Nordic walking improves postural alignment and leads to a more normal gait pattern following 8 weeks of training in older adults

Christopher Dalton

Thesis Supervisor
Dr. Julie Nantel

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School of Human Kinetics
Faculty of Health Sciences
University of Ottawa

Abstract

Background: Declines in gait velocity, stride length, cadence, and postural stability are common with advancing age and have further been linked to heightened fall risk and functional decline. Physical activity can slow or prevent such gait declines in older adults. In young adults, Nordic walking (NW) training has been shown to increase stride length and gait speed, yet has demonstrated inconsistent findings regarding joint loading, with reports of both increases and decreases in this respect. Further, research of this facet has very minimally been examined as it pertains to older adults.

Purpose: The aim of the present study was to determine both the initial effect, and the prolonged effect following an 8-week intervention, of Nordic walking (NW) on older adult gait performance and postural alignment and stability.

Methods: Gait and postural alignment and stability during NW and conventional walking were assessed and compared following an 8-week NW program (2x/week) in 12 healthy older adults (age: 68 ± 6.8 years; 8 female, 4 male). Participants performed six 5m walking trials, 3 with poles and 3 without, followed by two 6 Minute Walk Test (6MWT) trials, one with poles (WP) and the other without (NP). Gait characteristics and trunk measures in the sagittal and frontal planes were quantified using a 6 inertial sensor accelerometry system (APDM, Oregon, USA) as well as an eight camera 3-dimensional motion capture system (Vicon, Oxford, UK) with 2 force platforms (Kistler, Winterthur, Switzerland) embedded within. All variables were assessed using two-way repeated measures ANOVAs to compare NW to conventional walking and before and after the intervention.

Results: When comparing walking WP to NP at initial pre-testing, significantly longer stride length, slower gait speed, and increased double support time were found to coincide with decreases in power generation and absorption at the hip and knee WP. However, following prolonged practice, a longer stride length, faster gait speed, and increased power generation at pre-swing at the hip and power absorption during loading and terminal swing about the knee were found WP post-intervention.

Conclusions: An initial 8-week training period is necessary for novice NW in order to develop technique and to restore gait and postural alignment to more “normal” standards following training. Additionally, since the acquisition of the skill requires proper allocation of attention between two tasks: walking and pole manipulation, NW should be done so in a relatively safe environment, free of distraction and obstacles. Finally, with frail elderly, a longer acquisition period may be necessary since facilitation of movement must first occur.

Keywords: Nordic walking, gait, posture, older adults

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Table of Contents

Chapter I: Introduction

1 Introduction

From 2001 to 2011, the Canadian population experienced a reported 27% increase in the older adult population (≥65), equating approximately 14% of the overall population (Federation of Canadian Municipalities, 2013; Statistics Canada, 2012). With an aging population comes an increasing probability and occurrences of falls, functional decline, and activity restrictions (Rubenstein, 2006; Scheffer et al., 2008; Becker et al., 2013). Functional decline with age has been well documented, with reported changes in spatial-temporal measures, postural alignment, range of motion, strength, and muscle power (Fitzgerald et al., 1983Winter et al., 1990; Judge, Davis, & Õunpuu, 1996; Kerrigan et al., 1998; Balzini et al., 2003). Physical activity has been shown to be effective in falls prevention and has proven effective toward physical function improvements (Gillespie et al., 2003; Kannus et al., 2005).

Nordic walking (NW) is a simple and safe form of fitness walking using specially designed poles (Parkatti et al., 2012). Pole use has demonstrated the potential for enhancing postural stability and alignment as well as having various effects on the loading of the lower extremities during gait (Schwameder et al., 1999; Willson et al., 2001; Hansen et al., 2008; Hagen et al., 2011). Much of the existing literature supports improved physiological function, including: increased oxygen consumption and increased caloric expenditure due to a larger number of muscles during NW relative conventional walking (Rodgers et al., 1995; Porcari et al., 1997; Shim et al., 2013). Primary based on research of young and middle aged adults, research has further shown that NW may result in either a reduction (Willson et al., 2001), no change (Hansen et al., 2008), or an increase (Hagen et al., 2011) in joint loading.

In recent years, Becker et al. (2013) and Figueiredo et al. (2013) examined the effects of NW training in older adults, over a single training session and over 6 weeks of training, respectively. First, Becker et al. (2013) demonstrated an increase in gait speed and stride length, particularly following an unstructured training session. Similarly, Figueiredo et al. (2013) also found an increase in gait speed following 6 weeks of guided training with a frail elderly populations. The results of these studies demonstrate an important distinction, that being that NW possesses various benefits, regardless of the presence of disability. Moreover, Parkatti et al. (2012) examined the horizontal and vertical ground reaction forces (GRF) in two groups of older adults, one of sedentary adults and the second of novice Nordic walkers. They found no differences in GRF following a 9-week NW intervention. Despite this, it is tough to interpret these results as the authos examined the symmetry of gait rather than comparing between the two subject groups. As these studies have largely addressed the spatial-temporal measures and the symmetry of the GRF, more biomechanical analysis is required to ascertain the true effect of NW training on older adult gait.

