Fall Prevention for Older Women Using Online Dance Classes with Blood Flow Restriction

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ABSTRACT

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Emma Hsiaowen Chen

This project examined if online dance classes could provide a safe and accessible method for older women to improve their physical activity levels and reduce their risk of falls. Women aged 65 years and above were recruited to complete 12 weeks of twice-weekly 75-minute interventions, and were evaluated pre, mid and post via 30-second trials of quiet standing, the star excursion balance test (SEBT), 30-second Sit-to-Stand (30-CST) and the Calf Raise Senior (CRS). Significance was evaluated using non-parametric statistics ($p \leq .05$). Participants demonstrated high attendance rates (80.4 ± 13.8%), decreased mediolateral sway during eyes closed (pre-mid p=.003) and foam conditions (pre-mid p=.02), with smaller sway area for foam conditions (pre-mid p=.015), larger reaches on the SEBT (lateral: pre-mid p=.008, pre-post p=.008; posterior-lateral: pre-post p=.009) and higher number or CRS repetitions (mid-post p=.02, pre-post p=.015). A follow-up study was conducted to try and overcome intensity limitations encountered with the online environment by using blood flow restriction (BFR). Participants completed 12-weeks of online dance classes with half the group randomized to wear BFR cuffs. No improvements were found among the control group. Participants in the BFR group demonstrated increases in strength on the 30-CST (pre-mid p=.042; pre-post p=.039) and greater reaches on the SEBT in medial (mid-post p=.043) and posterior-medial directions (pre-post p=.043). Online dance classes are an effective, safe and accessible fall prevention program and the addition of low-cost BFR cuffs further enhances strength and dynamic balance, thereby increasing independence and quality of life through older age.

Keywords: Aging, postural stability, balance-training, tele-health, KAATSU training

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CONTRIBUTIONS OF AUTHORS

This thesis contains two manuscripts (chapters 2 & 3) entitled "Improvements in postural stability, dynamic balance and strength following 12-weeks of online dance classes for women aged 65 and above." and "Reducing the fall risk of older Canadian women following 12-weeks of online dance classes combined with blood flow restriction." For both, I wrote and obtained ethics, recruited participants, designed and led the interventions, carried out data collection, completed data and statistical analysis and wrote the manuscripts. Andreas Bergdahl and Mary Roberts acted as co-supervisors and provided access to equipment and significantly contributed to the creation, design, revision and editing of the ethics and the manuscripts. Mary Roberts additionally provided a list of potential participants as well as aided in recruitment and data collection.

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GENERAL INTRODUCTION

While dance is known to have a beneficial effect on the postural stability and strength of older women, studies have only used in-person instruction. The exclusive use of in-person instruction renders a large segment of older women unable to access dance. Online classes may offer a solution to increase accessibility and thereby allow a greater number of individuals to access fall prevention programs. However, it is currently unknown whether online dance classes are effective in improving postural stability.

Manuscript 1 Objective: To determine whether 12 weeks of online dance classes can improve the postural stability and lower limb strength of women aged 65 and above.

The study included in Manuscript 1 revealed the intensity of classes was insufficient to produce improvements in hip and knee extensor strength. Due to the remote ability to monitor participant safety during online classes, it was necessary for the intensity to be low. Blood flow restriction (BFR) provides a novel method to maximize the effects of online dance classes on muscular strength, dynamic balance and postural stability. This could allow older adults with a wider range of activity levels to benefit from dance. To date, no studies have used BFR during dance classes and no studies have investigated the effects of BFR on postural stability.

Manuscript 2 Objective: To determine whether the use of BFR cuffs during 12 weeks of online dance classes can augment expected improvements in postural stability, dynamic balance and lower limb strength among older women.

It is hypothesized that online dance classes will significantly improve postural stability and reduce the fall risk of older women, with greater improvements observed when combined with BFR due to an increase in muscle strength. It is hoped that the findings can provide evidence for an accessible, easy-to-implement fall prevention program for older women thereby working to improve their quality of life.

CHAPTER 1. THEORETICAL CONTEXT

1.1 Public Health Burden of Falls Among Older Canadian Adults

Falls are a leading cause of mortality, loss of independence and decreased quality of life among older adults in Canada (Public Health Agency of Canada, 2014). It is estimated that every year falls occur in 1 of 3 adults aged 65 years or older (Pearson et al., 2014) and of those who fall, half do so recurrently (Carter et al., 2001). In 2005, 4.94% of Canadian adults aged 65 and above sustained fall-related injuries, with this rising to 5.88% in 2013 (Do et al., 2015). Overall, falls cause 85% of injury-related hospitalizations (Public Health Agency of Canada, 2014) including fractures, contusions, abrasions, lacerations, strains and sprains, internal injuries and traumatic brain injuries (Stevens & Sogolow, 2005). Fractures comprise the most common reason for hospitalization and affect women at a rate of 37.8% (Stevens & Sogolow, 2005). Furthermore, 95% of hip fractures among Canadian older adults result from falls, with 20% of these hip fractures being fatal (Public Health Agency of Canada, 2014). Beyond injuries, consequences of falls may include increased fear of falling, loss of confidence and mobility, as well as the aforementioned loss of independence and decreased quality of life.

Injuries resulting from falls disproportionately affect women at significantly higher rates than men across all age groups (Stevens & Sogolow, 2005; Do et al., 2015). In 2002, 68.4% of Canadian older adults who reported injuries following falls were women. Additionally, older women accounted for 75% of the direct health care cost of falls (Scott et al., 2005) which totaled $2 billion and caused a total economic burden of $19.8 billion (Public Health Agency of Canada, 2014). Furthermore, it is suggested that women report more serious injuries as they have a hospitalization rate 1.8 times that of men, potentially reflecting gender differences in physical activity levels, muscular strength and bone mass density (Stevens & Sogolow, 2005; Do et al., 2015).

1.2 Etiology of Falls and Age-Related Reductions in Postural Stability

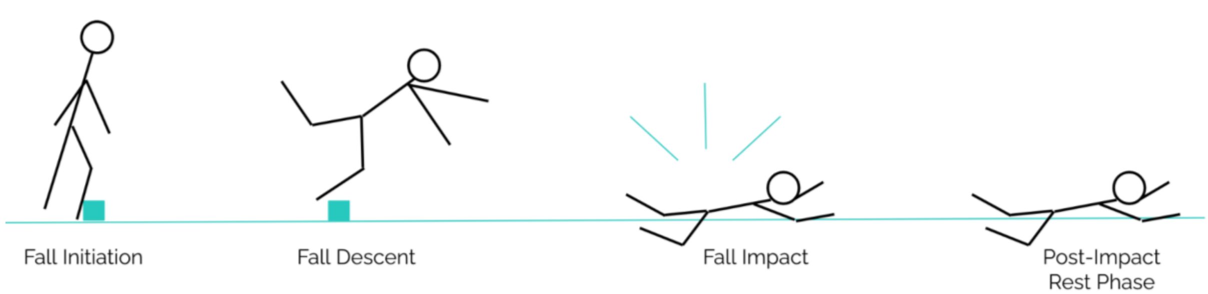

Figure 1. Four phases of falls as described by Hayes and colleagues (1996)

Falls occur in four phases: 1) fall initiation; 2) fall descent; 3) fall impact; and 4) post-impact rest phase (see Figure 1) (Hayes et al., 1996). Fall initiation occurs when a combination of intrinsic and extrinsic risk factors causes the centre of gravity (CoG) to move beyond the base of support (Carter et al., 2001; F. B. Horak, 2006; F. B. Horak et al., 1989; Winter, 1995). Common intrinsic risk factors among older adults include declines in visual acuity, cognitive status, leg strength, chronic disease status and medication use (Carter et al., 2001; Hayes et al., 1996; F. B. Horak, 2006); while extrinsic risk factors comprise environmental hazards (i.e., icy conditions, uneven sidewalks, ruffled carpets) (Carter et al., 2001; F. B. Horak, 2006).

The ability to control the position of the body and to remain upright against gravity is referred to as postural stability (F. B. Horak, 2006). This ability to remain upright, even when faced with external perturbations, may involve the use of corrective ankle, hip or stepping strategies to bring the CoG within the base of support (F. B. Horak et al., 1989; Winter, 1995). Ankle strategies involve contraction and relaxation of the gastrocnemius-soleus muscle complex to move the CoG in anteroposterior directions, while hip adductors and abductors contract and relax to correct deviations in mediolateral directions (Winter, 1995). These ankle strategies occur without flexion or extension of the hips and are normally used in response to small perturbations (F. B. Horak et al., 1989; Winter, 1995). Hip flexion and extension strategies are implemented during larger deviations and involve realigning the CoG via the hip loading/unloading mechanism (F. B. Horak et al., 1989; Winter, 1995). Finally, when ankle and hip strategies are no longer sufficient, stepping strategies may be used to find a new base of support (F. B. Horak et al., 1989).

The appropriate selection of each strategy depends on the ability of the systems to detect and encode deviations, the ability of the central nervous system to integrate information from many sensory inputs and choose an appropriate response, as well as the ability of the systems to properly execute the selected response (F. B. Horak et al., 1989; Woollacott et al., 1986). With age, deterioration in all systems causes decreases in postural stability, which interferes with the ability to correct body positioning, ultimately leading to increases in falls (Carter et al., 2001). The age-related degradation of various factors of postural stability will be explored in this section.

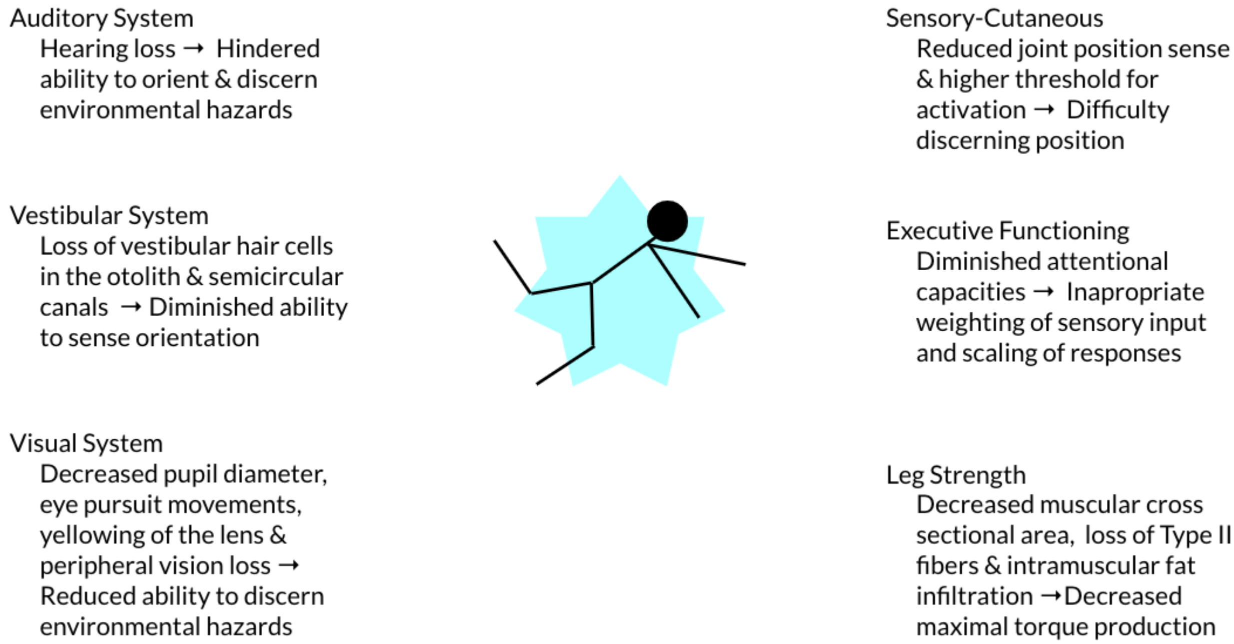

Figure 2. Normative risk factors for falls among older adults as described by Alcazar and colleagues (2020); Carter and colleagues (2001); F. B. Horak and colleagues (1989); F. B. Horak and colleagues (2006); O'Connell and colleagues (2017).

1.2.1 Sensory Components

Three peripheral sensory systems provide information on the positioning of the CoG necessary to achieve postural stability; they are the visual system, the vestibulocochlear system, and the somatosensory system. The visual system provides information on the position and motion of the body relative to the environment and helps discern environmental obstacles that could cause falls (Carter et al., 2001; F. B. Horak et al., 1989). The vestibular portion of the vestibulocochlear system provides information on linear and angular acceleration as well as the angle of the head through the semicircular canals while the vestibule provides information on the position of the head and limbs at rest (Carter et al., 2001; F. B. Horak et al., 1989). The cochlear component of the vestibulocochlear system provides auditory information useful in determining environmental hazards and understanding spatial orientation (Viljanen et al., 2009). The somatosensory system comprises both the sensory cutaneous system and the proprioceptive system. The former helps discern position and motion of the body relative to the support surface by sensing point discrimination and pressure on the feet (Carter et al., 2001; F. B. Horak et al., 1989). The proprioceptive system allows the perception of where body segments are with respect to one another, joint movement and position sense through information obtained from stretch receptors in the muscles (F. B. Horak et al., 1989). The information provided by these systems helps the central nervous system sense deviations of the CoG, as well as select and execute the appropriate motor response for the specific environmental context (F. B. Horak et al., 1989).

Normative age-related losses of sensitivity in peripheral sensory systems hinder postural stability and contribute to the increased fall risk of older adults. The auditory system shows early signs of aging with hearing loss presenting a twofold higher risk of falls (Viljanen et al., 2009). The vestibular system demonstrates the most significant deterioration (Carter et al., 2001; Pasma et al., 2015; Woollacott et al., 1986) as individuals over the age of 70 show decline in otolith function with 40% less vestibular hair cells than young adults (Carter et al., 2001) and significant Type I hair cell loss in the semicircular canals (Allen et al., 2016). Woollacott and colleagues (1986) demonstrated the impact of this degradation when, unlike young adults, their older participants were unable to remain upright when forced to rely on their vestibular system due to removal of visual and somatosensory information during an eyes-closed and sway-adjusted platform. Common visual impairments such as decreased pupil diameter, visual acuity, eye pursuit movement capabilities and yellowing of the lens, can make contrast sensitivity and discerning environmental hazards such as sidewalk curbs or obstacles in low light more difficult (O'Connell et al., 2017). Peripheral vision loss from a diminished field of view can additionally reduce the ability to sense movement in the environment (O'Connell et al., 2017). These visual impairments may be worsened by common conditions such as cataracts, macular degeneration and glaucoma (Carter et al., 2001). Somatosensory systems demonstrate the smallest age-related losses (Woollacott et al., 1986) but include reduced ankle joint position sense (Goble et al., 2009; F. B. Horak, 2006) and a higher threshold for activation of vibration perception or cutaneous sensation (Goble et al., 2009; Woollacott et al., 1986). Reduced somatosensation results in difficulty mapping the location of the body in space and difficulty obtaining feedback of foot pressure which aid in making postural corrections (Carter et al., 2001; F. B. Horak et al., 1989). As vestibular and visual systems decline the most with age, older adults favor proprioception by giving it increased sensory weight (Pasma et al., 2015). The weighting, integration and interpretation of information coming from all three systems are handled by the central nervous system (CNS).

