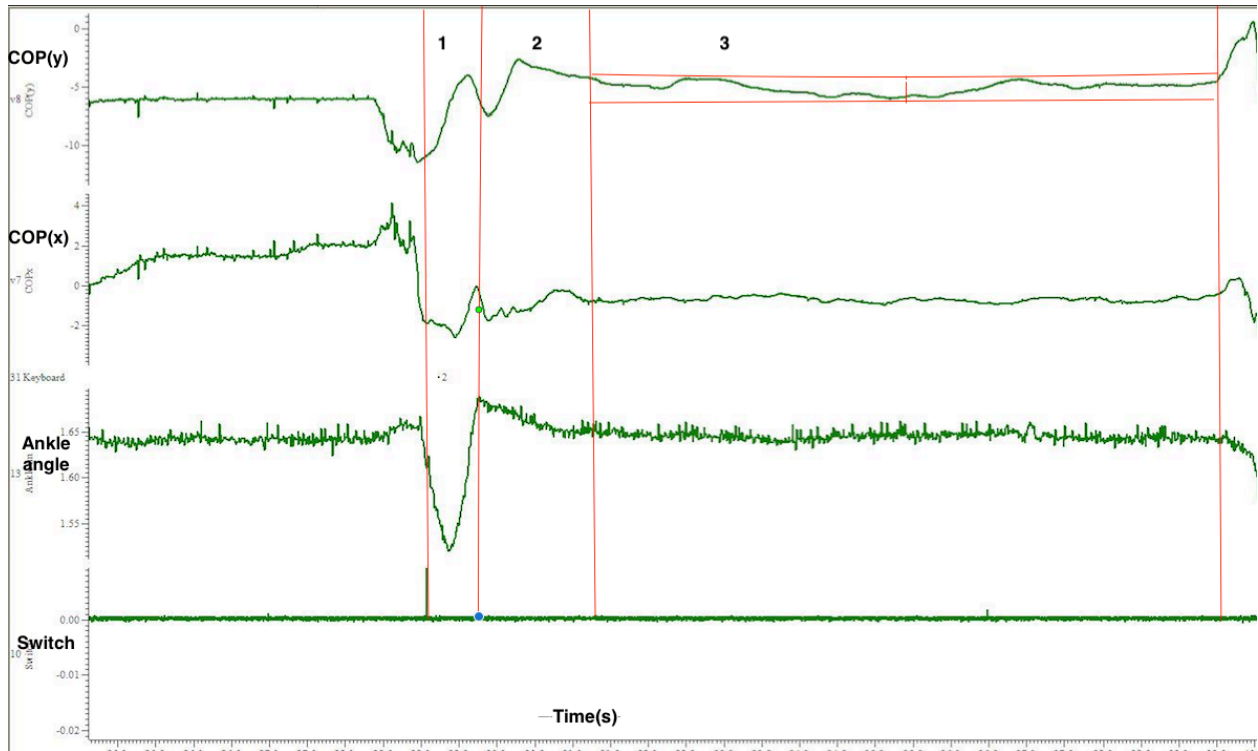


Figure 1: Diagram showing the determination of the three phases of a STS in a young adult. The Momentum transfer phase is denoted with “1”, the Stabilization phase denoted with “2” and the post-stabilization phase denoted with “3”. The Momentum transfer phase begins with seat-off, indicated by the switch signal (left cursor), and ends with extension, indicated by the ankle angle returning to a ~90-degree position when the participant is standing (middle-left cursor). The stabilization phase begins with extension and ends where the COP (A/P) returns to within 2 SDs of a mean calculated over the last five seconds of static standing (middle-right cursor).

3.5 Data and Statistical Analysis

Three STSs were recorded before and after every stair climb bout and data from those were summarized as an average. See Table 1 for phases COP variables calculated for each phase. A two-way mixed model ANOVA was performed to test the effects of age (older adults versus younger adults; between-group factor) and number of flights (pre, 1, 3, 5;

within group factor) on all postural control and joint angle variables. For the number of flights factor, the post values (1, 3, 5) were tested against the average of the three pre-flight values if those values were not significantly different (tested with a one-way ANOVA for repeated measures). If the three pre-flight values were different, a percent change for each respective flight numbers to climb was calculated and used in a two-way ANOVA model to test for the effects of age and number of flights (1, 3, 5); the results of this secondary analysis are shown in Table 6. Tests for sphericity were performed and values adjusted (using Greenhouse Geisser adjustment) if found significant.

Where appropriate, post-hoc t-tests with a Bonferroni correction were used for pairwise comparisons. Differences with a probability of less than 0.05 were considered significant.

All analyses will be performed using the statistical software packages SPSS 22 for Mac (IBM Inc., Armonk, NY, USA).

Table 1: Centre of Pressure (COP) variables calculated during and after the sit-to-stand (STS)

<p>Momentum Transfer Phase</p>	<ul style="list-style-type: none"> • COP position (cm) at seat-off in left/right (L/R) and A/P direction • COP range (cm) and standard deviation (SD) in L/R and A/P direction • Average and Peak COP velocity (cm/s) in L/R and A/P direction • Duration (s) from seat-off to extension
<p>Stabilization</p>	<ul style="list-style-type: none"> • COP SD (cm/s) in the L/R and A/P direction • Average COP velocity (cm/s) in the L/R and A/P direction • Time to stabilize (s)
<p>Post-Stabilization Phase</p>	<ul style="list-style-type: none"> • COP SD (cm/s) in the L/R and A/P direction • Average COP velocity (cm/s) in the L/R and A/P direction

Chapter 4: Results

4.1 Descriptive Statistics

With an age difference of roughly 46.8 years between the younger and older adults, there was a 12 point score difference on the Godin Leisure score. Both groups therefore are physically active, with the older adults typically being involved in more leisurely activities.

4.11 MVC, Heart rate and BORG scale of Perceived Exertion

MVC, heart rate and the Borg scale were first analyzed to determine differences in exertion between older and younger adults and the amount of flights climbed. See figure 2 and 3 for BORG and heart rate comparison, and table 3 for MVC averages. For MVC force there were no significant main effects of FLIGHTS ($p = 0.219$) or AGE ($p = 0.092$) and no FLIGHT x AGE interaction ($p = 0.933$). For heart rate, there was a significant main effect of FLIGHTS ($p < 0.01$), but no significant main effect of AGE ($p = 0.437$) and no significant FLIGHT x AGE interaction ($p = 0.682$). Next for the BORG scale of perceived exertion, there was a significant main effect on FLIGHTS ($p < 0.001$) and AGE ($p = 0.002$), as well as a significant FLIGHTS x AGE interaction ($p = 0.02$). See Table 4 for the detailed results of the ANOVA and Table 7 for the post-hoc results.

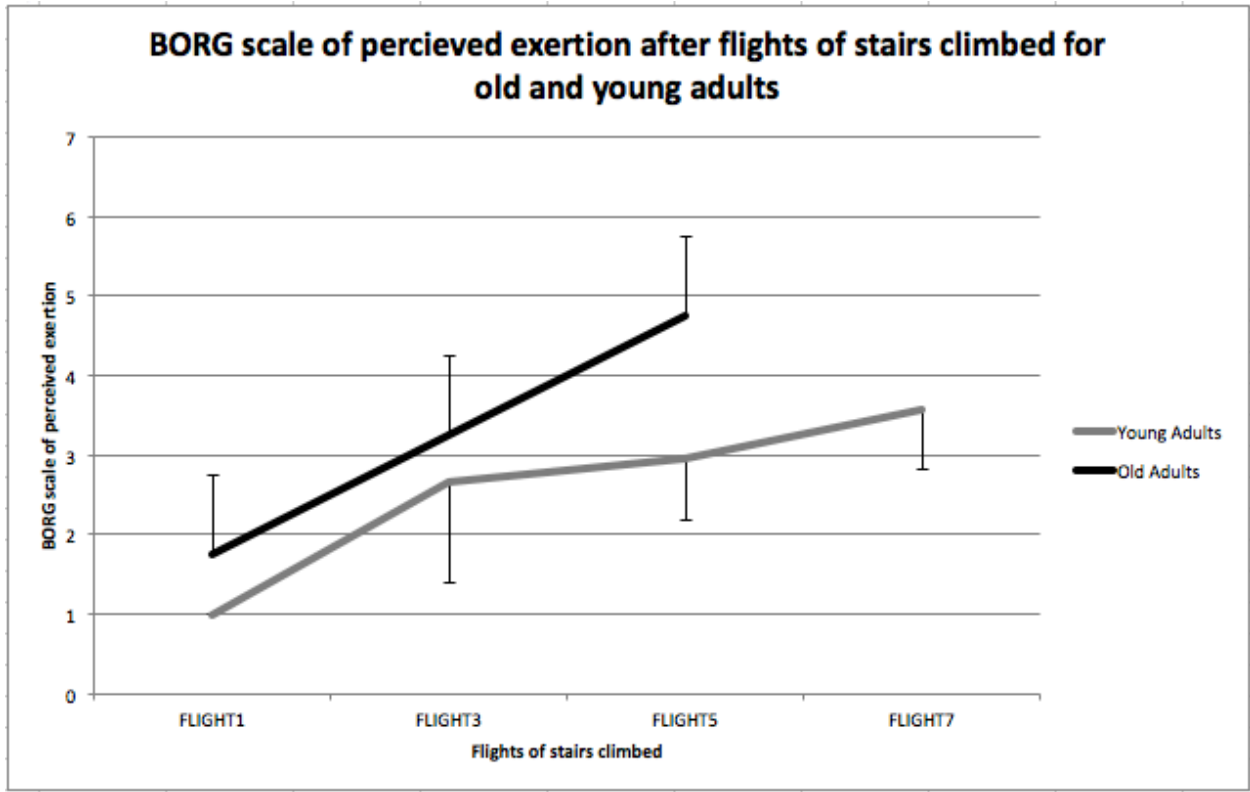


Figure 2: BORG Scale of perceived exertion (scale of 1-10) after flights of stairs climbed, with young and old adults compared



Figure 3: Heart rate(bpm) after flights of stairs climbed with young and old adult comparison

4.2 Momentum Transfer Phase Variables

4.2.1 COP Position in the left-right direction during Momentum Transfer Phase

Figure 4 shows the position of the COP in the left-right (L/R) direction at the moment of seat-off, before and after stair climbing. No significant main effects of FLIGHTS ($p = 0.33$, partial eta squared ($\eta_p^2 = 0.05$) or AGE ($p = 0.90$, $\eta_p^2 = 0.001$) and no FLIGHT X AGE interaction ($p = 0.96$, $\eta_p^2 = 0.005$) were found for this variable. See Table 5 for the detailed results of the ANOVA.