2 Purpose and Hypotheses

2.1 Purpose

The main purpose of this study is 1) to determine the effect of Nordic pole walking on gait patterns and postural alignment in older adults immediately and 2) to determine the effect following an 8-week training intervention. Hansen et al. (2008) examined whether walking with poles compared to without poles could reduce lower extremity joint loading in experienced NW middle-aged women (mean age=51 yrs.). In particular, these women performed multiple walking trials with and without poles along a 6-metre walkway using motion capture to record the movements. They found that in experienced women, walking poles did not result in change to the ground reaction forces (GRF) throughout the gait cycle and the moments of force. Similarly, Willson et al. (2001) used 3-dimensional motion capture to explore and compare conventional walking to 3 separate NW conditions, finding reduced vertical GRF, vertical knee reaction forces, and knee extensor angular impulse in young, healthy adults.

Although the work by Hansen et al. (2008) and Willson et al. (2001), amongst others, gave some insights towards the beneficial effect of pole walking on gait and posture, current literature fails to demonstrate a complete understanding of the effect of NW poles. Both of the aforementioned studies have only examined single test sessions, but have not provided insight into the role of a guided training intervention. Furthermore, the test sessions by both Hansen et al. (2008) and Willson et al. (2001) examined gait strictly in healthy young and middle-aged adults over a relatively short distance and duration (i.e. 6-metres). However, NW is typically performed for endurance, comprising longer duration activity and performed by individuals of all ages and physical activity levels. Therefore, further research must address NW as it is typically practiced on a daily basis (i.e. longer durations and distances) and must address the different age groups and populations capable of performing the task.

This study aims to better understand the effect of NW on gait patterns and postural stability, particularly following the initial acquisition of the pole technique and following 8-weeks of practice. This was assessed by examining:

1. The spatial-temporal gait parameters, including stride length, gait speed, and cadence as well as single and double support phases.
2. The moments of force and power absorption/generation of the lower extremity joints, including the hip, knee, and ankle.
3. The postural alignment of the trunk towards more normal, upright position

2.2 Hypotheses

Comparing NW to conventional walking as well as comparing before to after an 8-week intervention, the following was hypothesized:

1. Spatial temporal gait parameters including: stride length, gait speed, cadence, and single support time will all increase, while double support time, will decrease with the use of Nordic walking poles compared to without poles and post- intervention compared to pre-intervention.
2. The moments of force and power absorption/generation of the lower extremity joints during Nordic walking will initially increase due to the expected increase in stride length. Further, the moments of force and power absorption/generation will decrease post-intervention following practice and acclimatization to the poling technique.
3. Postural alignment will improve towards a more upright body posture with the use of Nordic walking poles compared to without as well as during post-intervention testing compared to pre-intervention testing.

Chapter II: Review of Literature

1 Canada's Aging Population

It is widely recognized that the Canadian population is aging. In 2011, the Canadian census reported a 27% increase in older adults from 2001-2011, making seniors the fastest growing population in Canada (Federation of Canadian Municipalities, 2013). Further, this proportion, due to increased life expectancy, declining replacement fertility rates, and an aging baby boomer generation, is expected to increase to approximately 25% of the population by 2036 compared to 9.7% in 1982 (Anderson & Hussey, 2000; Statistics Canada, 2012), with growth in all age ranges including 65-74 years, 75-84, and 85+ (Health Canada, 2002). More importantly, both Anderson and Hussey (2000) and Health Canada (2002) reported that the fastest growth is found within the oldest older adults (85+).

1.1 Health-related costs

With an aging population, it is believed that Canada's health care system may be unable to meet the needs of the population due to increased costs and utilization of such services (Canadian Institute for Health Information, 2011). In 2009-2010, 40% of short-term hospital stays for acute care, inpatient mental health, complex continuing care, and rehabilitative care were for those 65 and over.

Furthermore, Anderson and Hussey (2000) report that 40% of health care spending in Canada is for older adults, equalling 4.7 times more than that of younger populations. Cranswick & Dosman (2007) reported that 22% of older adults live in institutions and require primary care due to frailty, a percentage which sharply increases with advancing age (i.e. 65-74 = 9% (men) and 11% (women), 75-84 = 15% (men) and 20% (women), 85+ = 30% (men) and 40%

(women)). Despite these noted concerns, Roos et al. (1998), through trend analysis, and Barros (1998), concluded that this aging population is unlikely to overburden the health care system and health care expenditures. And yet despite this alleviated burden, we must continue to implement ways to minimize or eliminate functional decline.

1.2 Functional decline

Health Canada (2002) reports that the majority of older adults positively perceive their health as “good”, “very good”, or “excellent”. And yet despite this, greater than 25% of older adults are living with a long-term health condition such as arthritis, hypertension, and heart conditions, leading to restrictions in performance of activities of daily living (ADLs) (Health Canada, 2002). It is estimated that 8% of older adults struggle with at least one ADL and that for those 85+, due to advanced age, this percentage increases significantly to 38% and 56% for men and women, respectively. The ability to perform ADLs (e.g. eating and ambulating) and instrumental ADLs (IADLs) (e.g. housework and grocery shopping) determines an individual’s functional status or capacity, of which the inability to perform said tasks equates to functional decline (Kleinpell et al., 2008; Canadian Institute for Health Information, 2011).