1.2.2 Central Nervous System Integration

Sensory information about body orientation and positioning from the visual, vestibulocochlear and somatosensory systems must be integrated by the CNS to gain accurate representations of the COG relative to the base of support (F. B. Horak et al., 1989). By having an accurate representation, appropriate movement strategies (i.e. ankle, hip or stepping strategies) may be selected when the CoG deviates (F. B. Horak et al., 1989).

Depending on the context (the type of perturbation and the environment), certain sensory systems will provide differing or more accurate information. Sensory weighting adjusts the contribution of each system to focus on the most reliable sources of information (Pasma et al., 2015; Woollacott et al., 1986). The ability to select the appropriate source relies on executive functioning of the CNS that control attention (Teasdale & Simoneau, 2001). With age, normative declines occur in the capacity to divide attentional resources and thus older adults have diminished capacity to quickly select the most appropriate reference leading to a greater risk of falls when the sensory environment changes (Teasdale & Simoneau, 2001). Inappropriate sensory weighting may also lead to under or over-responding by motor components to postural deviations (F. B. Horak et al., 1989); this abnormal scaling of responses is exacerbated in situations of dual tasks (Montero-Odasso et al., 2012).

1.2.3 Motor Components

Once the appropriate motor strategy and magnitude has been selected, it must be executed by the motor systems. The execution of hip and ankle strategies is affected by muscle strength (F. B. Horak et al., 1989), which is in-turn affected by muscle size and quality (Goodpaster et al., 2001).

Alcazar and colleagues (2020) determined that women experience a significant loss of relative leg extensor power (-1.5% per year) beginning at age 40. This rate of decline significantly worsened in women above the age of 75 (-1.8% per year). This higher rate of reduction is in line with findings from Goodpaster and colleagues (2001), who showed a 19% decrease in muscular strength when comparing older adults aged 70 to 80. While decreased specific muscular power, and specific muscle strength (power and strength production per unit of muscle cross-sectional area), accounts for most declines from age 40 to 75, loss of fast-twitch Type II muscle fibers

(Kramer et al., 2017) and increases in fat mass and body mass index (BMI) account for changes above 75 years old (Alcazar et al., 2020).

When compared to healthy young adults, more stable older adults had significantly smaller Type II muscle fibers in the vastus lateralis, but no significant differences in slow-twitch Type I fibers (Kramer et al., 2017). However, older fallers show significant declines in both Type I and Type II muscle fibers as well as significant reductions in Type II muscle fiber size when compared to non-falling older adults (Kramer et al., 2017).

In addition to reductions in muscular size, older adults also experience decreases in muscle quality as intramuscular fat accumulates. An increase in intramuscular fat is both associated with age (Visser et al., 2002) and obesity (Goodpaster et al., 2001). Older adults may find themselves particularly susceptible to increased adipose deposits, as obesity rises during older adulthood in conjunction with sedentary behaviour (Alcazar et al., 2020). Increases in intramuscular fat content is correlated with decreased maximal torque of leg extensors among older women, such that with each quartile of increased muscular fat, there is a significant decrease in maximal torque production (Goodpaster et al., 2001). Visser and colleagues (2002) supported this finding by demonstrating that intramuscular fat infiltration is correlated with decreased performance on tests of functional leg strength even after adjusting for total body fat. With reductions in lean muscle size, muscle quality, maximal leg strength and power production, ankle, hip and stepping strategies are more difficult to execute; thereby leading to an increase in fall risk.

1.3 Effects of Exercise on Modifiable Risk-Factors

While decreased sensitivity in the visual, vestibulocochlear and sensory cutaneous systems are normative parts of aging, decreases in proprioception (Tsang & Hui-Chan, 2004), cognition (Quigley et al., 2020) and muscle loss (Frischknecht, 1998) as well as intramuscular fat infiltration may be slowed through exercise (Goodpaster et al., 2008).

Physical activity that requires balance and precise movement control such as Tai Chi and golf has been found to improve joint-position proprioceptive abilities among older adults (Tsang & Hui-Chan, 2004). It is suggested improvements occur as activities requiring exact motions stimulate the somatosensory cortex to reorganize and enhance cortical representation of muscle groups involved in balance, such as the core and lower limbs (Goble et al., 2009; Ribeiro & Oliveira, 2007). Physical activity may additionally induce plastic changes that increase the strength of synaptic connections from mechanoreceptors responsible for balance (Ribeiro & Oliveira, 2007).

Regular moderate-intensity physical activity improves executive functioning among older adults, which serves to ameliorate attentional processes required to maintain postural control (Chen et al., 2020). Enhancements in executive functioning demonstrated the largest effect sizes among Tai Chi and yoga type exercises, followed by resistance exercise and finally by aerobic exercise (Chen et al., 2020). While the mechanisms for progress are poorly understood, it is speculated that a decreased stress and inflammatory response along with increased cerebral blood flow and growth factors may increase cortical plasticity to strengthen executive functions (Quigley et al., 2020).

It is well known that exercise is effective in improving muscular strength and delaying muscular atrophy (Frischknecht, 1998). A one year aerobic, strength and balance training program prevented intramuscular fat infiltration and preserved muscular tissue among older adults, while sedentary controls experienced a 18% gain in intramuscular fat and significant loss of muscle tissue from within the thigh (Goodpaster et al., 2008). The maintenance of muscular tissue and prevention of intramuscular fat was further reflected by the lack of decrements in knee extensor strength (Goodpaster et al., 2008).

Through exercise, the preservation of proprioception, executive function and muscular systems can allow older adults to gain an improved ability to sense their body positioning, maintain attention, select the appropriate sensory cues and execute the proper corrective strategies. This reduced risk of falls among older adults ultimately contributes to higher levels of independence and quality of life. While the importance of remaining physically active in older age has been highlighted, less than 4% of women above the age of 65 obtain at least 30 minutes of physical activity per day (Colley et al., 2011). As the number of Canadian older adults is projected to double from 5 million in 2011 to 10.47 million in 2036, the Public Health Agency of Canada has highlighted the urgent need for fall prevention programs (Public Health Agency of Canada, 2014).

1.4 Dance is Fun

Over the last 15 years, the use of dance as a way to augment the physical activity levels and improve the health of individuals in special populations has increased. This rising popularity may be attributed to its fun, engaging and social nature. Dance interventions for postural stability have high levels of attendance among older adults with Britten and colleagues (2017) finding an 84.3% adherence rate. It should be noted that high adherence rates are found predominantly among women, likely due to gendered stereotypes regarding dance. During interviews, participants noted the expressive nature of dance and the fact that it was a new challenge increased the appeal and desire to attend classes (Britten et al., 2017).

The success of dance in engaging older adults can also be seen anecdotally with the increasing number of dance companies offering programming for older adults. In 2013, Les Grands Ballets Canadiens in Montréal, Canada opened the National Centre of Dance Therapy, an organization dedicated to using dance both for psychological therapy and to improve fitness among individuals with disabilities, as well as older adults (National Centre for Dance Therapy, n.d., About the Centre). In 2017, the Royal Academy of Dance in London England, launched "Silver Swans", ballet classes aimed at adults aged 55 and above (The Phoenix Newspaper, 2017); The program has grown in popularity and is now offered in Canada, the United States, the United Kingdom and Australia. Most recently in 2017, the National Ballet of Canada in Toronto, Canada began creating their outreach program for older adults in conjunction with the Baycrest Centre and the project was launched to the general public in 2020 (Skinner & Herron, n.d.; Canada's National Ballet School, 2020). This rising popularity of dance among older women makes it a prime candidate for engaging them in exercise to increase their physical activity levels and consequently reduce their fall risk. Accordingly, the specific use of in-person dance classes for improving postural stability of older adults has been growing in the literature since 2008.

1.5 Dance for Postural Stability

Dance is a complex and rhythmic sensorimotor activity which can stimulate a variety of benefits across motor and cognitive domains (Sofianidis et al., 2009). Additionally, the precision of movement involved in learning dance steps makes it an ideal balance training activity, suitable for reducing fall risk in a manner similar to Tai Chi (Ribeiro & Oliveira, 2007; Tsang & Hui-Chan, 2004).

Previous studies using various styles of dance have demonstrated reduced risk of falls for individuals aged 50 and above after as little as 8 weeks (Britten et al., 2017; Eyigor et al., 2009). Sofianidis and colleagues (2009) found 10 weeks of Greek dancing significantly decreased centre of pressure (CoP) displacement during single leg stances, while Filar-Mierzwa and colleagues (2017) found higher limits of stability following a 12-week folkloric and ballroom dance therapy program. It is suggested that significant single leg standing times, controlled weight transfers and rotations found in traditional dance improve the strength of lower limbs and decrease ankle stiffness resulting in increased ease in making corrective postural adjustments (Filar-Mierzwa et al., 2017; Sofianidis et al., 2009). This speculated increase in lower limb strength and mobility has been supported by Wu and colleagues (H. Y. Wu et al., 2016) who observed decreases in body fat percentage, increases in knee extension torque and ankle range of motion after 16 weeks of dance classes. Additionally, improvements on lower limb strength and power tests such as Sit-to-Stand and Timed-Up-and-Go have been consistently reported following dance interventions (Britten et al., 2017; Eyigor et al., 2009; Federici et al., 2005; Franco et al., 2020; McKinley et al., 2008). These findings support the mechanism suggested by Sofianidis and colleagues (2009) and demonstrate that dance may target individual components of postural stability necessary to improve postural motor adjustments. Dance may also reduce postural stiffness due to the constant changes in body positioning that require high levels of dexterity (Coubard et al., 2011; Ferrufino et al., 2011). As dance is largely based on motor improvisation, it may lead to improvements in motor flexibility which could aid in making rapid postural adjustments in response to unexpected deviations of the CoG. Reduced speed in implementing corrective strategies is further demonstrated by decreased reaction time following interventions using social and traditional Chinese dancing (W.-L. Wu et al., 2010; Zhang et al., 2008). This accelerated cognitive processing may reflect increased brain efficiency, which aids in weighting and selecting appropriate sensory information, thereby bettering the implementation of corrective postural systems. The ability to appropriately weigh incoming information is also reliant upon the attentional systems, which too gain benefits from dance interventions. Coubard and colleagues (2011) demonstrated that 23 weeks of contemporary dance improves attention switching among older adults over and above those in fall prevention and Tai Chi programming. It is speculated that the improvisational nature of contemporary dance facilitates expectations for rapidly changing sensory environments, thus simulating plasticity and flexibility in attentional processes (Coubard et al., 2011); this allows the body to improve in detecting and accurately weighing stimuli, and rapidly selecting an appropriate motor response.

Finally, in addition to objective improvements in measures of postural stability, following dance programs, older adults demonstrate an increase in balance confidence (McKinley et al., 2008; H. Y. Wu et al., 2016) and decreased fear of falling (Britten et al., 2017).

1.5.1 Effect of Dance Styles

While the style of dance (i.e., traditional, contemporary, ballroom etc.) has no apparent effect on improvements in balance, common movement elements may be necessary to facilitate changes. During dance classes participants experience many self-imposed deviations of the CoG that allow them to practice their postural control (Sofianidis et al., 2009). Dance involves frequent weight transfers, changes of direction, single leg support time, changes of support limb, alternations between wide and narrow stances and pushing the limits of stability in a controlled manner (Filar-Mierzwa et al., 2017; Granacher et al., 2012; Sofianidis et al., 2009); all of which are suspected to train the motor system to maintain control during postural shifts by teaching proper alignment and improving the range of motion of large joints (Federici et al., 2005). This constant change of body positioning and coordination of movement to the rhythm of the music further stimulates improvements in attentional demand and increases in dexterity and comfort (Coubard et al., 2011; Granacher et al., 2012). Additionally, repeated turns of the body, head rotations and deviations of the trunk from the CoG are thought to challenge the vestibular system and facilitate improvements in postural stability (Filar-Mierzwa et al., 2017; Sofianidis et al., 2009; Zhang et al., 2008). These common elements of movement are found in all the styles used in the studies above to produce improvements in postural stability.

1.6 Barriers to Dance and Online Solutions

Although dance is effective in reducing fall risk, unfortunately many older adults may face barriers to participation. Built environment factors such as remote living, difficulties in affording or accessing transport and difficulty parking are frequently cited as obstacles to adopting physical activity (Bethancourt et al., 2014; Britten et al., 2017). Canadians also face extreme weather environments which make accessing safe transportation and climate-controlled exercise environments challenging. Older adults living in remote locations may face additional difficulties finding qualified fitness instructors (Bethancourt et al., 2014). Without guidance, older adults may feel unsure and thus avoid adopting physical activity programming. Stay-at-home and social distancing guidelines of the COVID-19 pandemic have further exposed the limits of in-person fitness instruction and have highlighted the urgent need for remote exercise solutions.

Online dance classes may provide an innovative solution for those typically not able to access in-person programming. The remote nature allows interaction with a qualified instructor without the limitations of location or cost involved in transport. Online dance classes may have additional appeal for older adults as they are able to try a new activity in the comfort of their own home, thus removing intimidation and shyness often involved in dancing in front of others (Britten et al., 2017). To date, no studies have investigated the potential of online dance classes on the postural stability of older adults.

1.7 Increased Physiological Strain Using Blood Flow Restriction

To ensure safety, the intensity of online dance classes must be lower. The addition of blood flow restriction (BFR) cuffs may provide a novel solution to increase physiologic strain and augment the expected benefits.