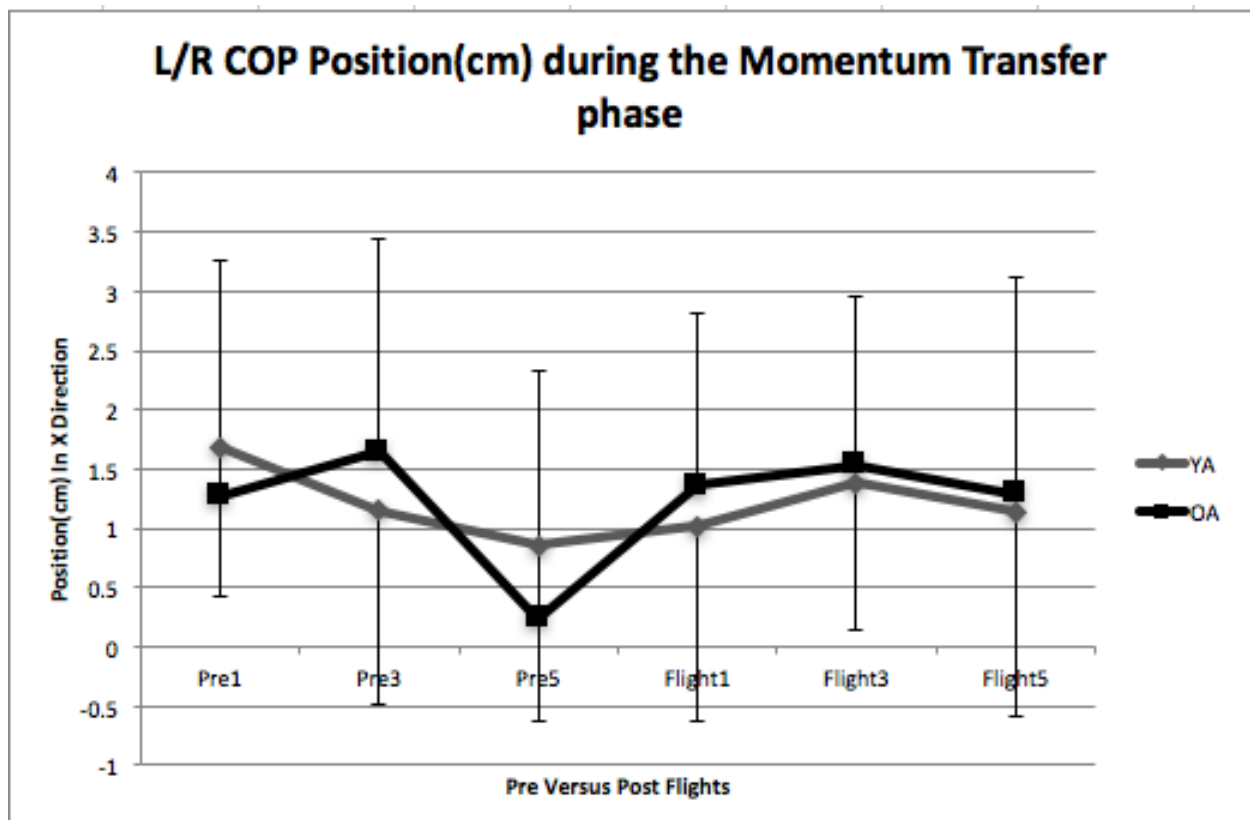


Figure 4: COP position (cm) in the L/R direction at seat-off

4.22 COP Position in the antero-posterior direction during Momentum Transfer Phase

Figure 5 shows the position of the COP in the antero-posterior (A/P) direction at the moment of seat-off, before and after stair climbing. No significant main effects of FLIGHTS ($p = 0.3$, $\eta_p^2 = 0.054$) or AGE ($p = 0.179$, $\eta_p^2 = 0.081$) and no FLIGHT x AGE interaction ($p = 0.534$, $\eta_p^2 = 0.032$) were found for this variable. See Table 5 for the detailed results of the ANOVA.

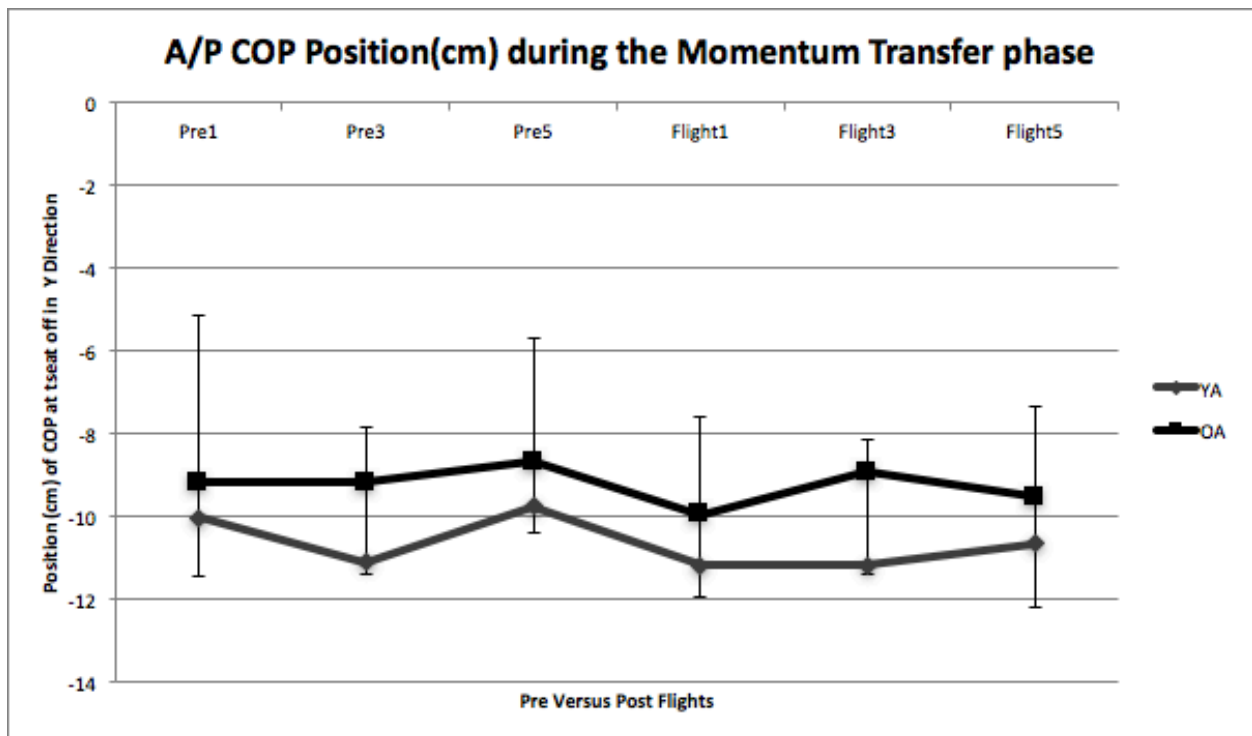


Figure 5: COP position(cm) in the A/P direction at seat-off

4.23 COP Range in the left-right direction during the Momentum Transfer phase

Figure 6 shows the COP range in the L/R direction during the Momentum Transfer phase, before and after stair climbing. No significant main effects of FLIGHTS ($p = 0.389$, η_p^2

= 0.044) or AGE ($p = 0.924, \eta_p^2 < 0.001$) and no FLIGHT X AGE interaction ($p = 0.686, \eta_p^2 = 0.022$) were found for this variable. See Table 5 for the detailed results of the ANOVA.

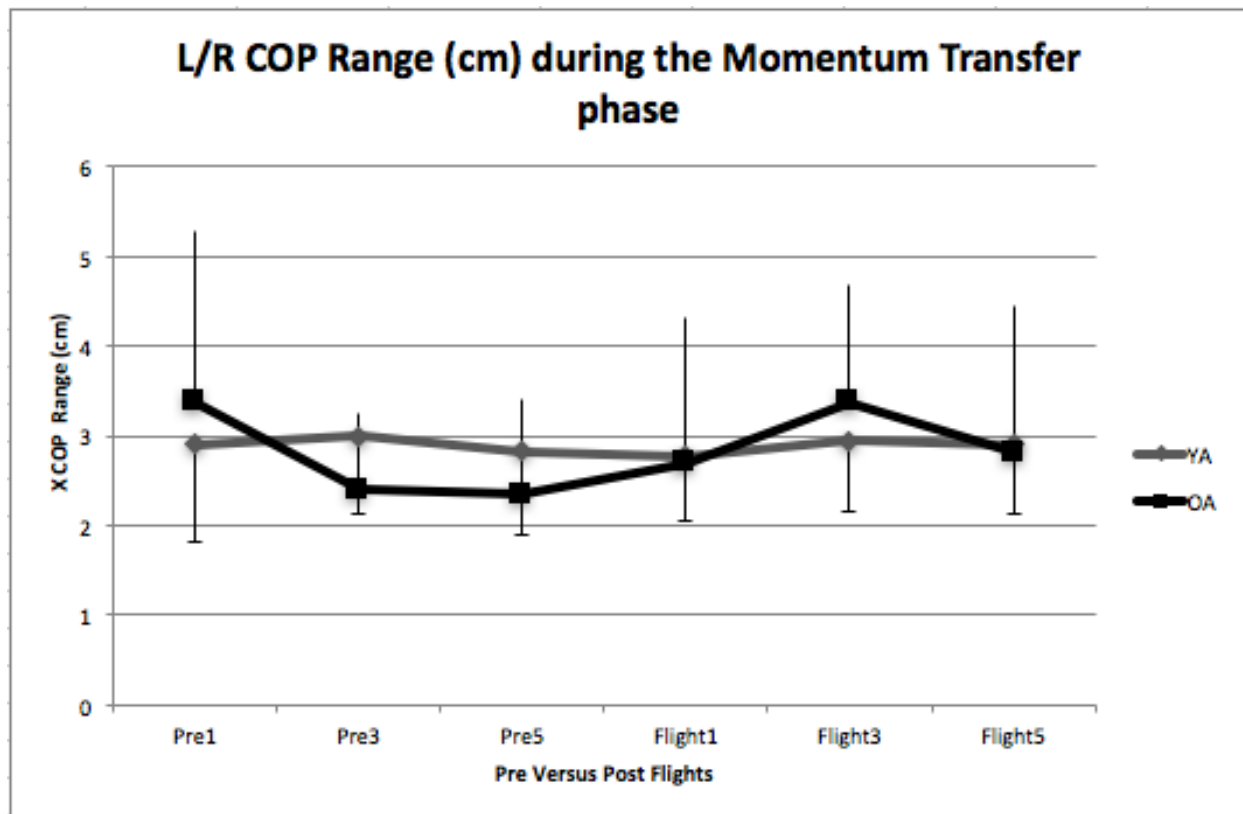


Figure 6: COP range(cm) in the L/R direction during the Momentum Transfer phase

4.24 COP Range in the antero-posterior direction during the Momentum Transfer phase

Figure 7 shows the COP range in the A/P direction between seat-off and extension. Data are shown to contrast before and after stair climbing. No significant main effects of FLIGHTS ($p = 0.23, \eta_p^2 = 0.065$) or AGE ($p = 0.22, \eta_p^2 = 0.069$) and no FLIGHT X AGE interaction ($p = 0.40, \eta_p^2 = 0.041$) were found for this variable. Because the ANOVA performed on the PRE trials found a difference between them ($p = 0.006$), a second ANOVA was performed on the % change from before to after stair climbing for this variable. Again, no main effects of FLIGHT ($p = 0.19, \eta_p^2 = 0.072$) or AGE ($p = 0.67, \eta_p^2 = 0.008$) and no FLIGHT X AGE

interaction ($p = 0.622, \eta_p^2 = 0.02$) were found. See Tables 5 and 6 for the detailed results of the ANOVAs.