According to Kleinpell et al. (2008), advancing age means diminishing physiological function. Decreases and deterioration in muscle strength and mass (Hughes et al., 2001), bone density and mass (Russo et al., 2003), sensory systems (Carter, Kannus, & Khan, 2001), and aerobic capacity (Fleg et al., 2005), amongst others, may potentially occur. With such changes, reductions in physical activity and functional status may contribute to a state of older adult frailty, embodied by musculoskeletal weakness and loss of structure and function.

2 Gait and Posture in Older Adults

2.1 Mobility decline: causes and consequences

Mobility-related disabilities are common in the elderly, where in 2006, 33% of those 65 and over and 44% of those 75 and older, were diagnosed with a mobility-related disability (Statistics Canada, 2007). Chappell and Cooke (2010) suggest that chronic conditions (e.g. cardiovascular disease, stroke, hypertension, arthritis), visual and hearing impairments, and mental health conditions (e.g. depression and dementia), make up such contributors to these disabilities, a statement in which Jagger et al. (2007) further support, stating living without stroke, cognitive impairment, arthritis, and visual impairment, means living without disability. Moreover, in itself, mobility disability is considered an early identifier of disablement towards greater disability, institutionalization, and mortality (Melzer et al., 2005).

With advancing age, mobility-related disabilities along with changes to the musculoskeletal system alter gait patterns and postural stability. Daley & Spinks (2000) suggest that both muscle mass and strength decreases by 30-50% between 30 and 80 years of age, accounting for much of one’s loss in strength, similar to the decline in bone mass accounting for weakened bones and greater susceptibility to injury from incidents such as falls. Furthermore, Daley and Spinks (2000) report altered flexibility with age, suggesting decreased range of motion and increased joint stiffness.

2.2 Posture and postural control in older adults

Posture, in general, is defined as the orientation of the whole body or a single segment relative to a gravitational vector (Winter, 1991). One aspect of posture is postural control, which in general refers to the ability to control and maintain one’s balance. During quiet standing, this simply requires keeping the centre of gravity within their base of support (Hay, 1996). However, contrary to quiet standing, gait initiation requires the initiation of a forward fall, resulting in a forward shift of the centre of gravity (Winter, 1991). This control is directly related to how the motor system regulates the body segments to the vertical direction of the global coordinate system, which changes depending on the action being performed (Winter, 1991). For instance, the centre of gravity is maintained within the base of support during quiet standing, but changes with gait initiation as this trajectory now travels along the medial border of the foot (Winter, 1991). As we age, postural stability and postural control mechanisms have been found to decline (Hageman, Leibowitz, & Blanke, 1995; Røgind et al., 2003; Choy, Brauer, & Nitz, 2003).

Woollacott (1993) stresses the idea that the aging process takes a toll on a person's ability to move independently and maintain balance. The ability to respond efficiently to postural perturbations, such as when walking on uneven terrains, diminishes with age (Woollacott, 1993). Choy, Brauer, and Nitz (2003) support this idea, finding a decrease in postural stability with age, under different visual (i.e. eyes open and eyes closed) and surface (i.e. firm and foam) conditions. When vision was occluded, postural stability was found to decrease by 60 years old, and remained at the same level into the 70s. However, with the introduction of an uneven surface during occluded vision, postural stability diminished at an earlier age (50-59 years) and continued declining with advancing age. Abrahamova & Hlavačka (2008) further assessed age related postural changes during quiet standing using centre of pressure (COP) measurements, finding increased postural instability (i.e. consistently larger COP) with advancing age from junior to middle-aged to seniors. With such studies, we can conclude that there is a clear detriment to postural control as we age and to consider this during ambulation.

Posture may also refer to the alignment of the body and its parts in relation to one another, such that bones, joints, connective tissues, and muscles work to maintain alignment

(Kauffman, 1987). Similar to postural control, postural alignment is modified as part of the aging process, often leading to a more flexed posture (Balzini, 2003). Based on previous research and through the examination of 6 different age groups (from 20s to 70s), younger adults (i.e. 20-29 and 30-39 years) fell within normative ranges in all lumbar spine motions (i.e. flexion, extension, lateral flexion) during static standing. However, with each 20 years, ROM measures significantly decreased away from normative values (Fitzgerald et al., 1983).

Additionally, Sforza et al. (2002) examined the effect of age on specifically cervical spine ROM while seated, in individuals aged 15-45. Adolescents (15-16 years) exhibited larger total ROM compared to young (19-25 years) and middle-aged (31-45 years) adults, but only significantly in the sagittal plane. However, this study only demonstrated changes up to 45 years old making it impossible to draw conclusions regarding older adults (65+). More recently, Simpson et al. (2008) performed a multivariate analysis to determine the effects of age, gender, and degeneration on cervical ROM. Using radiographs from both men and women ranging in age from 15-93 years, they found a significant correlation between age and cervical spine ROM, demonstrating that every 10 years of aging results in a 5° loss in ROM.