1.7.1 Blood Flow Restriction History and Benefits for Older Adults

Blood flow restriction, also known as KAATSU® Training, was developed by Yoskiaki Sato in 1966. Initially, BFR was a method that used pressure to stimulate muscular discomfort and swelling, similar to what is seen after strenuous resistance training. Through his training, Sato reported significant hypertrophy and strength gains, even while his leg was immobilized in a cast (Sato, 2005). In 1983, after overcoming difficulties in controlling pressure, Sato launched KAATSU® Training to the general public (Sato, 2005). Today BFR uses elastic cuffs, typically 5 cm wide, placed on the proximal portion of limbs to partially occlude blood vessels going to muscles exercising at low-intensity (Patterson et al., 2019). When combined with low intensity exercise, such as walking, this reduction in blood flow increases physiological stress and promotes increases in serum growth hormone, muscular volume and muscular strength after as little as 3 weeks (Abe et al., 2006, 2009). In studies with longer intervention times of 6 weeks, older adults have additionally demonstrated improvements on functional fitness tests, indicating that greater strength may translate into increased independence for everyday activities (Abe et al., 2010; Baker et al., 2020). Augmentations in functional fitness are believed to be due to improvements in strength as no significant changes in VO_2peak and VO_2max have been reported when using BFR during low-intensity exercise (Abe et al., 2010).

The increases in muscular strength and size after low intensity exercise with BFR are comparable to those following high-intensity exercise (Baker et al., 2020; Takarada, Takazawa, et al., 2000). Typically, high intensity resistance training is the only effective method to increase muscular size and strength; however, it may not be possible for many older adults as they often have comorbidities that contraindicate vigorous exercise (Centner et al., 2019). BFR shows particular promise for older adults who cannot participate in intense exercise to enhance their muscular strength and thereby improve postural stability and decrease their fall risk.

1.7.2 Hypothesized Mechanisms for Hypertrophy and Strength Gains

While the exact mechanisms for increased strength and hypertrophy after low-intensity exercise with BFR remain unclear, several studies have pointed to potential pathways. The decrease in perfusion induced by BFR creates a hypoxic intramuscular environment. As there is a lack of oxygen, muscles distal to BFR cuffs rely on the anaerobic glycolytic pathway to compensate for decreases in adenosine triphosphate (ATP) production via the Krebs cycle. With increased use of the glycolytic pathway, BFR has been found to significantly elevate plasma lactate levels both during resting and during low-intensity exercise (Takarada, Nakamura, et al., 2000; Takarada, Takazawa, et al., 2000). This suggests both a lack of oxygen driving use of the glycolytic pathway and a lack of clearance that would heighten the acidity of the intramuscular environment and interfere with contractions (Takarada, Nakamura, et al., 2000; Takarada, Takazawa, et al., 2000). The greater use of glycolytic processes may be supported by higher quantities of intramuscular glycogen in an arm that used BFR compared to one that did not (Burgomaster et al., 2003). Burgomaster and colleagues (2003) suggested the compromised O_2 delivery during training may have increased GLUT-4 translocation thus promoting glucose uptake post-exercise and increasing the availability of glycogen. The increased acidity of the intramuscular environment may contribute to declining force production capabilities. With difficulty activating motor units, additional ones, particularly fast-twitch glycolytic fibers, may be stimulated to compensate.

Following BFR training, participants demonstrate increased recruitment of fast-twitch muscle fibers, responsible for quick force production. According to the size principle, fast-twitch fibers should only be activated after slow-twitch fibers as their threshold for recruitment is higher (Henneman et al., 1965); That is, fast-twitch fibers are typically only recruited by strong stimuli such as high-intensity resistance exercises and not during low-intensity exercise (Henneman et al., 1965). The size principle does not seem to apply in the ischemic environment brought about by BFR training. During BFR training relative intramuscular electromyography (iEMG) was 1.8 times that of exercise without BFR even though the level of force output was the same (Takarada, Nakamura, et al., 2000). In the hypoxic and acidic intramuscular environment, additional recruitment of fast-twitch fibers is required to meet the same level of force production. With the increased training and stimulation of fast-twitch fibers received during BFR, they may significantly improve their activation and thereby significantly improve strength.

Finally, the increase in lactate production brought about by BFR may stimulate chemoreceptors to signal the hypothalamic-pituitary axis to release hormones related to muscle growth. Following BFR training, plasma levels of growth hormone and norepinephrine increase dramatically compared to low-intensity exercise alone which does not produce changes in growth hormone or norepinephrine levels (Abe et al., 2006; Takarada, Nakamura, et al., 2000). Furthermore, growth hormone levels following BFR were 1.7 times that of the increases following high-intensity exercise reported in previous literature (Takarada, Nakamura, et al., 2000). Growth hormone can then stimulate insulin-like growth factor-1 to induce muscular hypertrophy and thereby improve strength.

1.7.3 Safety of Blood Flow Restriction for Older Adults

The increased pressure and occlusion of blood vessels from BFR has raised concerns about potential thrombosis, pulmonary embolism and muscle damage; BFR however has a high degree of safety among older adults and those in clinical populations (Brandner et al., 2018; Nakajima et al., 2006; Wong et al., 2018; Yasuda et al., 2017). In 2006 Nakajima and colleagues surveyed 105 KAATSU® facilities, among which served a total of 5382 older adults. Reported side effects of KAATSU® training included bruising (13.8% occurrence ratio), numbness (1.23% occurrence ratio), cerebral anemia (0.28% occurrence ratio), feeling cold (0.13% occurrence ratio), venous thrombosis (0.055% occurrence ratio), pulmonary embolism (0.008% occurrence ratio) and rhabdomyolysis (0.008% occurrence ratio). In a follow-up study by Yasuda (2017) KAATSU® facilities also reported dizziness, drowsiness, nausea and itching as symptoms of concern. The incidence of bruising is reported to be higher when BFR is used in the upper extremity and primarily in the first weeks of training (Nakajima et al., 2006). It appears the incidence of bruising may also be higher in Japan where thinner 3cm cuffs are used more frequently (Brandner et al., 2018). Further, additional side effects of BFR training may be mediated by the experience of the trainer (Yasuda et al., 2017).

Due to the low incidence of adverse events, BFR has not been contraindicated in any special populations (Brandner et al., 2018). While hypertension has been speculated as a specific risk factor against BFR training, there have been no demonstrated acute or chronic effects on systolic or diastolic blood pressure (Wong et al., 2018). Additionally, despite the increased use of

BFR among those with cardiovascular disease at medical clinics and rehabilitation centres, no major adverse events have been reported (Brandner et al., 2018; Nakajima et al., 2006; Yasuda et al., 2017). Even with this low risk, it is recommended that BFR be avoided by those who have been physically inactive and have low levels of physical conditioning as the risk for muscular damage is increased (Brandner et al., 2018).

CHAPTER 2: MANUSCRIPT

Improvements in postural stability, dynamic balance and strength following 12-weeks of online dance classes for women aged 65 and above.

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This quasi-experimental pre-mid-post study investigated whether 12-weeks of online dance classes is sufficient to improve older women's postural stability, dynamic balance and strength. 16 participants (74.4 years ± 5.6) completed two weekly 75-minute interventions and were evaluated via 30-second trials of quiet standing, the star excursion balance test, 30-second sit-to-stand and the calf-raise-senior (CRS). Significance was calculated using non-parametric statistics ($p \leq .05$). Participants demonstrated a high attendance rate (80.4 ± 13.8%). From pre-mid a decreased mediolateral sway was observed in eyes closed ($p=.003$) and foam ($p=.02$) conditions, where the latter also gave a decreased area ($p=.015$). Greater dynamic balance was demonstrated in the lateral (pre-mid $p=.008$; pre-post $p=.008$) and posterior-lateral directions (pre-post $p=.009$). Finally, participants significantly improved their number of CRS repetitions (mid-post $p=.02$; pre-post $p=.015$). Online dance classes are engaging, accessible and effective to decrease older women's risk of falls and to maintain their independence.

KEYWORDS: dance-based exercise, aging, fall prevention, telehealth

2.1 Introduction

Falls among older adults are a leading cause of injury, loss of independence and mortality as approximately 30% experience falls each year (World Health Organization, 2007). Furthermore, these incidents cause 95% of hip fractures, leading to fatality among 20% of cases (Public Health Agency of Canada, 2014). Globally the average cost of these injuries is estimated to be $26,483 USD per hospitalized faller (Davis et al., 2010).

Women are disproportionately affected by falls across all age-groups (Do et al., 2015) and comprise 70.5% of all subsequent emergency visits (Stevens & Sogolow, 2005). This elevated incidence likely reflects differences in physical activity levels, muscular strength and bone mass density - all essential components of postural stability (Chang & Do, 2015; Do et al., 2015; Stevens & Sogolow, 2005).

Beginning at age 40, women undergo a significant loss of relative leg extensor power at a rate of 1.5% per year worsening to 1.8% as of 75 years old (Alcazar et al., 2020). This may also be due to reductions in Type I, and particularly, Type II muscle fibers observed among older adults who fall, when compared to non-falling age-matched individuals (Kramer et al., 2017). This age-related atrophy may interfere with the ability to correct body positioning in response to environmental hazards to avoid falls. While remaining physically active in older age helps preserve muscle strength, muscle mass and bone strength (Frischknecht, 1998), only 3.8% of women aged 60-79 years accumulate at least 30 minutes of physical activity per day (Colley et al., 2011). As the number of older women is projected to double by 2050 to 832 million (United Nations, Department of Economic and Social Affairs, Population Division, 2019), the World Health Organization has highlighted the urgent need for fall prevention programs (World Health Organization, 2017).

Dance is an increasingly popular form of exercise for older adults as its fun, engaging and social environment offers opportunities for creative expression (Sofianidis et al., 2009). Furthermore, the precision of movement involved in learning dance steps makes it an ideal balance training and thus suitable for reducing fall risk (Ribeiro & Oliveira, 2007; Tsang & Hui-Chan, 2004). High attendance (84.3%) to dance interventions targeted at improving postural stability has been observed primarily among women, likely due to gendered stereotypes regarding dance (Britten et al., 2017). Previous studies using traditional, folkloric, ballroom, and contemporary dance have observed improvements in postural stability after as little as 2 hours of classes per week for 10 weeks among adults older than 50 (Eyigor et al., 2009; Ferrufino et al., 2011; Filar-Mierzwa et al., 2017; Sofianidis et al., 2009; Wu et al., 2010; Zhang et al., 2008). The improvements in postural stability are linked to developments in lower limb strength (Eyigor et al., 2009; McKinley et al., 2008), reaction time (Wu et al., 2010; Zhang et al., 2008), trunk rotation (Sofianidis et al., 2009), balance confidence (McKinley et al., 2008) and limits of stability (Filar-Mierzwa et al., 2017). This suggests that the complex rhythmic nature of dance stimulates benefits across cognitive and perceptual-motor domains (Wu et al., 2010), by improving: 1) attention to surroundings, 2) rapidity in implementing corrective postural strategies and 3) strength needed for these corrections.

While dance is effective for improving postural stability, in-person classes may be inaccessible for many: living in remote locations, lacking transport, being a caregiver at home, or being immunocompromised may all act as barriers to participation. To date, no studies have investigated the potential of online dance classes to improve the postural stability of older adults.

Online dance classes are simple to implement, low cost, accessible and consequently warrant exploration for use in fall-prevention. The purpose of this study is to investigate whether 12-weeks of online dance classes reduce the risk of falls for women aged 65 years and above through evaluating postural sway, dynamic balance, lower limb strength, balance confidence and health related quality of life.

2.2 Methods

2.2.1 Participants & Study Design

Sixteen women (74.4 years, *SD*=5.6) from the local community participated in a 12-week quasi-experimental online dance study with pre, mid and post-testing. The women were recruited using an existing participant list and through ads in local recreation centers. Certification of Ethical Acceptability for Research Involving Human Subjects was obtained from the institutional human ethics committee and informed consent was collected from participants prior to pre-testing. Inclusion criteria are listed in Table 1. and baseline characteristics are listed in Table 2.

Inclusion	Exclusion
● Female ● Over 65 years old ● Understanding of spoken English ● Able to visit Concordia University for all testing sessions ● Access to a device with a webcam, Zoom and stable internet ● No contraindication for physical activity from their physician	● Male - those who indicated their interest were invited to participate in classes but were not tested ● Occurrence/onset of a stroke, vertigo, concussion or lower-extremity injury during the 12-week intervention period

Table 1. Inclusion and exclusion criteria for participants.

	Total *M (SD)*	**Analyzed** *M (SD)*	**Dropouts** *M (SD)*
N	22	16	6
Age (years)	74.68 (5.79)	74.38 (5.62)	75.50 (6.72)
BMI (kg/m^2)	22.68 (2.99)	23.38 (2.82)	20.80 (2.80)
PASE	148.95 (82.73)	142.00 (65.00)	167.50 (124.53)

Table 2. Mean (standard deviation) of participant characteristics and PASE scores. Abbreviations: Sample size (N), body mass index (BMI), Physical Activity Scale for the Elderly (PASE).

2.2.2 Dance Intervention

Two 75-minute dance classes were held over Zoom, every week, for the 12-week semester. Each session started with a 15-minute warm-up, followed by *pliés*, *tendus*, *Graham* and *Limón* modern-dance exercises, and a 5-minute stretch recovery (recordings of the classes are available upon request). Movements emphasized transfer of weight, dynamic balance while standing on one limb, bringing the body off center, fall recovery and strengthening of the lower limbs and core. To ensure safety, a helper was present to monitor each Zoom class and participants were asked to keep their webcams on. The helper was additionally tasked with tracking attendance. Recordings of the class were provided to anyone who was unable to attend and their completion was noted.

2.2.3 Baseline Physical Activity Levels

Physical Activity Scale for the Elderly (PASE) was used to measure baseline physical activity levels among the older women. The PASE score was calculated by multiplying time spent in each activity by standardized weights (Frenkel, 2016; Washburn et al., 1993).

2.2.4 Pre, Mid and Post Assessments

2.2.4.1 Postural Stability

Two Advanced Medical Technology Inc. force plates together with the NetForce Software™ were used for multi-axial data acquisition sampled at 100 Hz. Participants completed three 30-second trials of quiet standing under three conditions: 1) eyes open, 2) eyes closed, 3) on a 2-inch thick foam pad. Trials were staggered to avoid any effects due to fatigue.

Participants were asked to stand comfortably with one foot on each force plate and arms by their side. They were instructed to stay as still as possible for the duration of each 30-second trial while looking straight ahead to a point at eye-level on the wall. Measures of center of pressure sway displacement (cm) in anteroposterior and mediolateral directions and total sway area (cm^2) were collected.

2.2.4.2 Dynamic Balance

A modified version of the Star Excursion Balance Test (SEBT) was used to assess dynamic balance. Participants were asked to stand on their non-dominant leg in the center of a star taped to the ground composed of 8 lines 45^{o} apart. Without touching the floor, they were instructed to reach their dominant leg along the line as far as possible before tapping the foot to the floor on the tape, and then returning their foot to center. They then moved to the next line. A mark was placed on the ground where the participant touched the tape and it was measured to the nearest 0.50cm. A modification was made to allow participants to tap their toe upon returning to the center to reduce fatigue and apprehension. Two practice trials were given before the third was recorded. Additionally, a helper was present to ensure participant safety in the event of loss of balance. If they lost their balance or moved their supporting leg, the distance was not recorded.