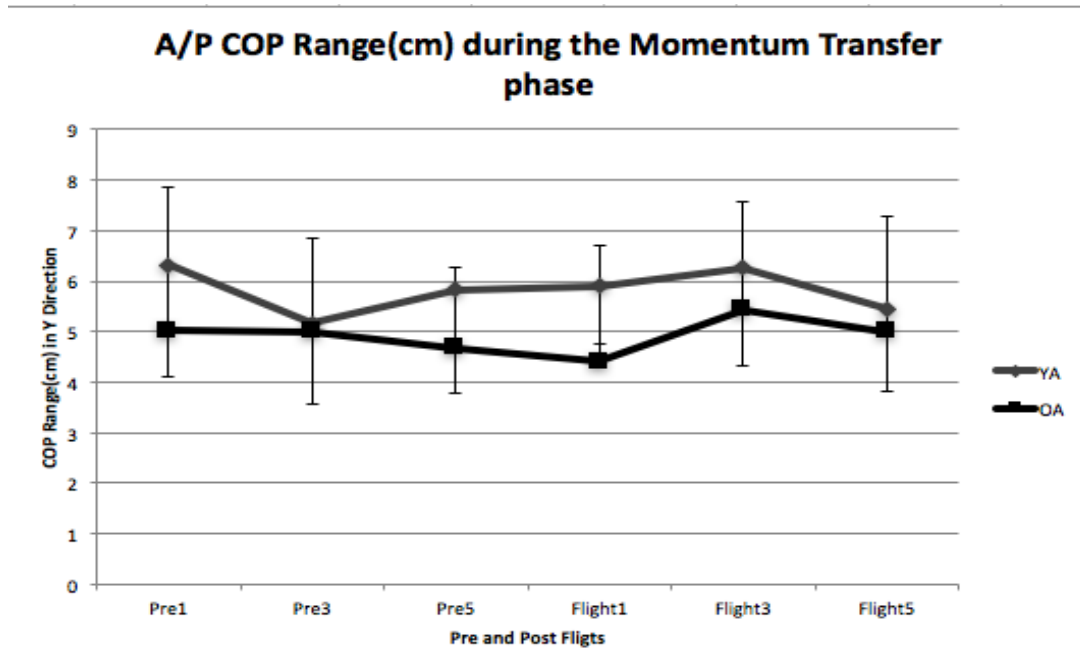


Figure 7: COP range (cm) in the A/P direction during the Momentum Transfer phase

4.25 Peak velocity of COP in the left-right direction the Momentum Transfer phase

Figure 8 shows the peak velocity in the L/R direction at the Momentum Transfer phase, before and after stair climbing. No significant main effects of FLIGHTS ($p = 0.81, \eta_p^2 = 0.01$) or AGE ($p = 0.82, \eta_p^2 = 0.01$) and no FLIGHT x AGE interaction ($p = 0.67, \eta_p^2 = 0.01$) were found for this variable. See Table 5 for the detailed results of the ANOVA.

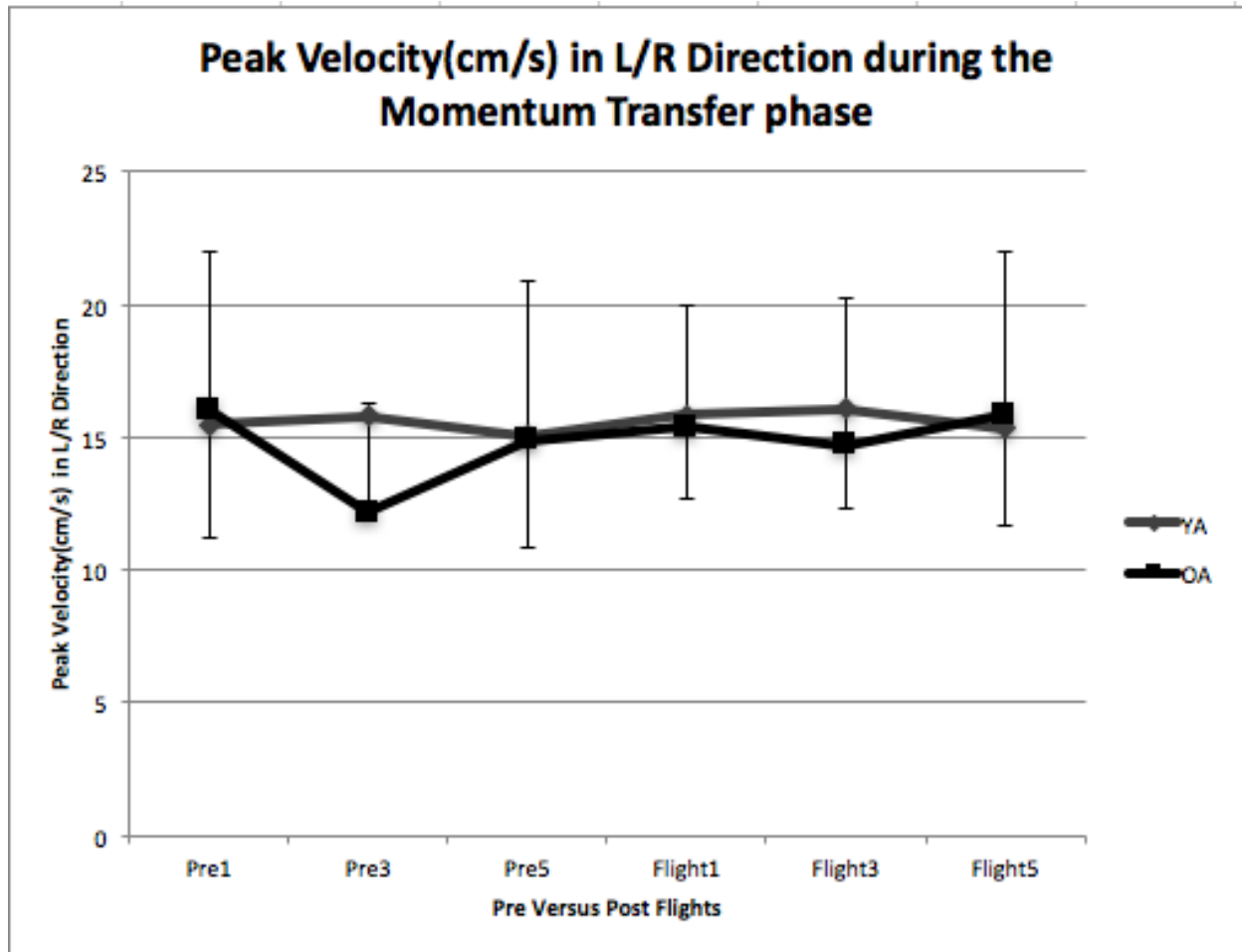


Figure 8: Peak velocity (cm/s) of COP in the L/R direction during the Momentum Transfer Phase

4.26 Peak velocity of COP in the antero-posterior direction during the Momentum Transfer phase

Figure 9 shows the peak velocity of COP in the A/P direction between seat-off and extension, before and after stair climbing. Data are shown to contrast before and after stair climbing. A significant main effect of AGE ($p = 0.015$, $\eta_p^2 = 0.242$) was found, with older adults showing a higher peak velocity compared to the young adults. No main effect of FLIGHTS ($p = 0.24$, $\eta_p^2 = 0.062$) or FLIGHTS x AGE interaction ($p = 0.27$, $\eta_p^2 = 0.057$) were found. Since the ANOVA performed on the PRE trials found a difference between them, ($p = 0.001$), a second ANOVA was performed on the % change from before to after the stair

climbing for this variable. No main effects of the FLIGHT ($p = 0.14, \eta_p^2 = 0.083$) or AGE ($p = 0.18, \eta_p^2 = 0.075$) and no FLIGHT x AGE interaction ($p = 0.88, \eta_p^2 = 0.006$) were found. See Tables 5 and 6 for the detailed results of the ANOVAs and Table 7 for detailed results of the post-hoc analysis.

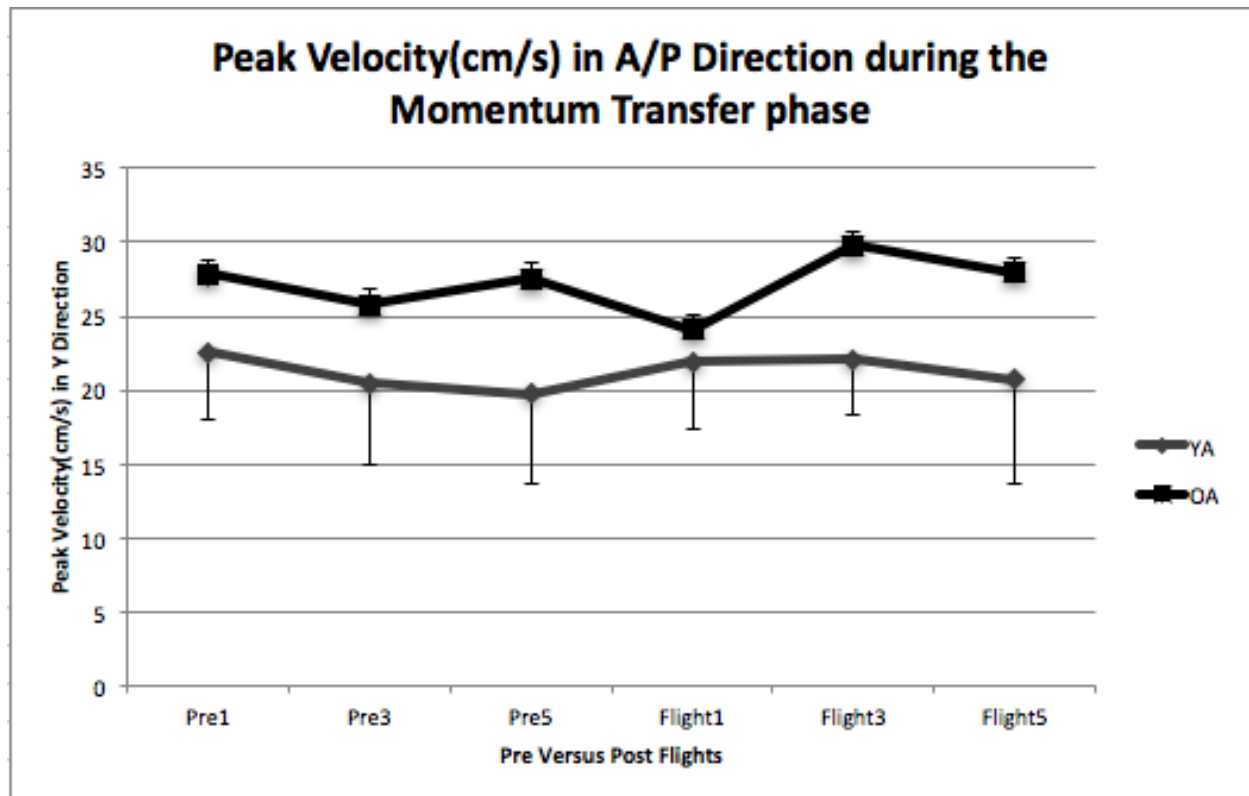


Figure 9: Peak velocity(cm/s) of COP in the A/P direction during the Momentum Transfer phase

4.27 Average Velocity of COP in the left-right direction during the Momentum Transfer phase

Figure 10 shows the average velocity of the COP in the L/R direction between seat-off and extension, before and after stair climbing. No significant main effects of FLIGHTS ($p = 0.45, \eta_p^2 = 0.039$) or AGE ($p = 0.76, \eta_p^2 = 0.005$) and no FLIGHT x AGE interaction ($p = 0.91, \eta_p^2 = 0.008$) were found for this variable. See Table 5 for the detailed results of the

ANOVA.