Trunk and postural alignment during dynamic tasks such as walking or running are also important to consider. Early research by Thorstensson, Nilsson, and Calrson (1984) found that during level ground walking of healthy young adults, maintenance of a forward inclination of the trunk exists, which varies at different phases of the gait cycle. Specifically, the authors conclude that trunk inclination is the most forward at the end of single support phase and the least forward at the start of double support phase. Leroux, Fung, and Barbeau (2002) took this a step further in recent years, particularly looking to determine how trunk range of motion (i.e. tilt) changed at various treadmill inclines and declines in young/middle-aged adults. With this, they report that forward trunk flexion increased with greater incline (i.e. walking uphill) and decreased with a smaller incline (i.e. walking downhill) relative to level ground gait.

Kasahara et al. (2015) further examined the trunk stability of older adults during a self-paced and self-initiated postural perturbation. First, they found that older adults demonstrate different movement strategies from that of young adults, resulting in decreased displacement of the centre of pressure (COP) and the centre of mass (COM) in older adults. The authors suggest that a lower COM might contribute to postural stability of older adults from the viewpoint of stability of a rigid body (i.e. stiffening); however, this rigidity may contribute to a loss of mobility. Thus older adults might demonstrate a trade-off in stability and mobility during dynamic movements.

The aging process characteristically modifies postural alignment, and in addition to declines in ROM, diminishing muscle strength may contribute to more of a flexed posture (Balzini et al., 2003). Balzini et al. (2003), using a simple occiput-to-wall measure, classified participants as having either a mild, moderate, or severe flexed posture. Of these, those with a severely flexed posture showed significantly less strength in the back extensors and ankle musculature suggesting the strength of such muscles plays a primary role in maintenance of an upright, normal posture. In addition, they suggest that a flexed posture can lead to compensatory mechanics as it pertains to movement, and an abnormal alignment, making the use of “normal” static and dynamic balance strategies more challenging.

2.3 Biomechanics of gait and compensation patterns

Spatial-temporal gait parameters refer to the measured output variables of time and length such as stride length, gait speed, and cadence (Winter, 1991). Further, kinematics refers to the study of motion without concern for the cause of that motion including velocity and acceleration, while kinetics is concerned with such causes of motion including forces, moments of force, and characteristics of that moment such as power (Robertson, 2004). Spatial-temporal, kinematic, and kinetic changes, as they pertain to older adult gait, have been extensively examined and refer to various aspects including stride length, gait speed, cadence, ROM, moments of force, and power generation/absorption of the hip, knee, and ankle joints.

In men aged 20-87 years, Murray et al. (1969) report significant reductions in stride length, gait speed, and cadence within the 3 oldest groups (67-73, 74-80, and 81-87 years) of their study. In addition, Winter et al. (1990) report conflicting findings to Murray et al. (1969) when comparing young adults to older adults screened for their fitness level. They report a reduction in stride length, an increase in double support time, as well as no difference in cadence. To this end, Winter (1991) suggests that due to varying levels of both fitness and degeneration, older adults do not represent a strictly homogenous group. Adding to such contradictions, Judge et al. (1996) compared younger and older adults, finding slower gait speed as well as shorter strides and stance times with older adults.

Prince et al. (1997) reviewed gait kinematics between younger and older adults, reporting older adults tend to maintain slight knee flexion (mean=5.3°) of the swing leg at terminal swing, while younger adults reach near full extension (mean = 0.5°). This was previously documented by Ostrosky et al. (1994), who propose that knee flexion at terminal swing is due to a desire to lower the centre of gravity and decrease quadriceps muscle demand. Prince et al. (1997), also in their review, found changes in knee extension at different phases of the gait cycle, specifically an increase at mid stance of approximately 0.5° per decade and a decrease of 0.5°-0.8° during the swing phase. This may further point to the notion that older adults prefer to maintain knee flexion and a lower centre of gravity.

Additionally, Kerrigan et al. (1998) examined specific limiting impairments in elderly gait, finding that peak hip extension for older adults does not change at different walking speeds. Kerrigan et al. (1998) suggested that these results may be consistent with the notion of contractures of the hip flexors, thus limiting the hip from reaching typical full hip extension. Due to these contractures, a shorter maximal contralateral step length was found. The authors suggested that in order to maintain or lengthen this contralateral step, older adults may adopt a gait compensation pattern whereby they increase their anterior pelvic tilt. This tilt assists with the initiation of the swing of the contralateral leg by tilting the pelvis backwards and allowing for the forward thigh rotation needed for gait progression. Otherwise, Kerrigan and colleagues (1998) suggest hip flexor and lower extremity stretching programs as well as walking more may help in reducing these contractures.