2.2.4.3 30-Second Sit-to-Stand

The 30-Second Sit-to-Stand (30-CST) measured lower body strength via the number of repetitions recorded in 30 seconds. Participants were instructed to complete the tests according to methods outlined by Jones and colleagues (1999). If the participant did not pass more than halfway up or did not touch the chair when sitting, the repetition was not counted (*30 Second Sit to Stand Test*, 2013).

2.2.4.4 Calf Raise Senior

The Calf Raise Senior (CRS) evaluated plantarflexor strength. The procedure described by André and colleagues (2016) was followed and the number of complete repetitions was recorded. The minimally important difference of 3.50 repetitions determined by André and colleagues (2020) was used to evaluate clinical significance.

2.2.4.5 Questionnaires (ABC, FES, SF-36)

Following each testing session, a survey containing the Activities-Specific Balance Confidence Scale (ABC), Falls Efficacy Scale - International (FES) and 36-Item Short-Form (SF-36) was sent to participants. The ABC and FES were used to evaluate balance confidence and fear of falling while the SF-36 was used to evaluate perceptions of health-related quality of life.

2.2.3 Statistical Analysis

Descriptive statistics (mean, median, standard deviation, minimum, maximum and frequencies) were obtained and normality tests (Shapiro-Wilk and Kolmogorov-Smirnov) were performed for all variables. To ease comprehension and comparison, the normative values (mean and standard deviation) are presented. As our data was not normally distributed, Friedman's test with a Wilcoxon Signed-Rank post-hoc was used to evaluate the longitudinal changes in our participants. All statistical analyses were performed on SPSS-28® (IBM) with an alpha value of 0.05 ($p \leq .05$).

2.3 Results

2.3.1 Attendance

Participants demonstrated a high attendance rate (80.2 ± 14.2%). When recordings were added to the calculation (for participants that missed the live class) attendance increased (83.3 ±

13.0%) with 10 out of 16 participants (62.5%) completing at least 80% of all classes (both live and with recordings).

2.3.2 Postural Stability

	Pre *M (SD)*	**Mid** *M (SD)*	**Post** *M (SD)*
Eyes Open			
Mediolateral displacement (cm)	4.29 (2.21)	3.80 (1.43)	3.66 (2.05)
Anteroposterior displacement (cm)	2.43 (0.51)	2.09 (0.58)	2.17 (0.48)
Area (cm^2)	13.31 (11.23)	8.23 (3.80)	8.20 (4.51)
Eyes Closed			
Mediolateral displacement (cm)	5.08 (2.47)**	3.46 (1.25)**	4.07 (1.91)
Anteroposterior displacement (cm)	3.12 (1.41)	2.84 (0.48)	2.90 (0.95)
Area (cm^2)	23.45 (33.39)	10.20 (4.64)	12.89 (8.88)
Foam			
Mediolateral displacement (cm)	8.43 (2.76)*	6.56 (2.66)*	6.87 (3.37)
Anteroposterior displacement (cm)	3.53 (0.87)	3.44 (0.65)	3.37 (0.78)
Area (cm^2)	33.59 (20.08)*	22.79 (10.53)*	23.67 (12.05)

Table 3. center of pressure sway displacement and sway area pre, mid and post 12-weeks of online dance classes *$p \leq .05$; **$p \leq .01$.

Significant reductions in mediolateral displacement were found from pre-mid in eyes closed (p=.003) and foam conditions (p=.020). Additionally, significant drops in sway area were observed when standing on the foam from pre-mid (p=.015), and similar trends were detected during eyes closed (p=.057). While no significant differences were found during trials with the eyes open, trends to significance in displacement were found in both mediolateral (p=.074) and anteroposterior directions (p=.074).

2.3.3 Dynamic Balance

	Pre *M (SD)*	Mid *M (SD)*	Post *M (SD)*
Anterior (cm)	57.70 (10.63)	56.90 (13.09)	59.83 (9.39)
Anterior-Lateral (cm)	61.90 (10.10)	64.13 (10.49)	64.97 (8.01)
Lateral (cm)	61.57 (8.72)**	64.80 (10.61)**	65.60 (7.74)**
Posterior-Lateral (cm)	61.17 (11.49)**	63.50 (13.80)	67.46 (11.26)**
Posterior (cm)	61.75 (15.33)	61.75 (12.62)	63.29 (7.95)
Posterior-Medial (cm)	55.21 (15.60)	58.29 (13.48)	59.58 (13.11)
Medial (cm)	46.19 (12.08)	45.96 (8.91)	46.96 (9.17)
Anterior-Medial (cm)	53.86 (9.35)	55.75 (9.08)	54.86 (8.27)

Table 4. Distances reached during a modified Star Excursion Test pre, mid and post 12-weeks of online dance classes **$p \leq .01$.

At mid-testing, participants were able to reach significantly further when completing lateral leg stretches (p=.008). This gain was also observed from pre-post (p=.008). Improvements in the posterior-lateral direction were also found from pre-post (p=.009) with trends seen from mid-post (p=.054).

2.3.4 Strength

	Pre *M (SD)*	Mid *M (SD)*	Post *M (SD)*
30-CST	13.53 (4.67)	14.73 (5.09)	15.67 (4.94)
CRS	22.60 (10.15)*	22.93 (7.62)*$^{+}$	25.67 (9.18)*$^{+}$

Table 5. Changes in lower limb strength pre, mid and post 12-weeks of online dance classes *$p \leq .05$, $^{+}$clinical significance.

No significant differences in the number of repetitions were observed using the 30-CST while the CRS was significantly higher from pre-post (p=.015) and from mid-post (p=.020). Furthermore, the change in plantarflexor strength demonstrated clinical significance as there was a mean difference of 4.44 from mid-post (minimally important difference = 3.50, André et al, 2020).

2.3.5 Subjective Questionnaires

	Pre *M (SD)*	**Mid** *M (SD)*	**Post** *M (SD)*
ABC	86.83 (12.08)	88.80 (7.27)	87.31 (11.10)
FES	22.69 (6.07)	21.77 (4.38)	23.69 (6.54)
SF-36			
Physical Functioning (%)	73.85 (20.93)	78.85 (17.58)	74.23 (22.06)
Role Limitations - Physical (%)	69.23 (39.73)	73.08 (38.81)	59.62 (37.55)
Role Limitations - Emotional (%)	82.05 (29.25)	82.05 (32.25)	82.5 (32.85)
Energy/Fatigue (%)	61.54 (13.45)	64.23 (10.58)	66.92 (15.21)
Emotional Well-Being (%)	68.62 (17.88)	68.31 (23.29)	69.54 (16.62)
Social Functioning (%)	83.65 (16.44)	85.58 (16.81)	75.00 (21.65)
Pain (%)	70.00 (20.77)	70.00 (18.68)	70.38 (20.94)
General Health (%)	65.77 (16.69)	70.00 (16.46)	63.85 (12.44)
Health Change (%)	51.92 (18.99)	65.38 (21.74)	57.69 (23.68)

Table 6. Scores on questionnaires related to balance confidence and health-related quality of life pre, mid and post 12-weeks of online dance classes *$p \leq .05$; **$p \leq .01$.

One participant did not complete the questionnaires due to a written language barrier. No significant differences or trends were found over the course of the 12-week intervention.

2.4 Discussion

The aim of this study was to determine whether online dance classes can improve postural stability, dynamic balance and strength for women aged 65 years and above. While studies have been done to assess the psychosocial effects of online dance classes, this seems to be the first study assessing the effects of online dance classes as fall prevention programming for older women.

2.4.1 Attendance Compared to In-Person Programming

Along with the high attendance rates (84.3%) noted in older adults participating in dance classes (Britten et al., 2017), a meta-analysis by Clifford and colleagues (2023) revealed dance classes that were designed as tailored fall prevention programming typically had an attendance rate above 80%. Our findings revealed a comparable attendance rate of 80.2% (83.3% when recordings were provided) indicating that online classes (and recordings) are engaging and offer a viable alternative.

2.4.2 Postural Stability

From pre to mid, participants demonstrated significant reductions in mediolateral sway displacement during eyes-closed and on foam, and decreases in sway area were also found during foam conditions. Additionally, while the reduction was not statistically significant, all sway values at mid and post remained below measures at pre.

The reported decreases in mediolateral sway displacement are consistent with previous work investigating the effects of in-person dance classes on postural stability. Granacher and colleagues (2012) found trends towards significant reductions in mediolateral displacement when participants completed a 30 second single leg stand following 8 weeks of salsa classes. Additionally, Sofianidis and colleagues (2009) showed significant reductions in mediolateral centre of pressure (CoP) displacement following 10 weeks of traditional Greek dancing, but like us, did not report improvements in anteroposterior directions. To be visible to the audience, most dance styles move in the frontal plane, unlike other balance programs that focus on functional movements in the sagittal plane that mimic daily tasks such as walking and climbing stairs. These side-to-side motions and use of external rotation may lead to higher recruitment and improved neural control of the glutes, adductors and abductors when compared to traditional balance programs and could explain reductions in mediolateral sway (Krasnow et al., 2011; Trepman et al., 1994).

Mediolateral improvements could also indicate that participants learned to widen their base of support during the trials of quiet standing, facilitating ease in maintaining their CoP within their base of support, thereby reducing sway (Nogueira Lahr et al., 2017).

The significant reductions found in the mediolateral direction may be clinically meaningful as a meta-analysis conducted by Quijoux and colleagues (2020) found that mediolateral sway displacement can accurately predict fall status, and has superior prediction abilities compared to anteroposterior values. This may suggest that the improvements observed in mediolateral sway following only 6-weeks of dance classes may in fact translate into tangible reductions in participants fall risk and rate, thus demonstrating online dance classes value as viable fall prevention programming.

No significant changes were observed in the eyes-open condition, probably as postural stability is heavily dependent on visual feedback. Low and colleagues (2017) have suggested that the reliance on visual feedback during eyes-open could obscure potential improvements in postural control following exercise, as the sensorimotor and neuromuscular paths that can be improved with exercise would not be given sensory weight.

2.4.3 Dynamic Balance

The significant improvements in the lateral (from pre-mid and maintained through post) and posterior-lateral (from pre-post and mid-post) directions were noted in the confidence participants gained in completing this test. At pre, many participants indicated that they felt unsteady during the trial and were only comfortable keeping their supporting knee straight, thereby limiting their reach. By post, participants appeared much more comfortable in bending their supporting knee while trying to stretch further.

Ambegaonkar and colleagues (2013) found that professional modern dancers were able to reach significantly further on the SEBT when compared to non-dancers. This is consistent with findings of Krityakiarana & Jongkamonwiwat (2022) who reported that Thai Khon masked dancers reached further in all directions when compared to non-dancers. In a 12-week combined strength, balance-training, and Tai Chi Chuan class for adults aged 60-80 participants reached significantly further in all directions except medial when compared to pre and when compared to a control group (Zhuang et al., 2014).

Movements practiced during the dance classes, particularly *tendus*, mirrored the test and could have led to an improvement in neuromuscular pathways and the transfer of skills. Tendus are performed by standing on the supporting leg and sliding the foot along the ground out and in. *Tendus* are typically performed in anterior, lateral and posterior directions, which could explain why improvements were seen in lateral and posterior-lateral directions. Neuromuscular changes generally occur in the first 3-5 weeks of training (Pearcey, 2021) which explains the initial increase from pre-mid in lateral reaches. Earl and Hertel (2001) used EMG during the SEBT to demonstrate that lateral and posterior-lateral directions utilize higher activation of biceps femoris and tibialis anterior; gastrocnemius keeps a consistent level of activation in all directions. Through the online dance classes, which specifically exercised those muscles (Trepman et al., 1994), activation could have been improved. Furthermore, Earl and Hertel (2001) found lateral and posterior-lateral directions require the least amount of knee flexion, perhaps leaving room for improvement detected after the dance classes.

The results from lower limb strength measures may aid in supporting the rationale that increased ankle stability underlies the greater dynamic balance we detected. This improvement can translate to reducing fall risk during dynamic activities of daily living that involve changing body positions and transfers of weight such as walking to the shop, sweeping the house, or stepping down from the sidewalk.

2.4.4 Lower Limb Strength

A clear training effect was demonstrated for improvements observed on the CRS. While there were no significant changes from pre to mid, there was both a statistically and clinically significant increase from mid to post and pre to post. Neuromuscular adaptations are the main drivers comprising the first phase of enhanced strength from the initial 3 to 5 weeks (Pearcey, 2021). As our effects were found at a later phase, it suggests that hypertrophy produced improvements in strength.

Surprisingly, few dance studies have specifically assessed plantarflexor strength. As suggested, the significant improvements in plantarflexor strength can be attributed to increases in pennation angle, muscle thickness and fascicle length in the gastrocnemius found by Cepeda and colleagues (2015) following 8 weeks of ballroom dancing. This would support our findings of the increased number of repetitions on the CRS and later trends in farther distances reached posterior-laterally on the SEBT. With greater gastrocnemius strength, participants may have increased ease in controlling anteroposterior sway with plantarflexors contractions and relaxations (Winter, 1995). Though no improvements in anteroposterior sway were found, higher repetitions on the CRS may be enough to explain better anteroposterior control.

While we did not observe improvements in knee and hip extensor strength, previous work may allude to our limitations. Prior studies of in-person dance classes by Cruz-Ferreira and colleagues (2015) only reported significant increases in knee extensor strength after 24 weeks and not at their 12-week mid-test. McKinley and colleagues (2008) were able to report significant increases in knee extensor strength by 10 weeks but their participants were completing an extra 1.5 hours of dance classes every week. Franco and colleagues (2020) demonstrated significant reductions in the amount of time needed to complete the Sit-to-Stand test, but authors noted that the classes were designed to be of a moderate intensity - which may not be safe in the online environment. This suggests that significant improvements in knee and hip extensor strength may have been found with an increased length of intervention, the duration of each session, or intensity.

2.4.5 Subjective Questionnaires

Surveys of balance confidence and fear of falling did not show any significant changes over the study period. It should be noted that baseline values on the ABC for 13 out of 16 participants were above 80%. Huang and Wang (2009) on their survey of 174 community-dwelling older adults reported the ABC may have ceiling effects and that participants with baseline values above 80% may be unlikely to demonstrate improvements. This ceiling effect may explain our lack of findings and may be the reason we did not find improvements on the FES. While Bjorner and colleagues (1998) do not report ceiling effects on the SF-36, perhaps our cohort's higher activity levels and good health led to one being detected.