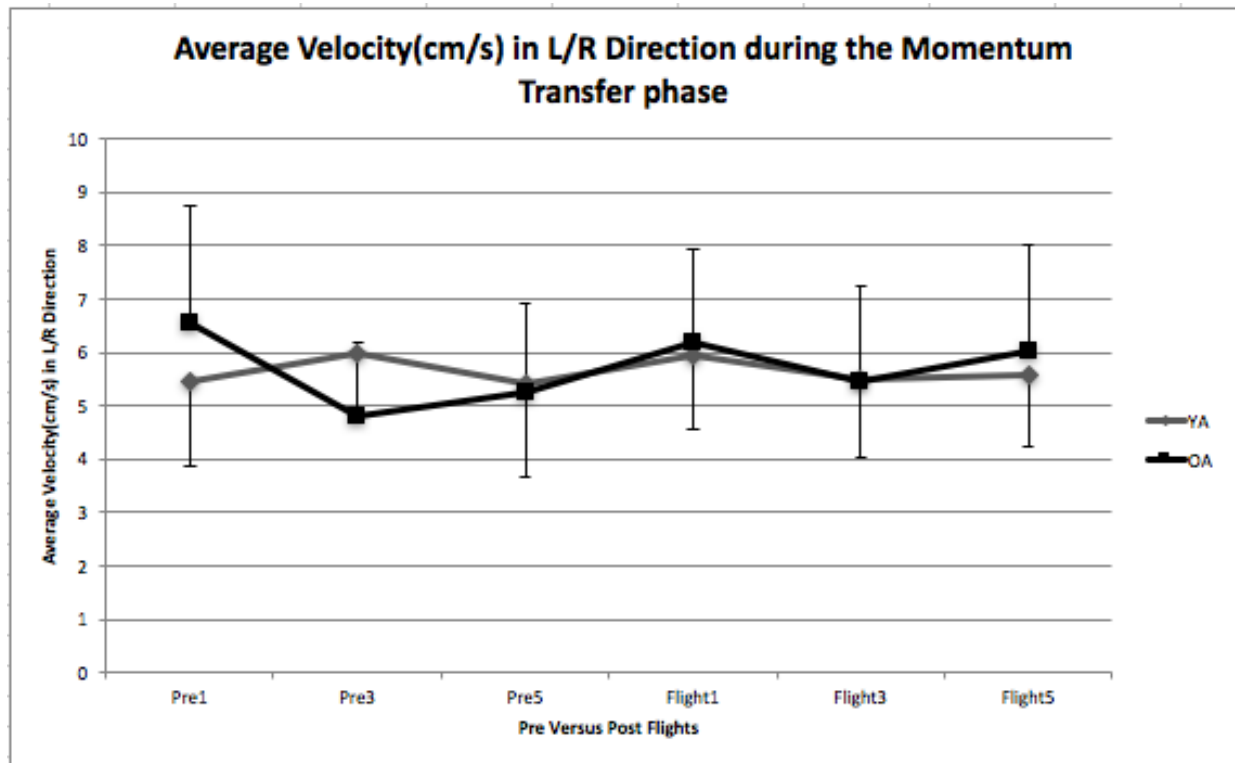


Figure 10: Average velocity (cm/s) of COP in the L/R direction during the Momentum Transfer phase

4.28 Average Velocity of COP in the antero-posterior direction during the Momentum Transfer phase

Figure 11 shows the average COP velocity in the A/P direction between seat-off and extension. Data are shown to contrast before and after stair climbing. A significant main effect of AGE ($p = 0.004$, $\eta_p^2 = 0.327$) was found, with older adults showing a higher average velocity compared with young adults. No main effect of FLIGHTS ($p = 0.21$, $\eta_p^2 = 0.0690$) or FLIGHTS X AGE interaction ($p = 0.15$, $\eta_p^2 = 0.082$) were found. Because the ANOVA performed on the PRE trials found a difference between them ($p < 0.001$), a second ANOVA was performed on the % change from before to after stair climbing for this variable. No main effects of FLIGHT ($p = 0.16$, $\eta_p^2 = 0.077$) or AGE ($p = 0.06$, $\eta_p^2 = 0.142$) and no FLIGHT X

AGE interaction ($p = 0.41, \eta_p^2 = 0.038$) were found. See Tables 5 and 6 for the detailed results of the ANOVAs and Table 7 for detailed post-hoc results.

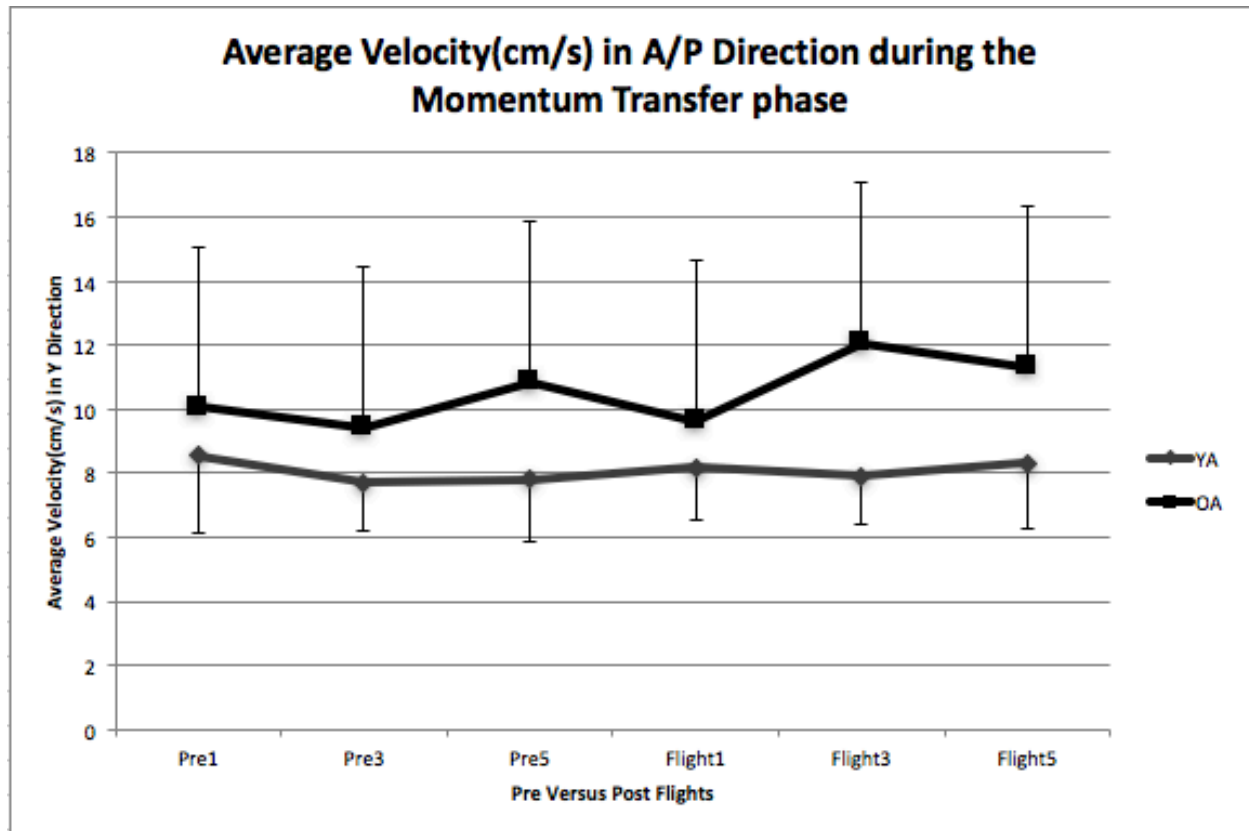


Figure 11: Average velocity (cm/s) of COP in the A/P direction during the Momentum Transfer phase

4.29 Seat-off to Extension Duration

Figure 12 shows the duration of the Momentum Transfer phase (seat-off to extension (in seconds)), before and after stair climbing. No significant main effects of FLIGHTS ($p = 0.43, \eta_p^2 = 0.041$) or AGE ($p = 0.083, \eta_p^2 = 0.13$) and no FLIGHT X AGE interaction ($p = 0.509, \eta_p^2 = 0.034$) were found for this variable. See Table 5 for the detailed results of the ANOVA.

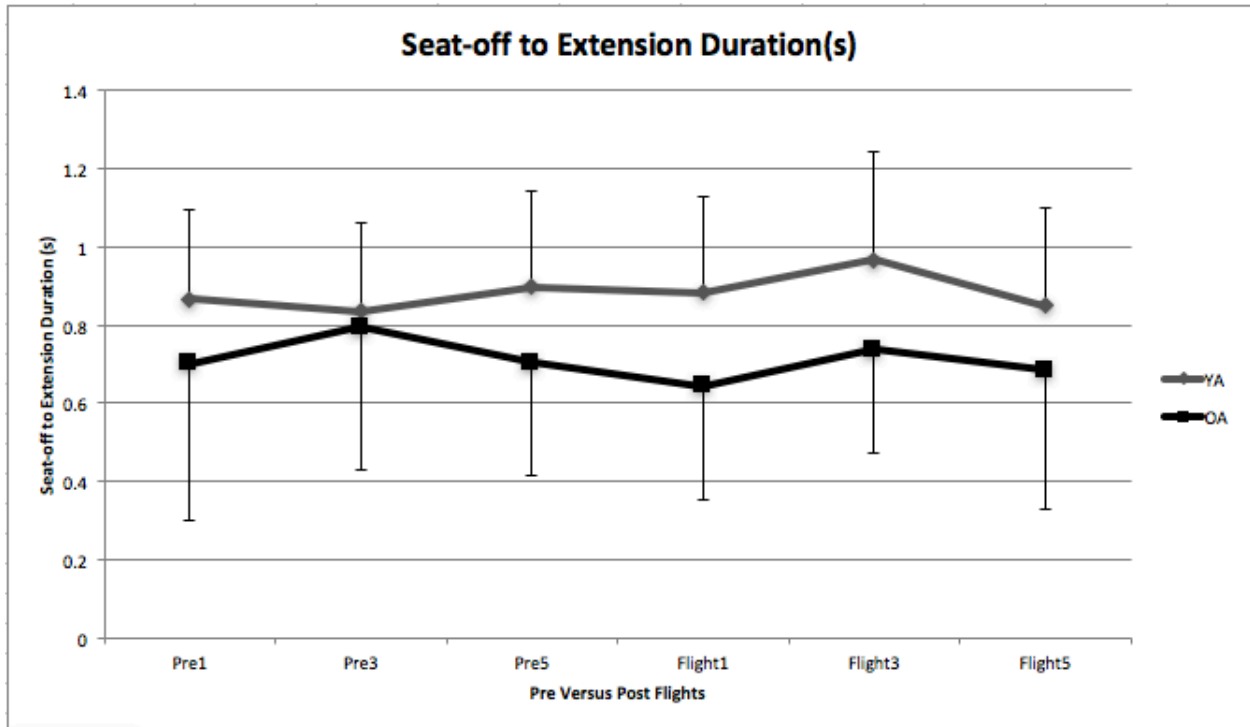


Figure 12: Seat-off to extension duration in seconds

4.3 During stabilization variables

4.3.1 Average Velocity of COP in the left-right direction during Stabilization

Figure 13 shows the average COP velocity in the L/R direction during stabilization, before and after stair climbing. A significant effect of AGE ($p = 0.003$, $\eta_p^2 = 0.323$) was found, with older adults showing a higher average velocity compared with young adults. No main effect of FLIGHTS ($p = 0.75$, $\eta_p^2 = 0.018$) or FLIGHTS X AGE interaction ($p = 0.16$, $\eta_p^2 = 0.072$) were found. Because there was a difference between the PRE trials, a second ANOVA, looking at the % change was performed. There were no main effects of FLIGHTS ($p = 0.89$, $\eta_p^2 = 0.003$) and AGE ($p = 0.95$, $\eta_p^2 < 0.001$) and no main interactions between FLIGHTS x AGE interac-

tion($p = 0.093$, $\eta_p^2 = 0.105$). See Tables 6 and 8 for the detailed results of the ANOVAS.