DeVita & Hortobagyi (2000), when comparing age-related gait adaptations between younger and older adults, found a general decrease in ankle ROM, decrease in knee ROM, and increase in hip ROM amongst the older adult population. However, considering hip ROM, Kerrigan et al. (2001) report contradictory results in examining hip extension of elderly fallers, elderly non-fallers, and younger adults. Elderly fallers presented with lower peak hip extensions compared to non-fallers, both of which were significantly lower than the young, healthy subjects, suggesting the presence of hip flexor tightness and contractures and preventing full hip extension during ambulation as opposed to the increases in hip ROM expressed by DeVita & Hortobagyi (2000).

Finally, decreased ankle ROM, more importantly peak ankle plantarflexion, has been consistently reported within older adult populations (Winter, 1991; Judge et al., 1996; Kerrigan et al., 1998; DeVita & Hortobagyi, 2000). Both Winter (1991) and Judge et al. (1996) have suggested that there is an age related decline in ankle plantarflexor strength that contributes to the decrease in ROM, and ultimately affects gait. Kerrigan et al. (1998), however, suggests that plantarflexor strength is sufficiently strong and that instead there is perhaps stiffness in the plantarflexors or co-contraction of the antagonistic dorsiflexors that limits this active ROM.

In terms of kinetics, at terminal stance, Winter et al. (1990) found reductions in the power generation of the plantarflexors, promptly termed an ankle plantarflexor “burst”. This “burst” is considered a main contributor to forward gait progression and is seen as potentially destabilizing to the body. For this reason, Winter suggests that the reduction in power generation may be purposeful as it may be a mechanism aimed at reducing the destabilizing forward momentum cause by this “burst”. Moreover, Winter et al. (1990) report a reduction in power absorption at the knee joint, specifically the quadriceps femoris muscle. During the late stance and early swing phases of gait, this reduction is evident in older compared to younger adults, of which Winter suggests is a typical gait alteration associated with advancing age.

Judge et al. (1996) suggested the reduced plantarflexor power could be a limiting factor in elderly gait. Furthermore, they suggested that to account for this limiting factor in gait, an increase in hip flexor power generation amongst older adults is employed as a compensatory mechanism. A larger concentric contraction of the hip flexors might allow for older adults to more efficiently pull the thigh forward and up, taking the focus off the reduced plantarflexor power. This places greater emphasis on the hip flexors in order to assist with initiating the swing phase of gait and ultimately, forward gait progression. In line with such plantarflexor results, Kerrigan et al. (1998) also found reduced plantarflexor power, but instead suggest it is due to the specific reductions in the concentric action of the calf muscles.

Further, DeVita and Hortobagyi (2000) found significant changes in various kinetic parameters including ankle, knee and hip moments of force and power generation/absorption. With this, the authors suggest that such changes are indicative of a simple redistribution of muscle moments and power generation/absorption that occur with age. Lastly, McGibbon et al. (2001) examined older adult gait, specifically mechanical energy transfer of the lower extremities, finding hip flexor tightness much like Kerrigan et al. (1998), which they considered advantageous to disabled gait. They suggest that when knee and ankle function are reduced, as is well established with advancing age, the energy stored in the hip flexors is released and used as a compensation strategy to progress the leg forward.

In summary, research has demonstrated several alterations to the spatial-temporal parameters of gait as we age, including reduced stride length and gait speed as well as a cadence that varies depending on fitness levels and levels of degeneration. Additionally, with age, older adults have demonstrated a tendency to maintain knee flexion through to terminal swing of gait as well as an increase in knee extension during mid-stance and a decrease during the swing phase. Finally, research has consistently demonstrated a reduction in ankle plantarflexor strength and subsequent power from the plantarflexors during the push-off phase of the gait cycle. As a compensation mechanism, research supports a redistribution of muscle activity such that older adults generate a greater amount of power from the hip flexors, as these muscles are both larger and closer to the centre of mass relative to the plantarflexors and thus aid in gait progression.

Such compensation patterns are ways in which elderly attempt to maintain their stability and steadiness during gait, whereas the inability to do so may result in undesired incidences. Parkatti et al. (2012) suggest that unsteadiness should be cause for concern as an unsteady gait tends to increase a person's fear and potential for falling, leading to decreases in activity and further devastating effects.

3 Falls in Older Adults

3.1 Epidemiology of falls

A fall is defined as "an unintentional change in position resulting in coming to rest on the ground or other lower level" (Tromp et al., 2001, p. 839). Yoshida (2007) reports falls can be caused by intrinsic (e.g. demographic and biological) factors such as age, sex, and medical and physical conditions and extrinsic (e.g. environmental and behavioural) factors such as sedentary behaviour, medication, and inappropriate footwear.