2.4.6 Limitations

This study was completed when regional COVID-19 mask mandates ended and an increase in cases affected older adults. This wave affected several of our participants and either caused them to miss classes or completely withdraw from participation. Additionally, the delay of physician appointments and late identification of conditions among older adults in Quebec contributed to some of our participants being diagnosed with ongoing health conditions and withdrawing.

Additionally, while community-dwelling older adults are generally a heterogeneous population, our cohort was highly active when measured using the PASE. Due to their already high fitness levels, improvements in strength and balance are harder to achieve, thus some of our failure to report significance may be attributed to an insufficient overload.

Finally, with regards to testing of dynamic balance, the difficulty and resulting apprehension of the SEBT could be a limitation. The SEBT was originally designed to be used in athletes, but has been validated and used for older adults (Stockert & Barakatt, 2005). To try and overcome apprehension among our participants, a modification of lightly tapping into the center between every excursion was added. This modification is unvalidated and may limit our ability to directly compare the results to other studies.

2.4.7 Strengths and Practical Applications

Our results demonstrate clinical significance as online dance classes are an enjoyable and novel way for older adults to reduce their risk of falls. There are practical applications as this is a low cost, easy to implement and wide-reaching fall prevention program. There is potential for many older women from across the globe to participate in the same sessions, including participants from remote communities. This increases accessibility of fall prevention programming by avoiding barriers such as transportation, lack of qualified instructors in the region or pandemic guidelines. This online format was also notably useful for several participants who were primary caregivers to partners at home. As caregivers were able to participate from home, they gained the opportunity to exercise, be in a social environment and express themselves creatively while still being present to take care of their loved ones.

2.5 Conclusion

Online dance classes are accessible and effective in reducing the fall risk of older women by improving postural stability, dynamic balance and strength. It is hoped that online dance classes can be adapted to a range of styles, such as traditional dances, which may aid in promoting inclusion and cultural diversity. By implementing this new and easily applicable fall prevention intervention, the risk of falls may be reduced, subsequently decreasing injuries as well as improving independence and quality of life of older women.

2.6 Acknowledgements

We would like to thank our participants for their trust, time and participation. EHC was supported by the Canadian Graduate Scholarship – Master's Program, Canadian Institutes of Health Research/Instituts de Recherche en Santé du Canada and Fonds de Recherche du Québec – Santé – Formation de Maîtrise for their financial support.

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2.8 Appendix

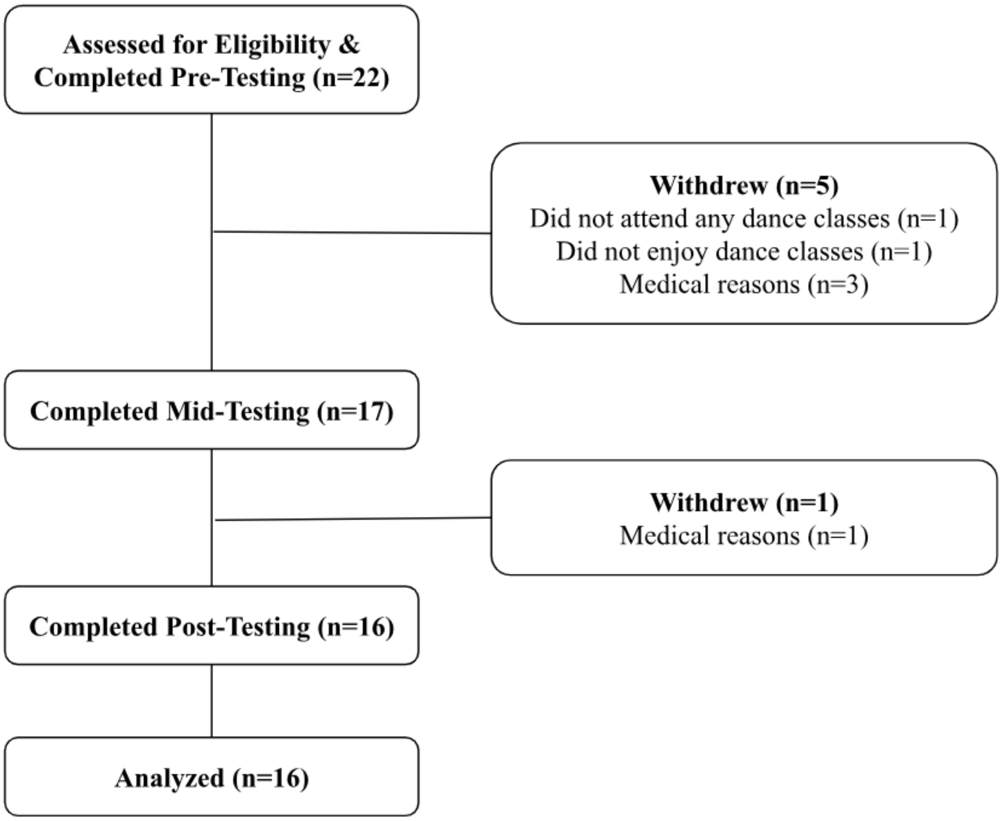

Figure 1. Participant flow diagram: 22 participants were recruited and completed pre-testing. Between pre and mid-testing, 5 participants discontinued and between mid and post-testing, another participant withdrew. Reasons for withdrawal are outlined.

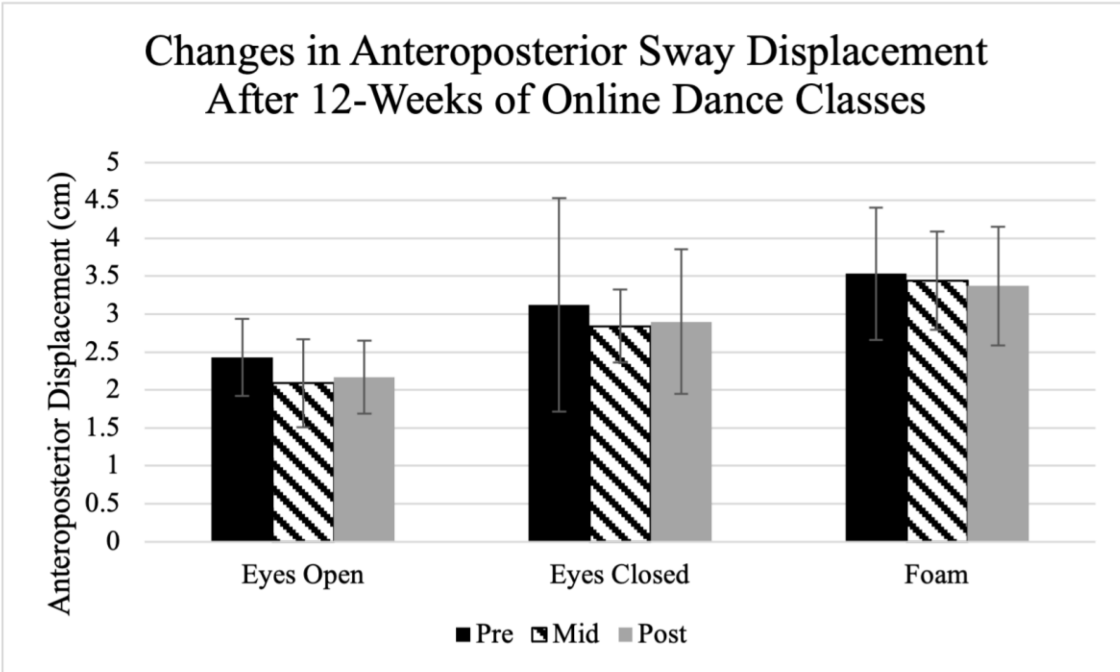

Figure 2. Changes in anteroposterior sway displacement pre, mid and post 12-weeks of online dance classes. Error bars represent standard deviation.

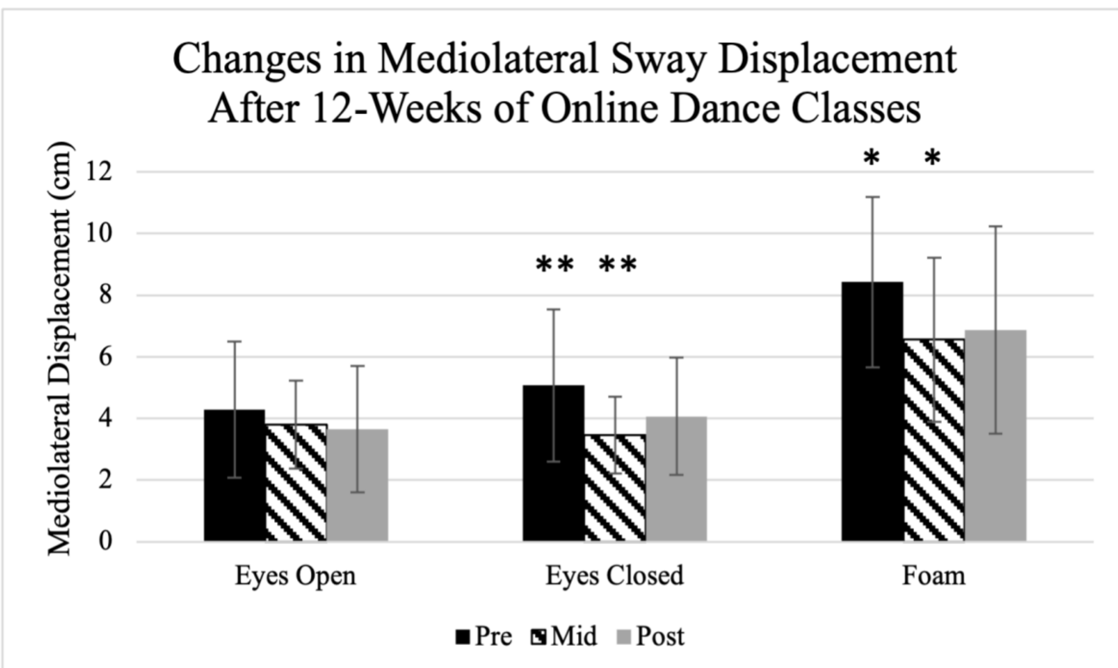

Figure 3. Changes in mediolateral sway displacement pre, mid and post 12-weeks of online dance classes *$p \leq .05$, **$p \leq .01$. Error bars represent standard deviation.

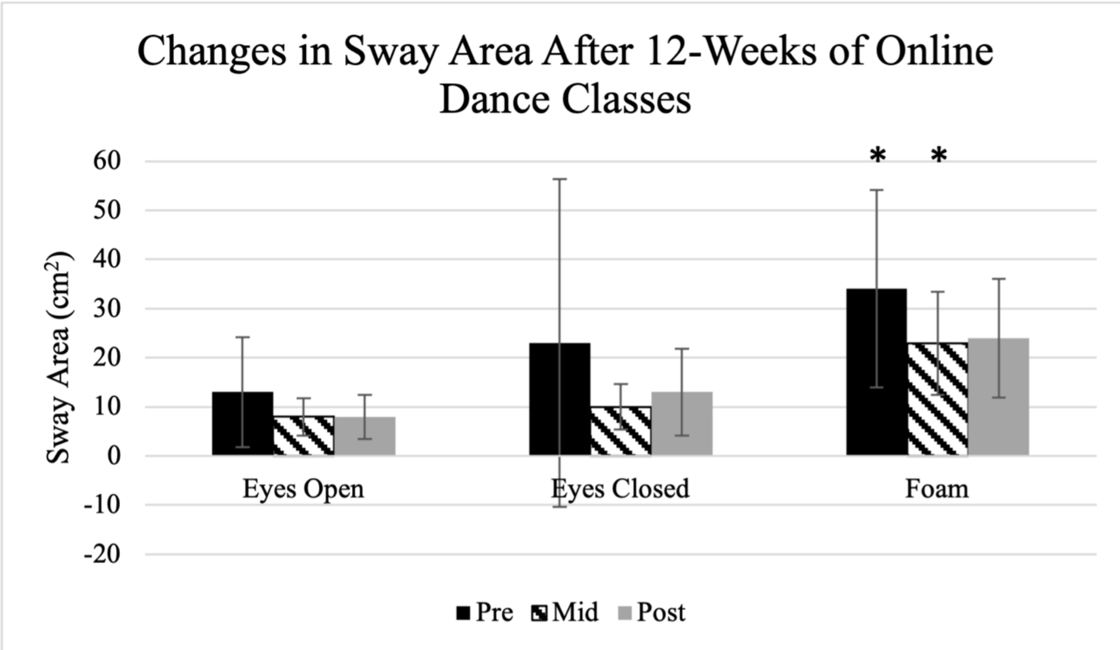

Figure 4. Changes in sway area pre, mid and post 12-weeks of online dance classes *$p \leq .05$. Error bars represent standard deviation.

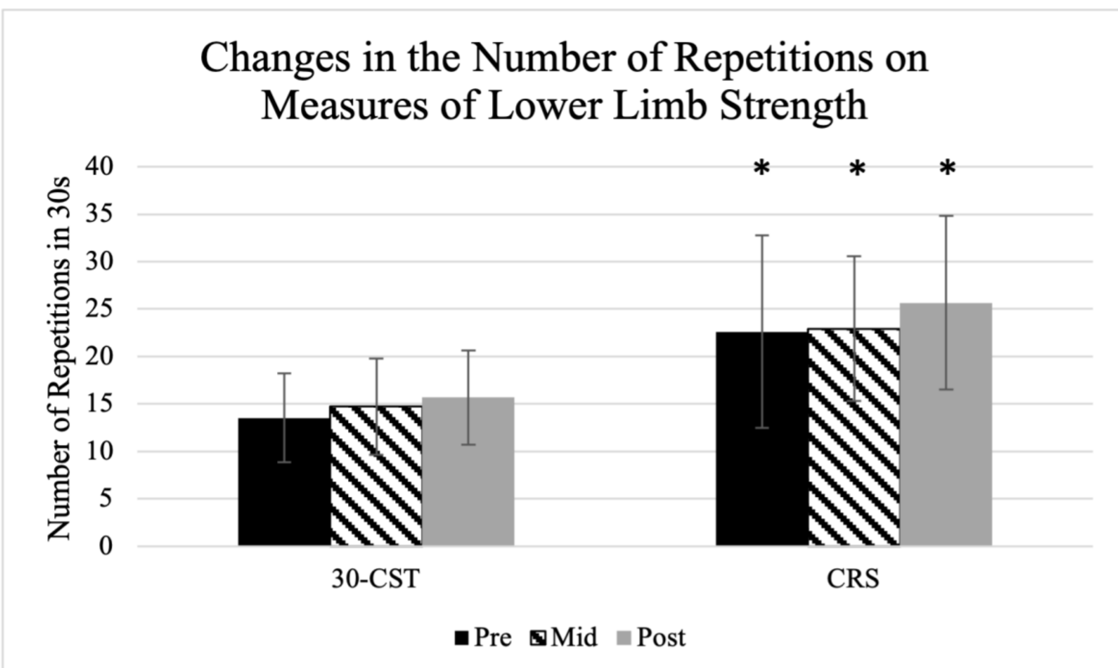

Figure 5. Changes in lower limb strength pre, mid and post 12-weeks of online dance classes *$p \leq .05$. Error bars represent standard deviation. Both clinically and statistically significant improvements were found on the CRS from pre-post and mid-post.