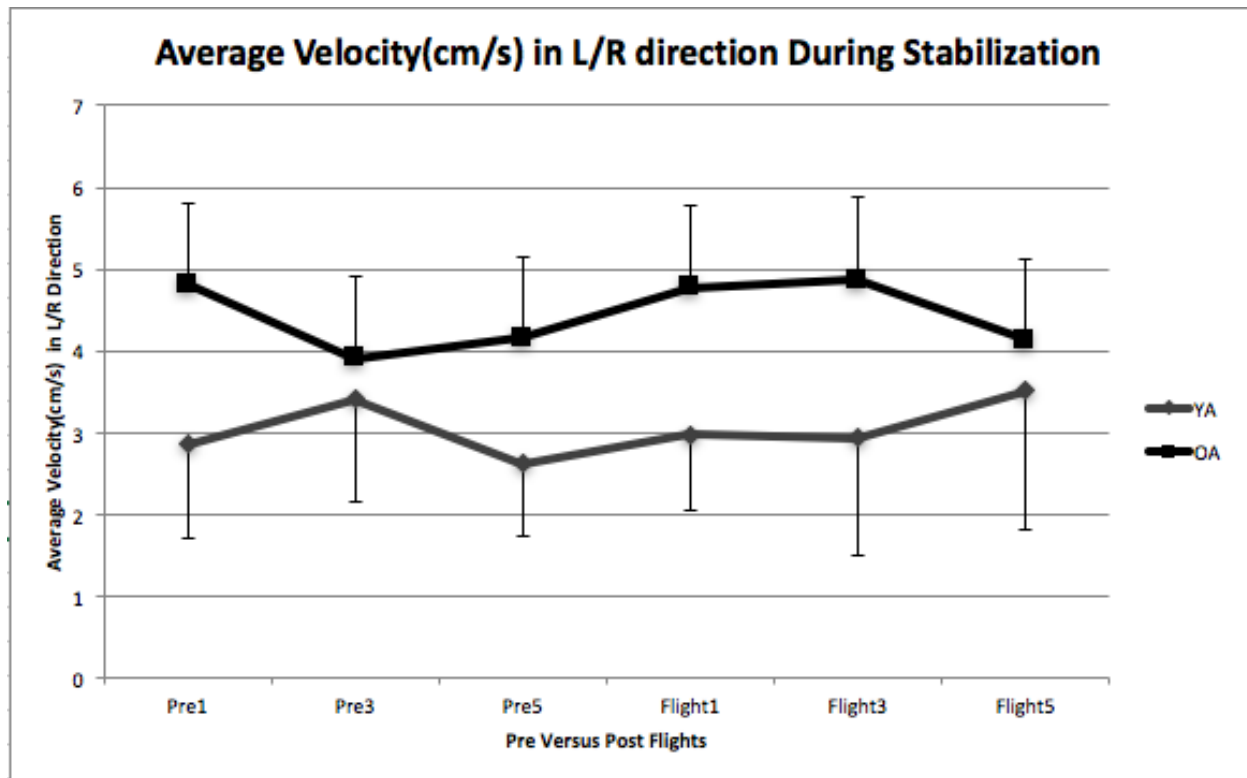


Figure 13: Average velocity(cm/s) of COP in the L/R direction during stabilization

4.32 Average Velocity of COP in the antero-posterior direction during Stabilization

Figure 14 shows the average COP velocity in the A/P direction during stabilization. Data are shown to contrast before and after stair climbing. A significant effect of AGE ($p < 0.001$, $\eta_p^2 = 0.543$) was found, with older adults showing a higher average velocity compared with the younger adults. No main effect of FLIGHTS ($p = 0.15$, $\eta_p^2 = 0.078$) or a FLIGHTS X AGE interaction ($p = 0.24$, $\eta_p^2 = 0.061$) were found. See Table 8 for the detailed results of the ANOVAs and Table 7 for the detailed results of the post-hoc analysis.

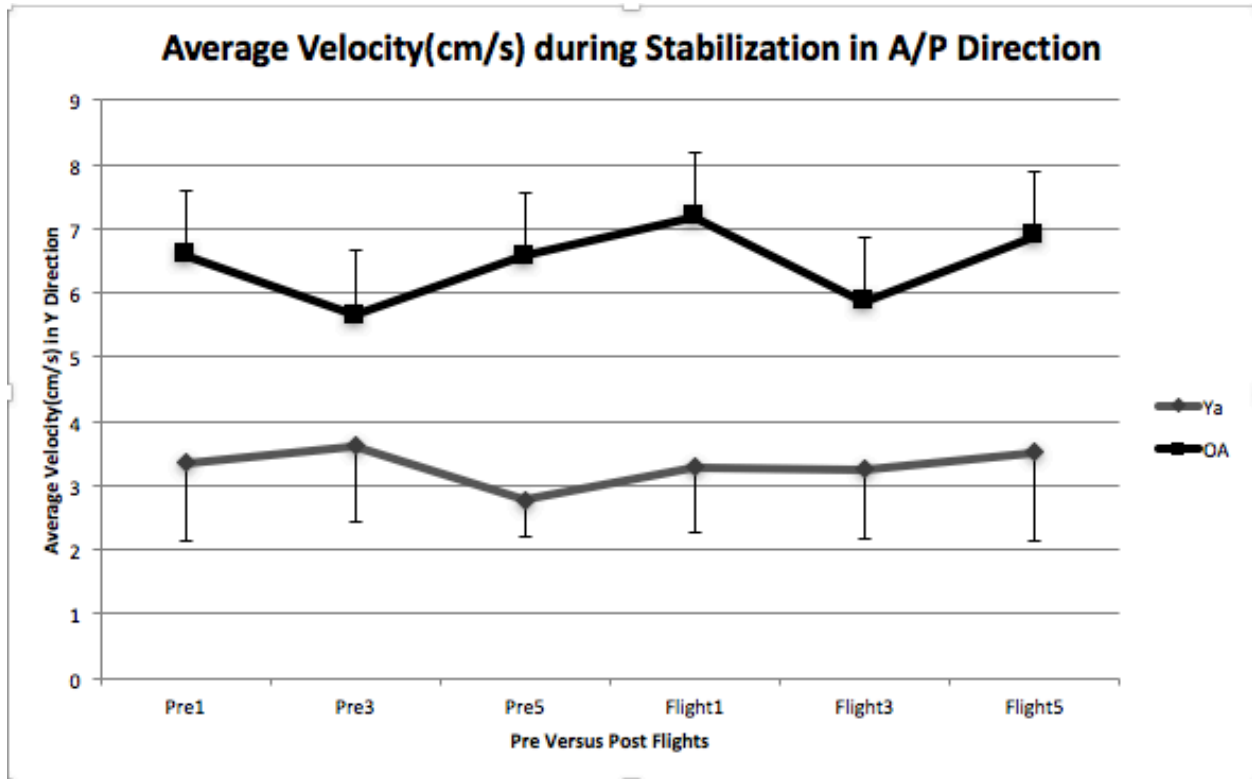


Figure 14: Average velocity(cm/s) of COP during stabilization in the A/P (antero-posterior) direction

4.33 Time to Stabilization

Figure 15 shows the time to stabilization during extension. Data are shown to contrast before and after stair climbing. There were no main effects of AGE ($p = 0.33, \eta_p^2 = 0.043$) and FLIGHTS ($p = 0.52, \eta_p^2 = 0.033$) or FLIGHT X AGE interaction ($p = 0.78, \eta_p^2 = 0.016$). See Table 8 for the details results of the ANOVAs.

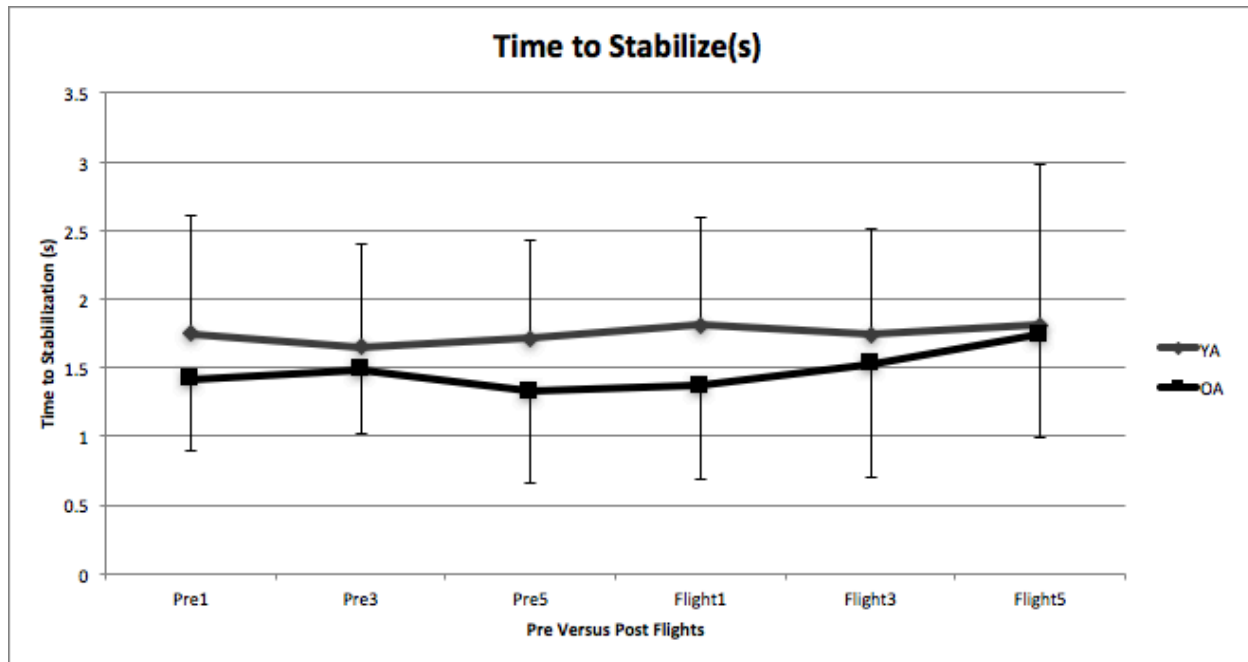


Figure 15: Time to stabilize (s) after extension.

4.4 After Stabilization Variables

4.4.1 Average velocity of COP in the left-right direction after stabilization

Figure 16 shows the average COP velocity in the L/R direction after stabilization. No significant main effects of FLIGHTS ($p = 0.76$, $\eta_p^2 = 0.013$) or AGE ($p = 0.06$, $\eta_p^2 = 0.151$) and no FLIGHT x AGE interaction ($p = 0.24$, $\eta_p^2 = 0.063$) were found for this variable. See Table 9 for detailed results of the ANOVA.