3.2 Fall incidences and consequences

Roughly 30% of community-dwelling older adults fall each year, some on a repeated basis, and some who do so more frequently with advancing age (Alexander et al., 1992; Tinetti & Williams, 1997; Tinetti & Williams, 1998; Tromp et al., 2001; Kannus et al. 2005, Berry & Miller, 2008). The percentage of falls requiring medical attention from serious injuries, including fractures, joint dislocations, lacerations, contusions, and head trauma (Kannus et al., 2005; Tinetti & Williams, 1997), varies. Tinetti and Williams (1998) report 10-15%, Kannus et al. (2005) report 20%, Alexander, Rivara, & Wolf (1992) report 20-30%, Berry and Miller (2008) report 31%, and Tromp et al. (2001) report 40% of falls result in such serious cases of injury. Of this, 30-40% of older adults are subsequently transferred to a nursing home due to their unresolved injuries (Tromp et al., 2001). Additionally, O'Loughlin et al. (1993) report that psychological stresses, namely fear of falling, may result in decreased self-confidence, social withdrawal, and depression, which may further lead to activity restrictions and decreases in mobility and independence.

3.3 Morbidity and mortality from falls

Falls hold an important association with respect to morbidity and mortality in older adults. Although most falls are non-injurious and non-fatal, fall injuries are the main cause of long standing pain, disability, and functional impairment, and remain a leading cause of death of those over 65 (Kannus et al., 2005; Soriano et al., 2007; Berry & Miller, 2008). In terms of morbidity, the prevalence of comorbidities in fallers is higher in older populations, primarily in those aged 75-84 (Vu et al., 2011) and certain types of injuries are associated with high levels of comorbidity. Vu et al. (2011) found those who sustain fractures have the highest prevalence of comorbidities such as osteoporosis, compared to other injuries including: open wounds, superficial injuries, dislocations, sprains, and strains.

Amongst all fall-related injuries, approximately 50% of older adults are discharged from hospital to a nursing home (Shumway-Cook et al., 1997). Fuller (2000) found that of the elderly who sustain a hip fracture, 25% die within the first six months following injury. Fuller (2000) also reports that with increasing age comes a higher mortality rate due to fall-related injuries. In understanding the possibility of morbidity and mortality from falls, falls prevention programs should be viewed as high priority.

3.4 Falls prevention

Falls prevention strategies are important to potentially limit injury and possible death. Current interventions attempt to reduce falls by working from multiple angles. Gillespie et al. (2003) reviewed available fall prevention programs to determine those that are useful. Muscle strengthening and balance retraining, home hazard assessment and modifications for those with a fall history, and withdrawal of psychotropic medications have been beneficial as fall prevention programs. Particularly, exercise requires deeper consideration in research. Kannus et al. (2005) concur, stating that strength and balance training can reduce the risk of fall-related injuries in the elderly because muscle strength, flexibility, balance, coordination, and gait are expected to improve with said training.

4 Effect of Exercise on Older Adults

4.1 Recommendations and benefits of physical activity in older adults

Exercise programs of varying intensity, frequency, and length have been shown to positively impact the physical capacity of older adults, including: strength, endurance, and aerobic capacity. According to Sherrington et al. (2008), exercise is an effective way to prevent functional decline and prevent falls in older adults. It is recommended that older adults perform 150 minutes of moderate or 75 minutes of vigorous intensity exercise weekly, strength training twice weekly, balance and falls prevention training, and minimal sedentary time (World Health Organization, 2010; Canadian Society for Exercise Physiology, 2013).

With the aims of improving strength, balance, flexibility, coordination, and preventing falls, various exercise programs have been examined for their appropriateness and merit towards older adult health. For those older adults with postural hypertension, impairments in muscle strength, ROM, and balance, and those using prescribed medications, Tinetti et al. (1994) used multifaceted exercise interventions as a tool to reduce fall incidences. They concluded that such an intervention has the potential to reduce the fall risk for community-dwelling seniors. Further, Shumway-Cook et al. (1997) used exercise in a similar population to determine its effect on balance and mobility. Each participant received a personalized program and like Tinetti et al. (1994), they concluded that a multidimensional program can improve these measures and reduce the fall rates in community-dwelling older adults.

Additionally, in a group of elderly men at high risk for falls, Rubenstein et al. (2000) analyzed the impact of 3 months of low to moderate intensity exercise on strength, gait, balance, and endurance. The program consisted of: 1) strength training with wrist and ankle weights and resistance bands, 2) endurance training using a cycle ergometer or treadmill, and 3) balance training with balance boards and obstacle courses. The exercise group was able to increase their amount of activity while at the same time experiencing fewer falls per activity, increasing their physical endurance as evidenced by increased 6 minute walk distance, and increasing isokinetic strength and functional measures, all compared to controls. These results demonstrate the important notion that moderate improvements in one's physical capabilities can positively impact independence, even in the presence of physical disability.

As the documentation of exercise in frail older adults is relatively limited, Binder et al. (2002) looked to determine whether intensive multidimensional training is beneficial towards reducing frailty in community-dwelling older adults. At approximately 3 month intervals, exercises involving stretching, flexibility, balance, coordination, and strength, were progressively introduced for successive training phases. The results indicate multidimensional exercise training is beneficial for reducing frailty in older adults as determined by improvements in multiple measured variables including balance, strength, perceived health, and physical functioning. Further, physiological improvements, namely oxygen uptake were also found, indicating improvement in aerobic capacity.