TRANSITION TO CHAPTER 3

Chapter 2 demonstrated that online dance classes provide an accessible way for older women to reduce their risk of falls. However, the intensity of classes was too low to stimulate improvements in hip and knee extensor strength, as well as anteroposterior sway. In the online environment, monitoring of participant safety is limited and therefore, the intensity of classes must be low.

Chapter 3 explores whether the addition of blood flow restriction (BFR) cuffs can provide a novel way to mimic high intensity exercise and reach overload, thereby increasing strength, postural stability and reducing fall risk. To our knowledge, the combination of BFR with dance and in the online exercise environment has yet to be explored.

CHAPTER 3: MANUSCRIPT

Reducing the fall risk of older Canadian women following 12-weeks of online dance classes combined with blood flow restriction.

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This randomized controlled trial examined whether 12 weeks of online dance classes combined with blood flow restriction (BFR) could reduce the risk of falls among older women. Nine females (74.5 ± 5.2 years) were activity-matched and randomized into BFR (n=5) and control (n=4) groups. Both groups completed two 75-minute dance classes on Zoom each week and the BFR group wore 5-centimeter elastic cuffs on their proximal thighs throughout the classes. Postural stability, dynamic balance and lower limb strength were evaluated at pre, mid and post via 30-second trials of quiet standing, the star excursion balance test (SEBT), 30-second sit to stand (30-CST) and the calf-raise senior (CRS). Non-parametric statistics were used to evaluate significance ($p \leq .05$). Improvements in strength were found among BFR group participants on the 30-CST (pre-mid p=.042; pre-post p=.039) and clinically meaningful gains were found on the CRS (pre-post MD=4). The BFR group demonstrated increases on the SEBT when reaching posterior-medially (pre-post p=.043) and medially (mid-post p=.043). No statistically significant improvements were found in the control group, however clinically meaningful increases were found on the CRS (mid-post MD=7.75; pre-post MD=10.75). Online dance classes with BFR show great potential as an accessible fall prevention program that will provide additional opportunities for women to increase their fitness, independence and quality of life as they age.

KEYWORDS: dance-based exercise, aging, balance training, tele-health, KAATSU Training

3.1 Introduction

Falls are a leading cause of injury, hospitalization and death among older adults. In Australia, Canada and the United Kingdom, hospitalization rates range from 1.6 to 3.0 per 10,000 individuals and generate an average cost of $6,646 USD (Ireland) to $17,483 USD (USA) per treated faller (World Health Organization, 2007). Women comprise 70.5% of subsequent emergency visits (Stevens & Sogolow, 2005) reflecting their lower levels of physical activity, strength and bone mass density (Chang & Do, 2015; Do et al., 2015; Stevens & Sogolow, 2005). With the number of older adults projected to increase to 832 million by 2050 (United Nations, Department of Economic and Social Affairs, Population Division, 2019), the World Health Organization has outlined the need for fall prevention and active aging programs (World Health Organization, 2017).

Age-related increases in falls are attributable to declines in postural stability, which is dependent on sensory information from the visual, vestibular and proprioceptive systems, as well as strength, muscle mass and mobility (Carter et al., 2001; Horak et al., 1989). Beginning at age 40, women display significant declines in leg extension power (-1.5% per year) (Alcazar et al., 2020). This loss accelerates in women above the age of 75 (-1.8% per year) due to decreases in lean muscular mass (Alcazar et al., 2020), primarily Type II fibers (Kramer et al., 2017), and increases in intramuscular fat infiltration (Alcazar et al., 2020; Goodpaster et al., 2001). This atrophy may affect the ability to execute quick postural adjustments and avoid falls (Horak et al., 1989). Despite the known benefits of regular physical activity for preserving strength, muscle mass and bone strength (Frischknecht, 1998), less than 4% of women above the age of 65 are physically active (Colley et al., 2011).

Dance is gaining popularity as a way for older women to boost their levels of physical fitness and has shown to improve postural stability after as little as 2 hours per week for 10-weeks (Eyigor et al., 2009; Filar-Mierzwa et al., 2017; Sofianidis et al., 2009; Wu et al., 2010; Zhang et al., 2008). Directional changes, single leg standing time, body rotations, improvisation and precision of movement have all been linked to improved lower limb strength (Eyigor et al., 2009; McKinley et al., 2008), reaction time (Wu et al., 2010; Zhang et al., 2008), balance confidence (McKinley et al., 2008) and postural stability (Eyigor et al., 2009; Filar-Mierzwa et al., 2017; Sofianidis et al., 2009; Wu et al., 2010; Zhang et al., 2008).

While dance is effective for improving postural stability, many women face barriers to in-person participation due to: living in remote locations, lacking transport, being a caregiver at home, or being immunocompromised. Online dance semesters of 12-weeks were shown to have high attendance rates of 80.3% as well as improve plantarflexor strength and dynamic balance (Chen, Bergdahl & Roberts, under revision). As intensity was low to ensure safety in the online environment, there was limited ability to reach overload and produce improvements in postural stability and leg extensor strength (Chen et al., under revision). Blood flow restriction (BFR) is proposed as a novel method to safely mimic a higher exercise intensity and maximize the potential benefits of online dance classes.

BFR uses cuffs on the proximal portion of limbs to partially occlude blood vessels going to muscles exercising at low intensity. This reduction in blood flow and subsequent hypoxia simulates a high intensity environment and increases in physiological stress to promote performance on strength tests to a level comparable to high-intensity exercise among older adults (Abe et al., 2010; Baker et al., 2020; Bryk et al., 2016). These improvements are related to enhanced Type II muscle strength and recruitment (Takarada et al., 2000), and may be particularly beneficial for reducing fall risk as postural corrections must be made quickly. Additionally, BFR shows particular promise for older adults who may have comorbidities that contraindicate high-intensity exercise (Centner et al., 2019). The safety of BFR for older adults has been confirmed in both clinic and at-home use with low rates of venous thrombosis (0.055% occurrence ratio), pulmonary embolism (0.008% occurrence ratio) and rhabdomyolysis (0.008% occurrence ratio) (Nakajima et al., 2006).

To our knowledge, no studies have examined the use of BFR for improving postural stability and no studies have combined BFR with dance classes or online exercise classes. This randomized controlled trial investigates whether 12-weeks of online dance classes combined with BFR can produce improvements in the strength, dynamic balance and postural stability of women aged 65 years and above.

3.2 Methods

3.2.1 Participants & Study Design

Nine women (74.5 ± 5.2 years) from the Montreal community completed a 12-week randomized controlled trial with pre, mid and post-testing. They were recruited using an existing participant list and through ads in local recreation centers.

Stratified randomization into BFR and control groups occurred by matching those with similar physical activity levels (baseline Physical Activity Scale for the Elderly 'PASE') and drawing subject numbers. PASE scores were calculated by multiplying time spent in each activity by standardized weights (Frenkel, 2016; Washburn et al., 1993). At week 0, 8 participants were allocated to the BFR group (skewed to account for expected drop-outs) and 6 were allocated to the control group.

Prior to allocation and pre-testing, Certification of Ethical Acceptability for Research Involving Human Subjects (30016017) was received from the Human Research Ethics Committee of Concordia University and informed consent was obtained.

Inclusion	Exclusion
● Female ● Over 65 years old ● Comprehension of spoken English ● Able to visit Concordia University for all testing sessions ● Access to a device with a webcam, Zoom and stable internet ● No contraindication for physical activity from their physician	● Males who indicated their interest were invited to participate in classes but were not tested ● Occurrence/onset of a stroke, vertigo, concussion or lower-extremity injury during the 12-week intervention period ● Presence of venous thromboembolism, peripheral vascular disease or sickle cell anemia

Table 1. Inclusion and exclusion criteria for participants.

3.2.2 Dance Intervention

Two 75-minute dance classes were held over Zoom every week, for 12 weeks. Each session started with a 15-minute warm-up, followed by *pliés, tendus, Graham* and *Limón modern-dance* exercises, and a 5-minute stretch recovery (see *YouTube Link* for archived exercises). Movements emphasized transfer of weight, dynamic balance while standing on one leg, bringing the body off center, fall recovery and strengthening of the lower limbs and core. A helper was present for each Zoom class to track attendance and ensure safety and participants were asked to keep their webcams on. Recordings of the class were provided to anyone who was absent and completion of the recordings was added to the attendance.

3.2.3 Blood Flow Restriction Parameters

At the end of the pre-test, participants in the BFR group were given 5-centimeter-wide elasticized fabric cuffs and the researcher provided instruction on how to place them on the proximal portion of their thighs. They were asked to pull the BFR cuffs as tight as possible until they felt slight discomfort and that point was marked to standardize the pressure and make it easier to use at home. At mid-testing participants were asked to bring the cuffs so that proper placement and use could be checked and the level of tightness could be adjusted.

3.2.4 Assessments

3.2.4.1 Postural Stability

Participants completed three 30-second trials of quiet standing under three conditions: 1) eyes open, 2) eyes closed and 3) eyes open on a 5-centimeter thick foam pad. Trials were staggered to avoid any effects due to fatigue. Participants were asked to stand with their feet at a natural and comfortable distance with arms by their side. They were instructed to stay as still as possible for the duration of each 30-second trial while looking straight ahead to a point at eye-level on the wall. During the test, cameras were placed so measures of anteroposterior displacement (cm) of the shoulders and hips could be analyzed using the open-source sports analysis software Kinovea.org version 0.8.27. As evaluating sway measures using Kinovea takes several hours per video, only pre and post tests were analyzed. The researchers completing data analysis were blinded to group allocation.

3.2.4.2 Dynamic Balance

The modified Star Excursion Balance Test (SEBT) was used to assess dynamic balance. Participants were asked to stand on their non-dominant leg in the center of an 8-line star on the ground. They were asked to reach their dominant leg above the line as far as possible before tapping their foot to the floor on the line, and then returning their foot to center. To reduce fatigue and apprehension, a modification was made to allow a tap of their foot upon returning to the center. After tapping into the center, participants were instructed to continue reaching to the next line. Two practice trials were granted and the third was recorded by placing a mark on the line where the participant tapped. The distances from the center to the mark were measured to the nearest 0.50

centimeter. If the participant lost balance or moved their supporting leg, the distance was not recorded. A helper was present to ensure safety.

3.2.4.3 30-Second Sit-to-Stand

The 30-Second Sit-to-Stand (30-CST) was used to measure hip and knee extensor strength. The procedure described by Jones and colleagues (1999) was followed and if the participant did not stand up more than halfway or did not touch the chair when sitting, the repetition was not counted (30 Second Sit to Stand Test, 2013).

3.2.4.4 Calf Raise Senior

The Calf Raise Senior (CRS) evaluated plantar flexor strength. Participants were asked to complete the tests according to instructions outlined by André and colleagues (2016) and the number of complete repetitions was recorded. The mean difference of 3.5 repetitions was used to determine clinical significance (André et al., 2020).

3.2.5 Statistical Analysis

Descriptive statistics were obtained and normality tests (Shapiro-Wilk and Kolmogorov-Smirnov) were performed for all variables. As the sample sizes were small, the assumptions were not met and non-parametric tests were used. Parametric descriptive statistics were reported in tables below to ease comparison. Baseline differences between groups were assessed using the Kruskal-Wallis test. Time effects for each group were evaluated using Friedman's test with post-hoc Wilcoxon Signed-Rank test. The Wilcoxon Signed-Rank test was additionally used to compare pre-post changes in shoulder and hip sway for each group. All statistical analyses were performed on SPSS-28® (IBM) with an alpha value of 0.05 ($p \leq .05$).

3.3 Results

3.3.1 Study Participants

As seen in Figure 1 (found in Appendix), 9 participants completed the study and were analyzed after 5 participants withdrew (3 BFR group and 2 control group).

One participant who withdrew from the BFR group had experienced discomfort and “throbbing” in her veins. It was revealed that she had varicose veins, a contraindication that was not specified on her intake forms or in the first assessment, though this was expressly asked. She was asked to stop using the BFR cuffs but completed the final 6 weeks of dance classes. She was not included in the analysis. No other side effects from the BFR cuffs were reported.

The other reasons for discontinuing from the BFR group included moving out of the country and an extended bout of COVID-19. Two participants withdrew from the control group due to a surgery or a scheduling conflict.

No significant differences between groups or between dropouts were found at baseline.

	BFR		**CONTROL**	
	Analyzed ***M (SD)***	**Dropouts** ***M (SD)***	**Analyzed** ***M (SD)***	**Dropouts** ***M (SD)***
N	5	3	4	2
Age (years)	76.0 (1.76)	79.0 (2.00)	72.8 (3.28)	80.5 (3.50)
BMI (kg/m^2)	25.7 (2.24)	24.0 (0.57)	22.1 (0.92)	25.2 (2.20)
PASE	147.2 (23.43)	98.3 (33.59)	139.0 (24.65)	97.0 (15.00)
Attendance (%)	71.4 (29.8)	/	68.3 (25.4)	/
Attendance with Recordings (%)	83.3 (24.9)	/	85.8 (12.0)	/

Table 2. Mean (standard deviation) of participant characteristics, PASE scores and attendance.

3.3.2 Attendance

Comparable attendance to the live Zoom classes was observed in both groups (BFR group 71.4% ± 29.8; Control group 68.3% ± 25.4). When recordings were provided to those who were absent, attendance rates increased to 83.3% (± 24.9) in the BFR group and 85.8% (± 12.0) in the Control group.