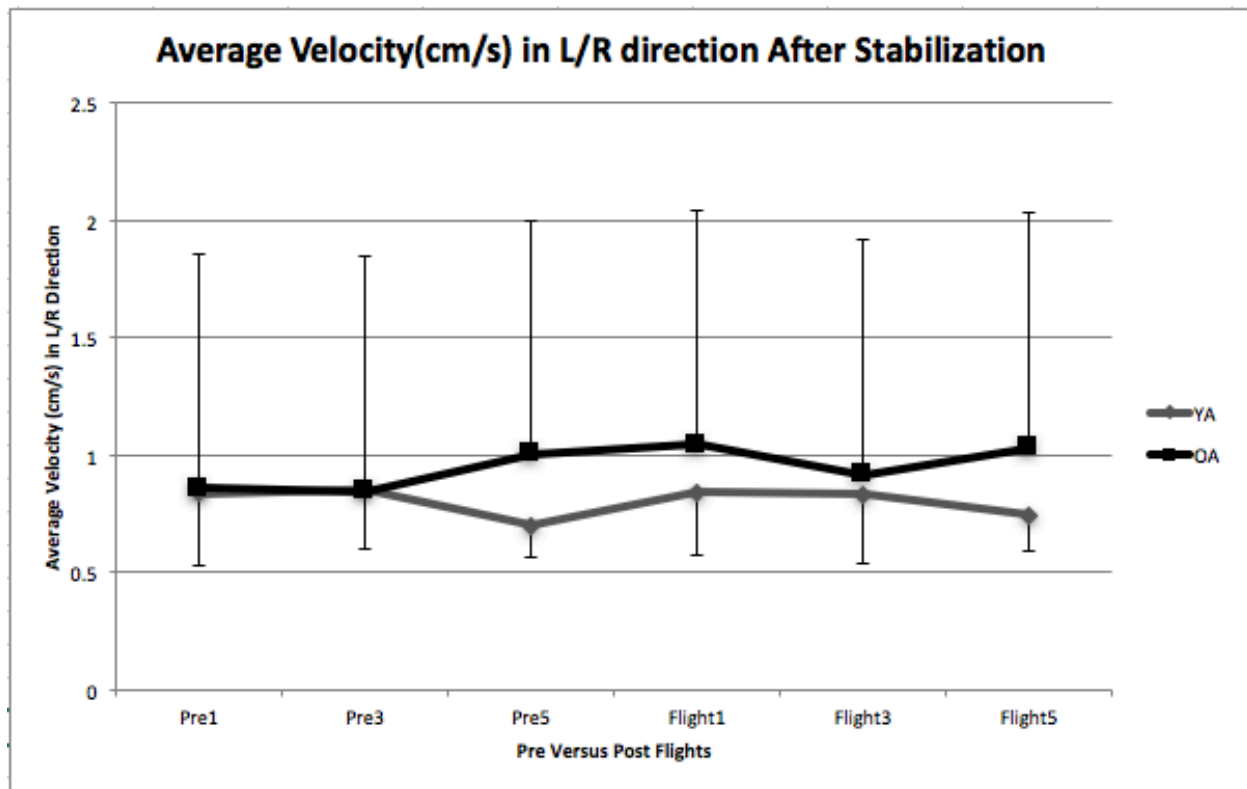


Figure 16: Average Velocity (cm/s) of COP in the L/R direction after stabilization.

4.42 Average Velocity of COP in the antero-posterior direction after stabilization

Figure 17 show the average COP velocity in the A/P direction after stabilization, before and after stair climbing. A significant main effect of AGE ($p < 0.001$, $\eta_p^2 = 0.433$) was found, with older adults showing a higher average velocity. No main effect of FLIGHTS ($p = 0.15$, $\eta_p^2 = 0.013$) or FLIGHTS X AGE interaction ($p = 0.08$, $\eta_p^2 = 0.063$). See Table 9 for the detailed results of the ANOVA and Table 7 for detailed results of the post-hoc analysis.

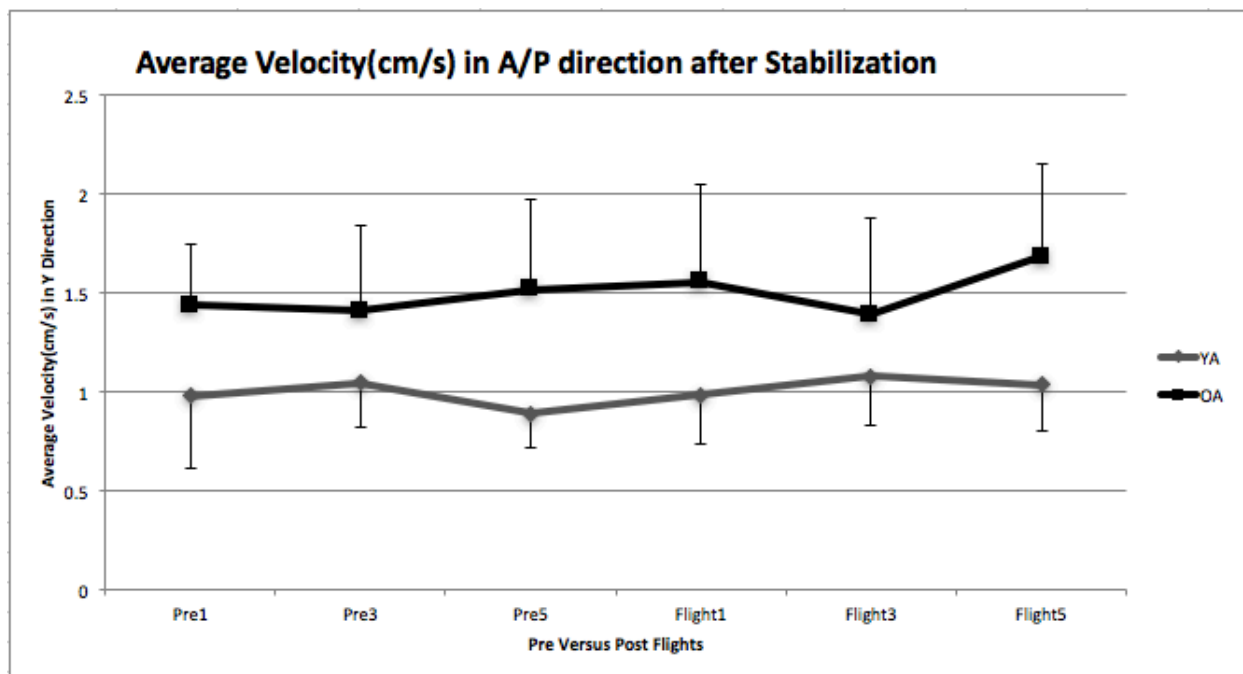


Figure 17: Average Velocity(cm/s) of COP in the A/P direction after stabilization

Table 2: Descriptive Statistics of younger and older adults tested.

	Younger Adults n=14	Older Adults n=14
Age ± SD	24.18 ± 2.85	71 ± 6.15
Godin Leisure Score	59.4 ± 20.24	47.4 ± 31.41

Table 3: Average ± SD MVC for young and old adults pre and post stair climb

	Pre MVC (Nm)	Post MVC (Nm)
Young adults ± SD	189.62 ± 13.23	194.80 ± 4.00
Old Adults ± SD	147.25 ± 1.94	151.59 ± 4.50

Table 4: Mixed-design ANOVA (significance, $p < 0.05$) for variables defining exertion, including MVCs, Heart rate and BORG scale of perceived exertion

Effects	Variables	F Value	p Value (P<0.05)
FLIGHTS Effect			
	MVC	1.511	0.219
	BORG	63.733	$p < 0.001$
	Heart Rate	43.587	$p < 0.001$
AGE Effect			
	MVC	3.088	0.092
	BORG	12.958	0.002
	Heart Rate	0.535	0.473
FLIGHTS X AGE			
	MVC	0.031	0.933
	BORG	4.252	0.02
	Heart Rate	0.387	0.682

Table 5: Mixed-design ANOVA (significance, $p < 0.05$) for variables during the Momentum Transfer phase

Effects	Variables	F Value	p Value (P<0.05)	Partial Eta Squared
FLIGHTS Effect				
	COP Position (cm) in L/R Direction during Momentum Transfer phase	1.163	0.331	0.05
	COP Position (cm) in A/P Direction during Momentum Transfer phase	1.248	0.3	0.054
	COP Range (cm) in L/R Direction during Momentum Transfer phase	1.022	0.389	0.044
	COP Range (cm) in A/P Direction during Momentum Transfer phase	1.522	0.227	0.065
	Peak COP Velocity (cm/s) in L/R Direction during Momentum Transfer phase	0.226	0.813	0.01
	Peak COP Velocity (cm/s) in A/P Direction during Momentum Transfer phase	1.445	0.238	0.062
	Average COP Velocity (cm/s) in L/R Direction during Momentum Transfer phase	0.884	0.454	0.039
	Average COP Velocity (cm/s) in A/P Direction during Momentum Transfer phase	1.62	0.205	0.069
	Duration from SO to Extension (s)	0.933	0.43	0.041
AGE Effect				
	COP Position (cm) in L/R Direction during Momentum Transfer phase	0.014	0.907	0.001
	COP Position (cm) in A/P Direction during Momentum Transfer phase	1.93	0.179	0.081
	COP Range (cm) in L/R Direction during Momentum Transfer phase	0.009	0.924	<0.001
	COP Range (cm) in A/P Direction during Momentum Transfer phase	1.63	0.215	0.069
	Peak COP Velocity (cm/s) in L/R Direction during Momentum Transfer phase	0.216	0.821	0.01
	Peak COP Velocity (cm/s) in A/P Direction during Momentum Transfer phase	7.005	0.015	0.242
	Average COP Velocity (cm/s) in L/R Direction during Momentum Transfer phase	0.1	0.755	0.005
	Average COP Velocity (cm/s) in A/P Direction during Momentum Transfer phase	10.681	0.004	0.327
	Duration from SO to Extension (s)	3.299	0.083	0.13
FLIGHTS X AGE				
	COP Position (cm) in L/R Direction during Momentum Transfer phase	0.101	0.959	0.005
	COP Position (cm) in A/P Direction during Momentum Transfer phase	0.736	0.534	0.032
	COP Range (cm) in L/R Direction during Momentum Transfer phase	0.497	0.686	0.022
	COP Range (cm) in A/P Direction during Momentum Transfer phase	0.953	0.402	0.041
	Peak COP Velocity (cm/s) in L/R Direction during Momentum Transfer phase	0.216	0.821	0.01
	Peak COP Velocity (cm/s) in A/P Direction during Momentum Transfer phase	1.323	0.274	0.057
	Average COP Velocity (cm/s) in L/R Direction during Momentum Transfer phase	0.18	0.909	0.008
	Average COP Velocity (cm/s) in A/P Direction during Momentum Transfer phase	1.952	0.146	0.082
	Duration from SO to Extension (s)	0.78	0.509	0.034

Table 6: Mixed-design ANOVA (significance, $p < 0.05$) of % change for all variables with significant differences between PRE values ($p < 0.05$)

Effects	Variables	F Value	p Value (P<0.05)	Partial Eta Squared
FLIGHTS Effect				
	COP Range (cm) in A/P Direction during Momentum Transfer phase	1.78	0.189	0.072
	Peak COP Velocity (cm/s) in A/P Direction during Momentum Transfer phase	2.073	0.137	0.083
	Average COP Velocity (cm/s) in A/P Direction during Momentum Transfer phase	1.906	0.16	0.077
	Average COP Velocity(cm/s) in L/R Direction During Stbl	0.065	0.894	0.003
AGE Effect				
	COP Range (cm) in A/P Direction during Momentum Transfer phase	0.186	0.67	0.008
	Peak COP Velocity (cm/s) in A/P Direction during Momentum Transfer phase	1.878	0.184	0.075
	Average COP Velocity (cm/s) in A/P Direction during Momentum Transfer phase	3.806	0.063	0.142
	Average COP Velocity(cm/s) in L/R Direction During Stbl	0.005	0.945	<0.001
FLIGHTS X AGE				
	COP Range (cm) in A/P Direction during Momentum Transfer phase	0.48	0.622	0.02
	Peak COP Velocity (cm/s) in A/P Direction during Momentum Transfer phase	0.128	0.88	0.006
	Average COP Velocity (cm/s) in A/P Direction during Momentum Transfer phase	0.908	0.411	0.038
	Average COP Velocity(cm/s) in L/R Direction During Stbl	2.7	0.093	0.105

Table 7: Results of independent t-tests completed as post hoc comparisons to further document differences between young and older individuals when a main effect of AGE was significant.