Carter et al. (2001) performed a systematic review and meta-analysis of literature regarding a reduction in falls due to exercise training interventions. Of those evaluated, the authors report that older studies (prior to 1996) were unable to demonstrate that exercise reduced the rates of falls, while more recent studies demonstrate the positive value of exercise in falls prevention. Other studies have also found that fall reductions due to exercise existed, but were not statistically significant. Carter et al. (2001) suggest that multifaceted exercise programs are good, however, this style of intervention makes it difficult to determine if one specific exercise aspect is more beneficial than others. Perhaps, further research investigating standalone exercise programs for falls prevention is required for older adults, which have been minimally examined investigated.

5 Nordic Pole Walking

Nordic walking (NW) is a form of fitness walking that involves the use of specially designed walking poles (Parkatti et al., 2012) and was initially employed as an off-season training program for cross-country skiers. Organizations and promoters of Nordic walking have indicated that such exercise works on many components of health, including: cardiovascular health, joint loading, posture, and strength, both for the upper and lower body. Dr. Klaus Schwanbeck (2012, p. 185) implies that the use of Nordic poles can provide better posture, balance, and stability, and help improve gait. Further, it is a low-impact activity that incorporates approximately 90% or more than 600 of the body’s muscles, compared with 35% for regular walking (Schwanbeck, 2012). This is due to the incorporation of more upper body musculature with NW compared to primarily lower body muscle activation with regular walking (Shim et al., 2013).

Research has demonstrated how pole walking can be beneficial towards numerous conditions including: Parkinson's disease (Van Eijikeren et al., 2008), chronic obstructive pulmonary disease (Breyer et al., 2010), and depression (Suija et al., 2009), amongst others. However, evidence supporting the biomechanical gait and posture advantages of pole use is lacking and requires further examination.

5.1 Physiological and functional effects of Nordic walking

Using treadmill tests set to a specific 6.7km/h pace, Rodgers et al. (1995) compared NW to regular walking, finding increased caloric expenditure and oxygen consumption with NW, despite no increase in rate of perceived exertion (RPE) and only a minimal and insignificant heart rate (HR) increase. These results suggest that 1) incorporating walking poles may add intensity and enhance the physiological benefits of walking and 2) a state of overexertion from NW may be difficult to reach. Further, they also suggest those who are limited in their exercise capacity due to stability issues, such as older adults, should be encouraged to use walking poles regularly. However, as this study did not assess stability, the efficacy of pole use for older adults remains unsubstantiated regarding stability and postural concerns.

Porcari et al. (1997) also compared NW to regular walking using a self-selected pace, which differs from the defined pace in Rodgers et al. (1995) protocol. Despite the use of different speeds between these two studies, Porcari et al. (1997) also found increases in caloric expenditure and oxygen consumption with the NW group, to coincide with increased RPE, which differs from Rodgers et al. (1995) and may simply be explained by the self-selected pace of the treadmill. Based on the findings, the authors suggest that NW may be beneficial particularly towards increasing walking intensity as evidenced by an increase in HR with NW (67% of HR max) compared to regular walking (58% of HR max), specifically for young adults.

Church et al. (2002) and Schiffer et al. (2006) further examined caloric expenditure, oxygen consumption, HR, and lactate concentrations with NW compared to walking and jogging. In line with Rodgers et al. (1995), significant increases with caloric expenditure and oxygen consumption were found without an increase in RPE. With these results, authors indicate that NW may be useful for elderly and those with orthopedic issues due to increased stability and reduced joint loading; although this is not supported. Additionally, Schiffer et al. (2006) specifically found increased lactate concentrations suggesting this is due to the increased use of the upper body musculature.

The improved physiological measures are well substantiated, however, the suggestions that NW is suitable for improved stability in older adults is unsupported by research and requires further examination, particularly biomechanical, to truly substantiate these claims.

5.2 Biomechanics of Nordic walking

Existing literature has largely examined the biomechanical effects of NW on gait patterns following a single test session, mainly in young or middle-aged adults. However, as NW is primarily an endurance activity, assessment over a longer duration would appear necessary as well as with various age groups and even special populations. Willson et al. (2001) compared gait patterns from conventional walking to NW, finding a faster gait speed and longer stride length with young, healthy, novice Nordic walkers. Further, Hansen et al. (2008), in studying a middle-aged population of female NW instructors (mean age = 51 yrs.), did not find any significant change in gait speed between with and without pole conditions. Unfortunately, these studies do not lend answers to the effect of pole walking on older adult gait. More recently, Becker et al. (2013) examined the effect of single session structured (i.e. constant instruction/ feedback during session) and unstructured (i.e. minimal instruction at start of session) NW training on older adult gait (mean age = 84.5 yrs.). Similar to Hansen et al. (2008), Becker et al. (2013) found no significant changes in gait speed and stride length with structured NW training. However, dissimilar from Hansen et al. (2008), results of the unstructured training indicated a longer stride length and faster gait speed, prompting the authors to suggest that NW training has the potential to promote a normal gait pattern.