3.3.3 Postural Stability

	BFR (n=5)		CONTROL (n=4)	
	Pre	**Post**	**Pre**	**Post**
	M (SD)	***M (SD)***	***M (SD)***	***M (SD)***
Eyes Open				
Shoulder Sway (cm)	2.25 (0.29)	1.97 (0.29)	2.28 (0.29)	1.90 (0.17)
Hip Sway (cm)	1.92 (0.30)	1.84 (0.30)	1.58 (0.19)	1.10 (0.14)
Eyes Closed				
Shoulder Sway (cm)	3.17 (0.48)	2.69 (0.40)	2.51 (0.24)	2.31 (0.01)
Hip Sway (cm)	2.40 (0.41)	2.09 (0.30)	1.56 (0.10)	1.41 (0.13)
Foam				
Shoulder Sway (cm)	3.40 (0.24)	2.99 (0.32)	4.27 (0.74)	3.71 (0.52)
Hip Sway (cm)	2.59 (0.20)	2.34 (0.21)	2.91 (0.34)	2.40 (0.36)

Table 3. Anteroposterior shoulder and hip sway pre and post 12-weeks of online dance classes

No significant differences in anteroposterior shoulder or hip sway were found in either group after the 12-weeks of online dance classes. Reductions in anteroposterior hip sway trended towards significance in the control group during eyes-closed (p=.068) and foam (p=.068) conditions.

3.3.4 Dynamic Balance

	BFR (n=5)			CONTROL (n=4)		
	Pre ***M (SD)***	**Mid** ***M (SD)***	**Post** ***M (SD)***	**Pre** ***M (SD)***	**Mid** ***M (SD)***	**Post** ***M (SD)***
Anterior	0.72 (0.03)	0.75 (0.04)	0.78 (0.04)	0.65 (0.07)	0.67 (0.04)	0.68 (0.06)
Anterior-Lateral	0.83 (0.02)	0.83 (0.04)	0.85 (0.04)	0.70 (0.07)	0.73 (0.03)	0.74 (0.06)
Lateral	0.85 (0.03)	0.86 (0.05)	0.91 (0.06)	0.70 (0.03)	0.75 (0.03)	0.76 (0.04)
Posterior-Lateral	0.88 (0.04)	0.80 (0.06)	0.93 (0.08)	0.72 (0.03)	0.77 (0.04)	0.83 (0.04)
Posterior	0.79 (0.03)	0.75 (0.08)	0.81 (0.05)	0.77 (0.10)	0.80 (0.14)	0.84 (0.10)
Posterior-Medial	0.65 (0.05)*	0.72 (0.06)	0.79 (0.07)*	0.67 (0.08)	0.74 (0.05)	0.76 (0.05)
Medial	0.60 (0.05)	0.54 (0.06)*	0.66 (0.07)*	0.56 (0.03)	0.60 (0.09)	0.58 (0.03)
Anterior-Medial	0.65 (0.02)	0.64 (0.02)	0.69 (0.03)	0.60 (0.05)	0.57 (0.04)	0.62 (0.05)

Table 4. Distances reached during the modified SEBT pre, mid and post 12-weeks of online dance classes *$p \leq .05$. Values are expressed as a ratio of limb length.

At post-testing, participants in the BFR group were able to reach significantly further in the posterior-medial (pre-post p=0.043) and medial directions (mid-post p=.043). This improvement was not observed in the control group.

Trends to significance were observed in the BFR group when extending in the anterior-medial (p=.074) and anterior directions (p=.074).

3.3.5 Strength

	BFR Group			**CONTROL Group**		
	Pre ***M (SD)***	**Mid** ***M (SD)***	**Post** ***M (SD)***	**Pre** ***M (SD)***	**Mid** ***M (SD)***	**Post** ***M (SD)***
30-CST	16.0 (4.00)*	18.6 (4.45)*	19.8 (4.32)*	13.8 (3.86)	15.0 (4.08)	17.5 (3.70)
CRS	28.6 (13.69)$^+$	29.4 (10.36)	32.6 (12.03)$^+$	25.3 (4.99)$^+$	28.3 (9.61)$^+$	36.0 (12.08)$^+$

Table 5. Changes in the number of repetitions on strength assessments pre, mid and post 12-weeks of online dance classes with and without BFR *$p \leq .05$, $^+$clinical significance.

	BFR Group			**CONTROL Group**		
	Mid-Pre ***MD (SD)***	**Post-Mid** ***MD (SD)***	**Post-Pre** ***MD (SD)***	**Mid-Pre** ***MD (SD)***	**Post-Mid** ***MD (SD)***	**Post-Pre** ***MD (SD)***
30-CST	2.6 (1.14)	1.2 (0.84)	3.8 (1.79)	1.3 (3.59)	2.5 (0.58)	3.8 (3.50)
CRS	0.8 (5.67)	3.2 (2.17)	4.0 (6.00)$^+$	3.0 (7.26)	7.8 (5.91)$^+$	10.8 (10.34)$^+$

Table 6. Mean differences (standard deviation) in the number of repetitions on strength assessments pre, mid and post 12-weeks of online dance classes with and without BFR $^+$clinical significance.

A significant increase in the number of repetitions on the 30-CST was observed in the BFR group from pre-mid (p=.043) and pre-post (p=.039). While no statistically significant changes were found on the CRS, mean difference of 4.0 from pre-post passed the threshold for clinical significance of 3.50 outlined by André and colleagues (2020).

No statistically significant differences were found on either the 30-CST or the CRS in the control group, however a trend to significance (p=.057) and clinically significant changes were found among control group participants on the CRS. From mid-post, participants had a mean difference of 7.8 repetitions and from pre-post a mean difference of 10.8 repetitions was observed.

3.4 Discussion

This randomized controlled trial evaluated whether the addition of BFR to online dance classes can improve postural stability, dynamic balance and lower limb strength of older women beyond online dance classes alone. The addition of BFR mimics a higher intensity environment and leads to improvements in hip and knee extensor strength, as well as induces improvements in dynamic balance.

3.4.1 Attendance and Safety

This study confirmed the safety and feasibility of using BFR during dance classes and online exercise trials. The BFR group showed similar attendance to the control group throughout the intervention. Both groups demonstrated moderate attendance to live Zoom classes but had similarly high attendance rates when recordings were provided. This resemblance suggests that BFR was an acceptable addition to the dance classes. The participation rate of our classes (including recordings) is consistent with other dance for postural stability research included in a meta-analysis by Clifford and colleagues (2023) which showed high attendance rates of above 80%. Our findings in the BFR group were also consistent with Harper and colleagues (2019) randomized control trials of BFR walking for older adults which demonstrated 81.4% attendance.

3.4.2 Postural Stability

While no significant results were found, trends to significance in the BFR group were observed in anteroposterior hip sway during eyes closed and foam trials. The low sample size of both groups likely led to underpowered results therefore, another semester of this study is underway.

Force plates were originally intended to measure center of pressure sway displacement, but broke at pre-testing. Kinovea was enacted as a backup plan to analyze shoulder and hip sway. On average, it takes 7 hours to analyze one assessment using Kinovea. For this reason, anteroposterior video analysis, which contains 2 tracking points instead of 4, was prioritized. It is speculated that anteroposterior improvements are less likely to occur as most dance movements take place in the sagittal plane and using external rotation (Trepman et al., 1994). Consequently, there is high recruitment of glutes, and thigh adductors and abductors which do not primarily contribute to anteroposterior sway, which is predominantly controlled by the ankle plantar and dorsiflexors. Additionally, previous studies by Sofianidis and colleagues (2009) found improvements in mediolateral center of pressure displacement after as little as 10 weeks of dance classes, but not in anteroposterior sway. Our previous semesters of online dance classes revealed a similar pattern in mediolateral sway improvements after 12 weeks (Chen et al., under review). Future analysis of mediolateral sway will be completed.

3.4.3 Dynamic Balance

The significant improvements in posterior-medial (from pre-post) and medial (from mid-post) reaches were accompanied by an increased number of participants bending their supporting leg at post. Hertel and colleagues (2006) demonstrated that reaches in posterior-medial, medial and anterior-medial directions are important indicators for chronic ankle instability. Our gains in posterior-medial and medial reaches seem to indicate that the combination of online dance classes with BFR affected the muscles involved in ankle control and allowed participants in the BFR group to reach further. Findings by Earl and Hertel (2001) indicate that posterior-medial reaches and medial reaches require the most tibialis anterior activation. Furthermore, these directions, along with anterior-medial, require the highest degrees of knee and ankle flexion (Earl & Hertel, 2001). During the dance classes, the *plié* exercise (the movement of bending and extending the knees) utilized knee flexors and tibialis anterior and could have contributed to strength increases needed for farther reaching (Trepman et al., 1994).

The addition of BFR during dance classes may have been instrumental in allowing for higher knee flexor strength as Bowman and colleagues (2019) showed greater isokinetic knee flexion in BFR groups than for exercising controls. The timing of improvements only after 6 weeks supports the hypothesis that changes on the SEBT are related to BFR induced strength gains (Abe et al., 2010). It should be noted, studies evaluating BFR on tibialis anterior activation have shown no benefit (Burkhardt et al., 2021).

Progress in posterior-medial and medial reaches may have clinical and practical implications as they are indicators for improved ankle stability (Hertel et al., 2006). With greater stability, particularly related to dorsiflexors, older women benefit from support during the swing phase of stepping and shifting the center of gravity about the ankle joint when unbalanced (Laughton et al., 2003).

3.4.4 Lower Limb Strength

Improvements found in knee extensor strength on the 30-CST from pre-mid and pre-post in the BFR group demonstrate the efficacy of online dance classes with BFR for building strength. Findings are supported by Abe and colleagues (2006, 2009) who found greater muscle strength and muscle volume after only 3-weeks of BFR walking, and improved performance on isokinetic knee extensor tests after 6 weeks (Abe et al., 2010). The 30-CST is a largely anaerobic test utilizing Type II muscle fibers (Gastin, 2001). During BFR, distal muscles, in this case the knee extensors, experience a hypoxic environment which drives utilization of glycolytic pathways and stimulates Type II fiber improvements (Takarada et al., 2000) and consequently, gains on the 30-CST.

This increase in knee extensor strength is much quicker than in previous studies of dance for older adults which required a minimum of 3 classes per week for 10-weeks (McKinley et al., 2008). As well, greater knee extensor strength was not observed during our previous research of online dance classes (Chen et al., under review). Our findings indicate that the addition of BFR is an easy and effective way to safely simulate an increase in intensity during online dance classes and to build strength. Further, these improvements in knee extensor strength may aid in making larger hip adjustments when unbalanced (Horak et al., 1989).

While no statistically significant differences in plantarflexor strength were observed, clinically meaningful improvements were found in both the BFR and the control groups. The control group had a much higher mean improvement than the BFR group, opposite to what was expected. One explanation for these results may be an extreme outlier in the BFR group who did 54 repetitions at their pre-test and did not improve to post. This may be indicative of a ceiling effect of the CRS, as André and colleagues (2020) found a mean of 25 repetitions in 30 seconds among their sample of older adults. In the control group, there was another extreme case of a participant having an increase of 25 repetitions from pre-post. At pre-testing this participant indicated they felt they were having an off day, and perhaps at subsequent tests they felt better and thus improved their performance. It could also be that familiarity with the tests from mid to post allowed them to feel more confident in their fitness capacities and lead to elevated results. A final explanation for this participant's score could be performance bias or the "good participant effect" as they were not blinded to study aims.

3.4.5 Limitations

A primary limitation in our ability to draw conclusions is the low sample size of this study. We had a number of dropouts (35.7%) due to various medical incidents and participants moving away. We are currently running an additional semester of online dance classes with BFR to double the sample size of each group; the final testing session will occur the week of August 14, 2023. With a greater number of participants, it is expected that the effects of extreme outliers may be controlled and true effects be more apparent.

An additional limitation was our use of Kinovea to assess only anteroposterior postural stability. Initially, we had planned to use force plates to evaluate mediolateral and anteroposterior sway displacement and sway area. Unfortunately, the force plates broke during pre-testing and we had to pivot and adopt Kinovea as a backup plan. Recordings of quiet standing trials were taken from frontal and sagittal views. So far, we only have results from the sagittal videos as the length of analysis led us to prioritize these videos. Frontal videos take longer to analyze as they have twice as many points (2 shoulder and 2 hip points) and the interference from hand movement and video pixelation of the shoulders requires more adjustment of Kinovea during analysis. Analysis of frontal videos is planned to obtain mediolateral sway values and the force plates have been fixed for our ongoing study semester (and videos are being recorded for Kinovea analysis).

At present, the use of Kinovea for postural sway analysis of older adults has not yet been validated. We are addressing this by analyzing videos from when the force plates were working and comparing shoulder and hip sway to center of pressure displacement obtained by the force plates, and by measuring agreement between raters. This validation is expected to be completed by September 2023.

The modified version of the SEBT also has yet to be validated. As the SEBT was originally designed for athletes, the modification of tapping the foot to the center was made to cater to our older participants and reduce apprehension and fatigue. While Stockert and Barakatt (2005) have validated the use of the SEBT for older adult populations, our modification has not been investigated and therefore limits our ability to directly compare our results to other studies.

A final limitation was our ability to measure and standardize occlusion pressure using the BFR cuffs. Elastic cuffs do not include a way to measure the restriction of blood flow and thus a tightness based on subjective discomfort was selected. Additionally, the elastic bands did have a limit to how tight they could be pulled, potentially limiting the occlusion pressure. In future, using non-elastic BFR bands may be a more effective low-cost way to use practical BFR (Duarte de Oliveira et al., 2023).

3.4.6 Strengths and Practical Applications

This study demonstrates the safety, feasibility and efficacy of using BFR during online dance classes to maximize gains in knee extensor strength and dynamic balance. BFR cuffs are low cost and do not interfere or alter attendance rates, allowing for enjoyable and engaging dance classes. Additionally, the low occurrence of adverse events supports the further use of BFR both with older adults and in an online environment. There are great practical implications as the accessibility of this program can provide opportunities to older adults from various remote locations to increase their levels of physical activity in a safe manner and thereby improve their strength and dynamic balance. The affordability may also aid in adoption by community health and recreation centers as an easy-to-implement fall prevention program that helps to increase the fitness and quality of life of older women.

3.5 Conclusion

Online dance classes combined with BFR are a safe, novel and low-cost way for older women to improve their strength and dynamic balance. Ongoing trials are intended to increase the sample size to overcome power limitations. The accessibility of this online program may allow for women, regardless of location, to improve their fitness, reduce their risk of falls, and increase their independence and quality of life as they age.