Variable	t Value	p value(p<0.03)
Peak COP Velocity in A/P Direction during the Momentum transfer phase		
PreTrial 1	-1.277	0.016
Flight 3	-3.116	0.001
Average COP Velocity in A/P Direction during the Momentum transfer phase		
Flight 5	-1.054	0.03
Average COP Velocity in L/R Direction during Stabilization		
PreTrial 1	-1.102	0.016
PreTrial3	-2.585	0.015
Flight 1	-1.422	0.014
Flight3	-4.373	0.007
Average COP Velocity in A/P Direcion during Stabilization		
PreTrial 1	-5.025	0.03
PreTrial 2	-2.687	0.01
PreTrial3	-6.488	0.006
Flight 1	-4.511	0.014
Flight 3	-3.847	0.004
Average COP Velocity in A/P Direction after Stabilization		
PreTrial 3	-4.67	0.002
Flight 1	-3.69	0.023
Flight 5	-4.297	0.027
BORG		
Flight 1	-4.358	p<0.001
Flight 5	-3.819	0.001

Table 8: Mixed-design ANOVA (significance, $p < 0.05$) for variables during the Stabilization phase.

Effects	Variables	F Value	p Value (P<0.05)	Partial Eta Squared
FLIGHTS Effect				
	Average COP Velocity(cm/s) in L/R Direction During Stbl	0.412	0.745	0.018
	Average COP Velocity (cm/s) in A/P Direction During Stbl	1.861	0.145	0.078
	Time to Stabilization (s)	0.754	0.524	0.033
AGE Effect				
	Average COP Velocity(cm/s) in L/R Direction During Stbl	10.995	0.003	0.323
	Average COP Velocity (cm/s) in A/P Direction During Stbl	26.168	p<0.001	0.543
	Time to Stabilization (s)	0.98	0.333	0.043
FLIGHTS X AGE				
	Average COP Velocity(cm/s) in L/R Direction During Stbl	1.795	0.156	0.072
	Average COP Velocity (cm/s) in A/P Direction During Stbl	1.433	0.241	0.061
	Time to Stabilization (s)	0.362	0.781	0.016

Table 9: Mixed-design ANOVA (significance, $p < 0.05$) for variables during the Post-Stabilization

Effect	Variables	F Value	p Value (P<0.05)	Partial Eta Squared
FLIGHTS Effect				
	Average COP Velocity(cm/s) in L/R Direction after Stbl	0.287	0.762	0.013
	Average COP Velocity (cm/s) in A/P Direction after Stbl	1.94	0.146	0.081
AGE Effect				
	Average COP Velocity(cm/s) in L/R Direction after Stbl	3.907	0.061	0.151
	Average COP Velocity (cm/s) in A/P Direction after Stbl	16.804	p<0.001	0.433
FLIGHTS X AGE				
	Average COP Velocity(cm/s) in L/R Direction after Stbl	1.477	0.239	0.063
	Average COP Velocity (cm/s) in A/P Direction after Stbl	2.574	0.076	0.105

Chapter 5: Discussion

The present study was conducted to determine whether physical exertion caused by sustaining the performance of an ADL, stair climbing, can influence the performance of another ADL, standing up from a chair (STS) in both younger and older adults. It was proposed that an increased number of flights climbed would affect COP movement, velocity and time to stabilize during a STS, however this was not the case. The majority of the significant findings were limited to an age effect.

5.1 L/R and A/P COP Position and Range

To begin, it was interesting that the COP range and position was not different between the older and younger adults. Previous studies have found that older adults typically have a more anterior position and show a more medial-lateral movement during the STS (Schot et al., 2003; Choy et al., 2003). The increased anterior position is likely due to the stabilization strategy that is commonly used with older adults (Schot et al., 2003) due to lesser muscle strength and an assumed kyphosis (Merlo et al., 2011). The stabilization strategy leads to a more exaggerated trunk flexion at seat-off, which would cause the COP to move forward (Schot et al., 2003; Savelberg et al., 2007). If the older adults had used the stabilization strategy, a significant difference may have been seen in the A/P direction COP position at seat off. However, the older adults may have been either too strong or too young to use that strategy. The lack of significant difference between the age groups when it comes to COP position and range in the L/R and A/P direction is likely due to the fact that the older adults were all relatively strong for their age as they were able to climb up five flights of stairs. As seen from the results, there was no significant difference between age

groups in MVC force, indicating the older participants were not particularly weak, and therefore a lack of difference for COP position is not necessarily surprising. Furthermore, the increase in flights was seemingly not fatiguing for either young or older participants, as suggested by the absence of a FLIGHTS effect on MVC force.

Moreover, it is also important to note that a difference in left-right COP positions and movements could have been seen between the two age groups (Choy et al., 2003). Medio-lateral sway has been used as an indicator of fall risk in the older adult community (Melzer et al., 2004). This is because of the increase in control needed when rising from a chair. Again, there was no difference between the present younger and older adults and this may be due to the fact that older adults were relatively strong, which may be explained by the inclusion/exclusion criteria used for participation in the study. Before the study, the older adult participants would answer a question about whether they were unfit for stair climbing, which included any recent falls in the past six months. If any of the participants had answered “yes” to that question, they would not have continued in the study.

Apart from using strong older adults, the age range for that group was between 65 to 80 years old. This is a wide range, however Gomes et al (2013) found that there are no significant changes in COP velocity and COP displacement between the ages 60 to 79 for both a static balance task with eyes closed and a dynamic balance task of STSs.

5.2 Time to Stabilization and Seat-off to Extension Duration

Next, there was no significant interaction between AGE and FLIGHTS climbed when it came to time to stabilize. The stabilization phase begins when the knee is fully extended (Kralj et al., 1990) and is challenging in that the centre of mass needs to become stabilized

at the end of the STS after being controlled dynamically (Akram., 2011). It was expected that time to stabilize would be longer in the older adults due to a decreased ability to control their COP because of aging (Akram., 2011); however they showed no significant difference with younger adults. Age-related differences in time to stabilize following a STS is not a consistent finding in previous studies. Akram (2011) found an age effect on stabilization time, but no age by task interaction, the task being different foot positions. In contrast, Cheng et al (2014) found no difference in stabilization time between younger and older adults. It will be important to conduct further research on stabilization time between younger and older adults as it could potentially be used as an indicator of fall risk, with the longer it takes to stabilize indicating a lesser ability to control posture. Moreover, because the two age groups in the present study were similar in muscle strength, we cannot comment on the role of muscle weakness on stabilization time. However, Akram (2011) believed that muscle strength does not play a role in stabilization time, therefore if there was a significant difference in muscle strength between the younger and older adults, there still might not have been a significant difference between the age groups. There was no significant difference between seat-off to extension time between the two age groups, and this time remained consistent across the number of flights climbed for both age groups. Again, this result is not surprising considering the high functioning level of our older participants.

5.3 Average velocity in Older and Younger Adults during a STS

Older adults presented with a greater COP velocity compared with their younger counterparts as there was an age effect for the Momentum Transfer phase in the A/P direction, during stabilization for both directions and after stabilization in the A/P direction.

This was expected as a greater COP velocity indicates altered postural control during both static tasks and walking (Burke et al.,2012; Ilmane et al.,2015), and is typical of older adults. Overall, COP velocity in both L/Rand A/P directions increases with age and this has been explained in part by a decrease in strength in the lower extremities (Burke et al.,2012). Again, the older adults in the present study did not present with significantly lower extremity strength than the younger adults. Furthermore, stair climbing did not negatively affect those muscles in either age group (No evidence of fatigue) which would explain the lack of change in COP velocity following stair climbing.

Amongst the potential factors that could explain the difference in COP velocity between young and older adults, is joint stiffness. Older adults typically have stiffer joints, which is associated with poorer control of the COP (Burke et al.,2012). The ankle joint is an important joint in terms of postural control because the COM is right in front of that joint (Vette et al, 2017). Vette et al (2017) had found that in quiet stance, older adults frequently activated the tibialis anterior (an antagonist ankle muscle), causing the co-activation around the ankle joint, while young adults rarely activated this muscle in quiet stance. This was also associated with a decrease in postural steadiness in older adults. However, it has also been suggested that a role of co-activations is to induce joint stiffness, in order to increase postural stability (Hortobargyi & DeVita, 2000). Co-activation may also decrease the sensory perception of that joint (Ortega & Farley, 2015). Thus, possibly leading to an increase in COP velocity. Unfortunately, joint stiffness was not tested in this study, and this cannot be verified.

Another possibility is that older adults were using an anticipatory response when told to stand up. This response would cause a more forward movement to avoid backward

movements when rising from the bench, and this would in turn, make it harder to control the COP causing a faster velocity to overcompensate (Bhatt et al.,2013). As well, anticipatory responses can be slower in older adults, causing the COP to move at a higher velocity to complete the task (Hortobargyi & DeVita. 2000). However, because no EMG was used to assess muscle activation, this cannot be verified. As well, it was shown that the younger and older adults had insignificant difference between COP position and COP range, meaning not one group was seemingly more forward than the other.

The increase in velocity of the COP, a characteristic of postural control deficit (Baloh et al.,1998) very common in older adults, could also be explained by age-related deficits in proprioception and central processing of sensory information (Bellew et al.,2006; Stur-nieks, St.George & Lord.,2008).

There were no significant differences between age groups in the L/R direction velocity during the momentum-transfer phase and after stabilization, and this was expected because the older adults were stable between their two feet and did not show any indication of being at risk of falling, which appears when there is increased sway in the L/R COP direction. The majority of the age differences occurred in the A/P direction.

5.4 Limitations

There were a few limitations with this study, the first being that the older adults chosen may have been relatively young and active. They were active enough to agree to walk up five flights of stairs and that should have been an indicator that they were an active group. However, safety issues could have been present if older adults at risk of falls would have been recruited. Moreover, it may have been better to get the participants to complete

five STSs each trial as opposed to three, as five STSs is a common test for a fall risk indicator.

Also, I believe it would make a difference if the older adults had stairs in their homes versus no stairs. The majority of the older adults tested lived in homes with stairs, while the majority of younger adults tested lived in apartment buildings and had limited availability to stair climb.

Conclusion

In the end, two functional tasks not commonly compared were tested against each other to see any interaction in terms of postural control. The aim of this study was to determine if postural change during a STS was affected by aging and stair climbing. There was only an Age effect on some variables, however stair climbing up to 5 flights did not lead to changes in the performances of STSs, in either age group. This study was conducted on healthy, active old and it would be interested to conduct further research on older adults with more mobility limitations.

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Appendices

Appendix 1: List of Exclusion Criteria

List of Criteria		
Have you had any falls in the past year?	Yes	No
Do you have any of the following medical conditions?		
Any cardiovascular problems (e.g. infarct, aneurysm, angina) or pulmonary problems (e.g. embolus).	Yes	No
If yes, is it one of the following:		
<ul style="list-style-type: none"> • a myocardial infarction within the previous 2 years • a thrombophlebitis within the previous 2 years • a pulmonary embolus within the previous 2 years • a cardiac illness such as symptoms of aortic stenosis, acute pericarditis, acute myocarditis, aneurysm, severe angina, clinically significant valvular disease, uncontrolled dysrhythmia, claudication within the previous 10 years 	Yes	No
History of cerebrovascular disease	Yes	No
Neurological disease (e.g. Alzheimer, Parkinson's, Huntington's)	Yes	No
Acute feverish illness within the previous 3 months	Yes	No
Severe airflow obstruction	Yes	No
Uncontrolled metabolic disease (e.g. diabetes, thyroid disease)	Yes	No
Major systemic disease active such as cancer, severe rheumatoid arthritis within the previous 2 years.	Yes	No
Significant emotional distress, psychotic illness or depression within the previous 2 years	Yes	No
Lower limb problems (arthritis, injuries)	Yes	No
If yes, is it one of the following:		
<ul style="list-style-type: none"> • Lower limb arthritis, classified by inability to perform maximal contractions of lower limbs without pain • fracture sustained within the previous 2 years • non-arthroscopic lower limb joint surgery within the previous 2 years 	Yes	No
Any reason for a loss of mobility for greater than 1 week in the previous 2 months or greater than 2 weeks in the previous 6 months	Yes	No
High resting blood pressure (systolic; first number > 200 or diastolic; second number > 100)	Yes	No
Taking medications affecting heart rate (beta-blockers or digoxin), or not in sinus rhythm (excluded from ergometry because of difficulty interpreting heart rate)	Yes	No
On daily analgesia	Yes	No
Loss of sensation (peripheral neuropathy)	Yes	No
Severe back pain	Yes	No

Appendix 2: Mini-Mental State Examination

The Mini-Mental State Exam

Patient _____ Examiner _____ Date _____

Maximum Score

5 ()

5 ()

3 ()

5 ()

3 ()

2 ()

1 ()

3 ()

1 ()

1 ()

1 ()

Orientation

What is the (year) (season) (date) (day) (month)?

Where are we (state) (country) (town) (hospital) (floor)?

Registration

Name 3 objects: 1 second to say each. Then ask the patient all 3 after you have said them. Give 1 point for each correct answer. Then repeat them until he/she learns all 3. Count trials and record.
Trials _____

Attention and Calculation

Serial 7's. 1 point for each correct answer. Stop after 5 answers.
Alternatively spell "world" backward.

Recall

Ask for the 3 objects repeated above. Give 1 point for each correct answer.

Language

Name a pencil and watch.

Repeat the following "No ifs, ands, or buts"

Follow a 3-stage command:

"Take a paper in your hand, fold it in half, and put it on the floor."

Read and obey the following: CLOSE YOUR EYES

Write a sentence.

Copy the design shown.



Total Score

ASSESS level of consciousness along a continuum _____

Alert Drowsy Stupor Coma

Appendix 3: Godin Leisure-Time Exercise Questionnaire

Godin Leisure-Time Exercise Questionnaire

INSTRUCTIONS

In this excerpt from the Godin Leisure-Time Exercise Questionnaire, the individual is asked to complete a self-explanatory, brief four-item query of usual leisure-time exercise habits.

CALCULATIONS

For the first question, weekly frequencies of strenuous, moderate, and light activities are multiplied by nine, five, and three, respectively. Total weekly leisure activity is calculated in arbitrary units by summing the products of the separate components, as shown in the following formula:

$$\text{Weekly leisure activity score} = (9 \times \text{Strenuous}) + (5 \times \text{Moderate}) + (3 \times \text{Light})$$

The second question is used to calculate the frequency of weekly leisure-time activities pursued "long enough to work up a sweat" (see questionnaire).

EXAMPLE

Strenuous = 3 times/wk

Moderate = 6 times/wk

Light = 14 times/wk

$$\text{Total leisure activity score} = (9 \times 3) + (5 \times 6) + (3 \times 14) = 27 + 30 + 42 = 99$$

Godin Leisure-Time Exercise Questionnaire

1. During a typical **7-Day period** (a week), how many times on the average do you do the following kinds of exercise for **more than 15 minutes** during your free time (write on each line the appropriate number).

Times Per
Week

a) **STRENUOUS EXERCISE**

(HEART BEATS RAPIDLY)

(e.g., running, jogging, hockey, football, soccer, squash, basketball, cross country skiing, judo, roller skating, vigorous swimming, vigorous long distance bicycling)

Appendix 3: Godin Leisure-Exercise Questionnaire Cont'

Godin Leisure-Time Exercise Questionnaire

1. During a typical 7-Day period (a week), how many times on the average do you do the following kinds of exercise for more than 15 minutes during your free time (write on each line the appropriate number).

- | | Times Per Week |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|
| a) STRENUOUS EXERCISE
(HEART BEATS RAPIDLY) | _____ |
| (e.g., running, jogging, hockey, football, soccer,
squash, basketball, cross country skiing, judo,
roller skating, vigorous swimming,
vigorous long distance bicycling) | |
| b) MODERATE EXERCISE
(NOT EXHAUSTING) | _____ |
| (e.g., fast walking, baseball, tennis, easy bicycling,
volleyball, badminton, easy swimming, alpine skiing,
popular and folk dancing) | |
| c) MILD EXERCISE
(MINIMAL EFFORT) | _____ |
| (e.g., yoga, archery, fishing from river bank, bowling,
horseshoes, golf, snow-mobiling, easy walking) | |

2. During a typical 7-Day period (a week), in your leisure time, how often do you engage in any regular activity long enough to work up a sweat (heart beats rapidly)?


1. Often _____ 2. Sometimes _____ 3. Rarely/Never _____

Appendix 4: BORG Scale of Perceived Exertion

1 - 10 Borg Rating of Perceived Exertion Scale	
0	Rest
1	Really Easy
2	Easy
3	Moderate
4	Sort of Hard
5	Hard
6	
7	Really Hard
8	
9	Really, Really, Hard
10	Maximal: Just like my hardest race

Appendix 5: Consent Form

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INFORMATION LETTER AND CONSENT FORM

Acute effects of exercise-induced neuromuscular fatigue on posture control with aging

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Invitation to participate: I am invited to participate in the research “Acute effects of exercise-induced neuromuscular fatigue on posture control with aging” conducted by the research team headed by Dr. Martin Bilodeau. I am a healthy adult between 18 and 35 years old, or between 40 and 55 years old or older than 65 years of age.

Purpose of the study: The purpose of this research study is to assess and compare the effects of muscular fatigue of the leg on mobility and/or balance, standing on one or both legs, in young and older adults.

Participation: If I agree to participate, my involvement will consist of at least one and up to a maximum of three visits (with about one week interval) to the Aging and Movement Research Laboratory at the Elizabeth Bruyère Research Institute. Some participants may be asked to participate in a session done at the University of Ottawa’s Lees Campus or Roger Guindon Campus. Each visit will last between 30 and 90 minutes. For each of the experimental visits, the following tasks will be performed.

1) First, surface electrodes may be taped to my skin over three to six of my leg muscles. To facilitate this, I will be asked to wear shorts. Some of the electrodes will be placed below my knee, and some may be placed above the knee on the thigh and on the side of my buttock. I will then have to briefly push as hard as I can with my leg against an apparatus or the hands of a researcher in three to six different directions. Small electronic devices may also be taped to the skin at my ankles, knees and hips to measure changes in the position of those joints. Changes in joint position may also be measured with a system

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Appendix 5: Consent Form Cont'

consisting of eight infrared cameras and small markers taped to the skin.

- 2) My mobility and/or balance on one or two legs will be tested. I will be asked to perform one or more of the following activities: 1) stand still on one of my legs or on both legs on a platform able to measure how much I sway for bouts of 30-60 seconds; 2) lean in different directions by matching targets presented on a screen placed in front of me; 3) walk 8 meters to a memorized target on the floor while blindfolded or, 4) sit down and stand up from a chair or the floor. I may also be asked to listen to or give a verbal response to a tone or give a verbal response or push a button as fast as possible in response to a light, before and/or while my balance is tested.
- 3) After this, my strength may be assessed using a device designed to measure muscular strength and for rehabilitation exercises. If so, I will be asked to sit with one of my legs strapped to avoid unwanted movement. Then, I will be asked to push or pull as hard as I can up to five times with either my hip, knee or ankle.
- 4) Then my leg muscles may be fatigued by performing one of the following activities: 1) in the same position as for the maximal force test, I may be asked to do continuous repetitions of maximal efforts or hold a target force level with my ankle, knee or hip until my force decreases by a given percentage (25, 50 or 75%) of my maximum force; 2) I may be asked to raise-up on my toes and maintain this position for as long as I can; 3) I may be asked to go up and down a flight of stairs or a platform until my heart rate increases to a pre-determined level; or 4) I may be asked to rise up and sit down from a chair repeatedly until I can no longer maintain a given pace.
- 5) Immediately and up to 30 minutes after fatigue is reached, I will be asked to execute the same task as described in 2.
- 6) During post fatigue assessments, the level of fatigue of my muscles may be maintained by repeating the step in 4 between balance trials.
- 7) I may be asked to perform the mobility/balance task described in 2 while wearing a weighted suit, goggles to diminish my vision and earplugs.
- 8) My participation may involve the electrical stimulation of one of my muscle. If so, from five to ten brief (5/1000 of one second) pulses of electrical stimulation will be given to my muscle.
- 9) My hearing may also be tested by the researchers in a sound booth.

Risks: I understand that the possible risks associated with participating in this research project are as follows:

- 1) **Minor irritation** of the skin at the surface electrode sites is possible, but uncommon because of the use of non-irritating, non-abrasive, non-sensitizing conductive cream. If present, the irritation should disappear in a few hours. Also, some discomfort is possible when removing the surface recording electrodes (like removing a band-aid).
- 2) **Muscle soreness** associated with performing maximal contractions with my leg might be experienced after the experimental visits. However, a warm-up period before

Appendix 5: Consent Con't

testing begins will be provided and should minimize the muscle soreness. For my safety and well-being, the investigators may decide to end a session at any time.

- 3) **The loss of balance** during testing is possible but any fall will be prevented through the use of a harness and rope system anchored to the ceiling or a belt worn around my waist. A member of the research team will be in appropriate proximity to provide additional support when necessary.
- 4) If applicable, **discomfort** from electrical stimulation may be present as the sensation is similar or somewhat stronger than from a shock experienced with static electricity. In our experience, participants do tolerate these shocks relatively well. However, if the stimulation was to become too uncomfortable for given individuals, the study would be ended. Subjects will be reminded periodically that they are free to end the session if they feel uncomfortable for any reasons.

Benefits: I understand that I may not benefit personally from participating in this study. However, we hope that, in the future, other people might benefit from this study because of the increased knowledge of factors affecting balance, postural control and falls with aging.

Cost: I will not have any costs for participating in this research study. I will be compensated to cover expenses associated with my participation in the study. By providing consent to participate in this research study and receiving payment for participation, we wish to inform you that a research administrator at the Institute will be reviewing the participant lists of all research studies of this nature (in which participant payments are made) once per year. He or she will sign a confidentiality pledge and will keep your personal information confidential. However, in the event that the research administrator identifies that you have received more than \$500 per year in payments for your involvement in research studies at our organization, he/she will notify our Finance Department so that a T4A form can be issued to you for income tax reporting purposes (at which time your SIN number will be required).

Confidentiality and anonymity: I understand that the investigators will keep my participation in this research study confidential to the extent permitted by law. My identity will be kept confidential by using a subject code or number instead of personal information. Any document with my personal information will only be accessed by the investigators and will be kept in a locked cabinet in Dr. Bilodeau's office.

Data Conservation: I understand that the results of this study (including mine), will be presented at scientific meetings and submitted for publication in scientific journals. When a report or article is written about this study, the results will be described in a summarized manner so that I cannot be identified. I understand that all data will be destroyed after 7 years.

Voluntary Participation: I understand that taking part in this research study is completely voluntary. I may choose not to take part at all. If I decide to be in this study, I may stop participating at any time. If I decide not to be in this study, or if I stop participating at any time, I will not be penalized and will still receive the reimbursement for expenses for which I otherwise qualify.