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3.8 Appendix

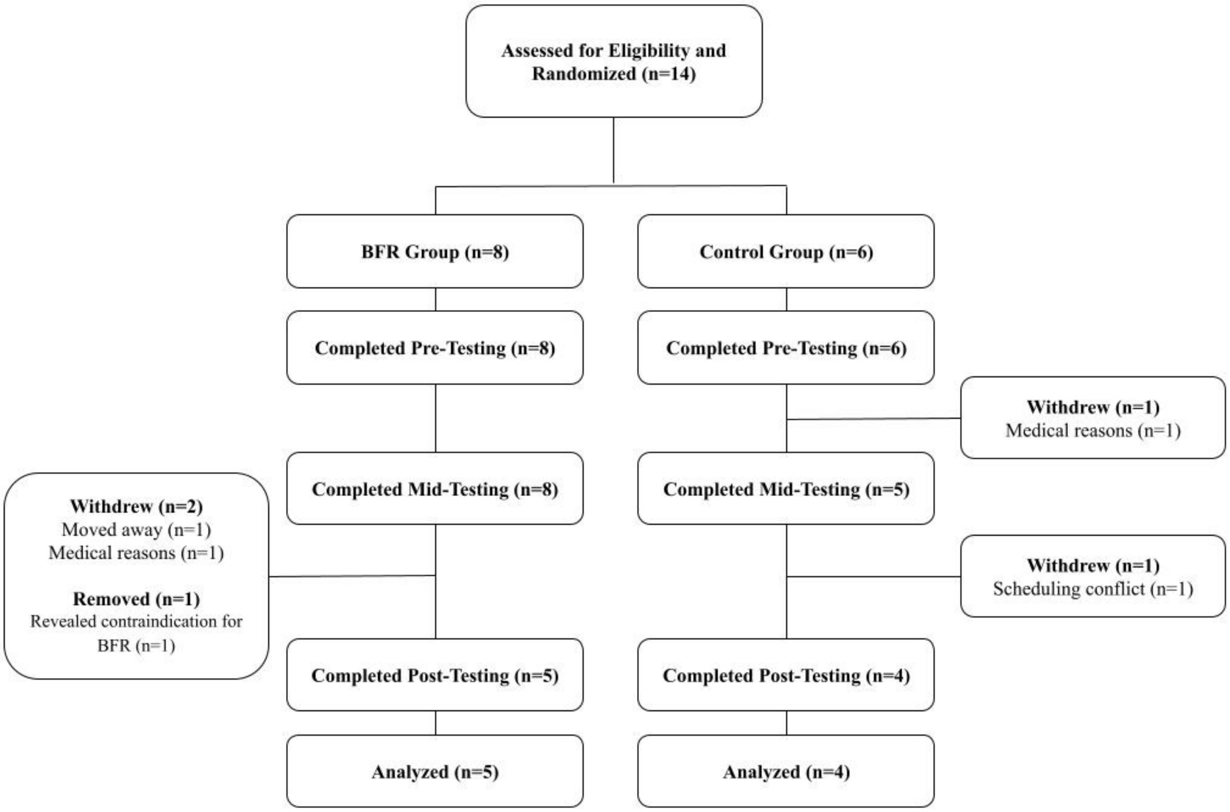

Figure 1. Participant flow diagram: 14 participants were recruited with 8 allocated to the BFR group and 6 to the control group. All participants completed pre-testing with 1 participant in the control group discontinuing prior to mid-testing. Between mid and post-testing, another participant withdrew from the control group and 2 withdrew from the BFR group. Finally, 1 participant was removed prior to analysis. Reasons for withdrawal and removal are outlined.

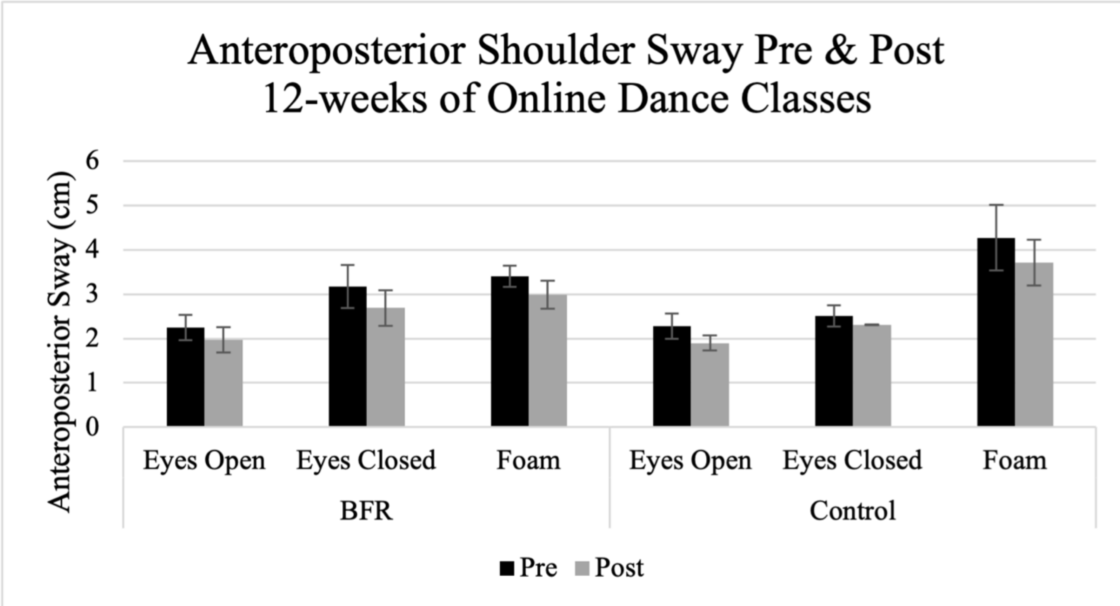

Figure 2. Displacements of anteroposterior shoulder sway pre and post 12-weeks of online dance classes. Error bars represent standard deviation.

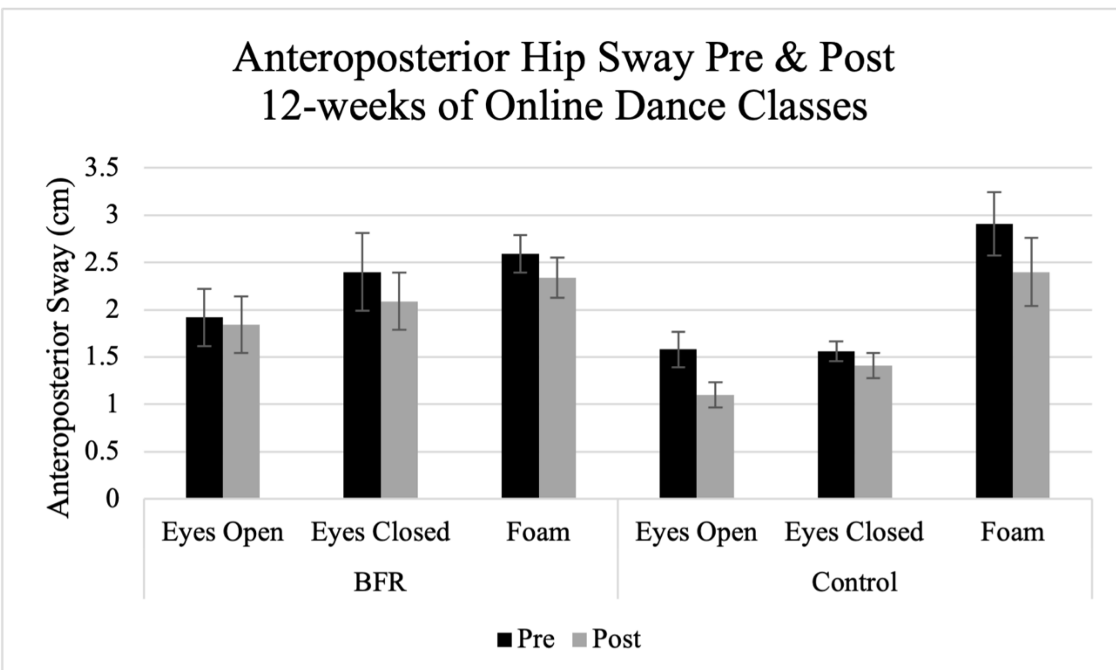

Figure 3. Displacements of anteroposterior hip sway pre and post 12-weeks of online dance classes. Error bars represent standard deviation.

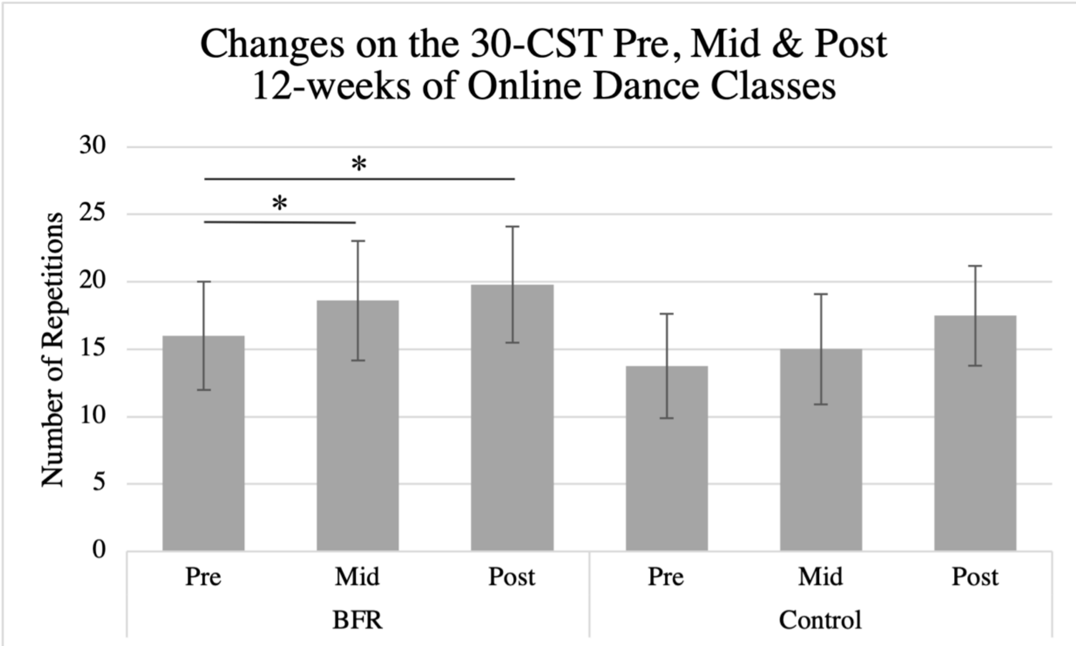

Figure 4. Number of repetitions on the 30-CST pre, mid and post 12-weeks of online dance classes *$p \leq .05$. Error bars represent standard deviation.

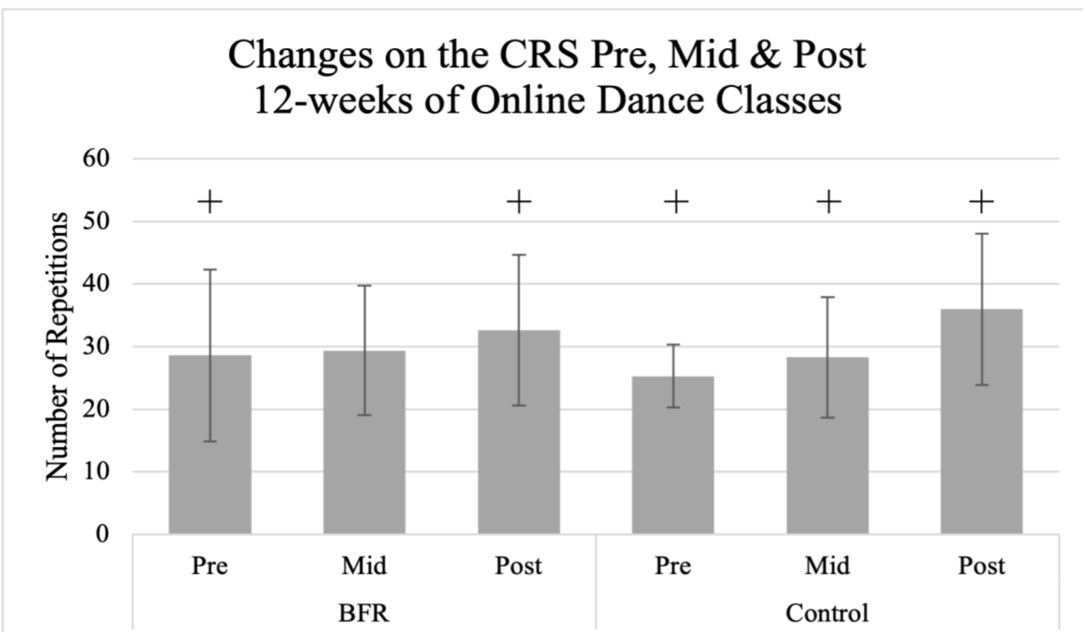

Figure 5. Number of repetitions on the CRS pre, mid and post 12-weeks of online dance classes $^{+}$clinical significance. Error bars represent standard deviation. No statistically significant differences were found however clinically significant improvements were found from pre-post in the BFR group and from mid-post and pre-post in the control group.

CHAPTER 4: SUMMARY, CONCLUSION AND FUTURE DIRECTIONS

These two projects demonstrate that online dance classes are an effective and enjoyable way for older women to develop strength, dynamic balance and postural stability, and that benefits can be enhanced with the addition of blood flow restriction. It is my hope that these results will allow community health and recreation centers to adopt classes as accessible fall-prevention programming.

As next steps, I would like to validate and use remote assessment methods to create a fully online version of this project. This would allow us to reach those in more isolated communities such as northern indigenous communities. I would also like to use other dance styles to create culturally affirmative classes for members of minority communities who often do not receive tailored programming.

Finally, with the knowledge learned from these projects, if I had the opportunity to repeat it, I would make the following changes:

1. Collect more demographic data of social determinants of health such as educational background, marital status etc. In getting to know participants, I noticed many of them were highly educated. I feel having more information on the types of people who choose to participate in our studies may be useful in generalization and in understanding and fixing our recruitment gaps.
2. Replace Likert scale questionnaires with open form journals to assess balance confidence and health-related quality of life. We received a number of emails from participants indicating that they felt their balance improving and had increased confidence in their daily lives, however this was not reflected on the questionnaires due to high baselines. Having open-ended questions may allow for more valuable perspective and insights.
3. Film the dynamic balance and strength assessments to allow for more accurate qualitative observations regarding performance and progress. At pre, many participants were apprehensive on the Star Excursion Balance Test, had “heavy taps” and did not bend their knees. By mid and post testing a number of participants were coaching themselves and using cues that were often given in the dance classes (i.e. “center your hips over your supporting leg” “use your core” etc.). Having videos would allow us to go back and note how many people were self-coaching and improving their performance quality.

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