NW has been touted as a form of physical activity that helps to reduce lower extremity joint loading, an idea in which early research has supported. Schwameder et al. (1999) assessed downhill walking with hiking poles to analyze external (i.e. ground reaction forces (GRF), knee joint forces, knee joint moments) and internal (i.e. shear and compression forces) knee joint loading. Use of hiking poles resulted in reduced GRF and knee joint moments as well as shear and compression forces to specific tendons (i.e. patellofemoral and quadriceps tendons) of the knee, which were analysed using calculations from a two-dimensional knee joint model. However, with assessment of solely downhill walking, the reduced knee joint loading may be a result of the forward posture associated with such activity as opposed to the poles and further may not be transferrable to NW due to a different design and technique with hiking compared to NW poles. Willson et al. (2001) also examined various kinetic measures, finding reduced vertical GRF, vertical knee reaction forces, and knee extensor angular impulse with poles. However, with this study, drawing valid conclusions is challenging due to inconsistent reporting of data including reporting ankle impulses only at toe-off and not heel contact and knee and hip impulses only at heel contact without regard for toe-off or mid-stance. More recent research has begun opposing this notion, suggesting the idea of reduced joint loading may not fully be the case during NW gait.

Hansen et al. (2008) looked to determine whether NW reduces joint loading of the lower extremities, specifically the GRF and moments, and from this determine if poles are a useful tool for rehabilitation of lower extremity joint conditions. The authors found no significant change in moments, apart from a 25% increase in plantarflexor moment, or GRF at either phase of the gait cycle (i.e. heel contact or push-off). The authors appropriately caution use of poles in rehabilitation, however, it is difficult to generalize these results to a larger population as this study only assessed middle-aged women, without concern for others including males, different age groups, or those with joint conditions.

Stief et al. (2008) further compared experienced male Nordic walkers to conventional walking (and running). They found significant differences in lower extremity ROM, particularly with hip flexion, knee extension, and ankle plantarflexion with NW. They also report higher braking and propulsive forces and higher knee extensor and abduction moments with NW compared to walking as well as similar GRF between the two conditions. Additionally, there was a trend towards significance with a smaller max peak force at push-off with poles, similar to that found by Willson et al. (2001). In this particular study, this may be due to increases in hip ROM and stride length with poles. And yet despite all of this data, questions remain as this study focuses solely on young males, without regard for other populations, including older adults.

Additionally, more recent research by Hagen et al. (2011) compared joint loading parameters of NW across different speeds as well as to walking and running, ultimately in an attempt to estimate upper and lower extremity injury risk with NW. Concurring with Stief et al. (2008), Hagen et al. (2011) also found increases in peak vertical GRF at heel contact as well as smaller GRF at push-off at both 5 and 7 km/h. Higher joint loading rate were also found at heel contact at both 5 and 7 km/h during NW, with authors suggesting the increase may be due to increases in stride length and ankle dorsiflexion with poles. To estimate injury risk, the authors compared NW to running, finding 30% higher vertical GRF and 50% higher loading for running and ultimately recommend NW as an appropriate low impact activity.

Furthermore, research has largely focused on young and middle-aged adults, without regard for older adult populations. Koizumi et al. (2011) examined internal joint loading, meaning compression and shear forces, during level ground walking and stair climbing in 5 experienced older adult Nordic walkers. Primarily attributed to the force absorbed by the poles, significant reductions were found at L4 (shear), L5 (shear), hips (compression and shear), and knees (compression and shear) with level ground walking as well as at L1 (shear), L3 (shear), L4 (shear), hips (compression), and knees (shear) with stair climbing. And yet despite this older adult study, 5 subjects is relatively small to demonstrate power in order to generalize this to the broader population and the inclusion of external variables (e.g. GRF, moments, and powers) may provide greater insight into the biomechanics of older adult NW.

Along with Koizumi et al. (2011), recent research on young adults by Jensen et al. (2011) found that with increased pole force there is no change in either the vertical GRF or peak knee compression force during the first half of stance. But similar to earlier research, the second half of stance (i.e. push-off) resulted in a small, but significant decrease in GRF. Despite this small reduction, the authors still suggest that pole use does not reduce compressive joint loading, but may be interesting to examine in other populations. Also, Shim et al. (2013) demonstrated small, but insignificant differences in lower extremity muscle activation with poles compared to without. However, significance in much of the upper body musculature was found, which confirms previous claims made by Dr. Schwanbeck (2012).

More recently, NW appears to have garnered interest from more of a training perspective as opposed to that of single testing sessions. Parkatti et al. (2012) employed a 9-week training program in 23 older adults and compared them to 14 sedentary controls in order to determine both the efficacy of pole use in improving functional capacity (e.g. arm curls, chair stands, etc.) and their effect on gait. With improved mobility, flexibility, and strength in the NW group compared to controls, NW may be helpful towards improving function. Biomechanically, however, no differences were found in vertical and horizontal GRF of the braking and propulsive phases at normal and fast paces, when comparing left and right foots strikes suggesting minimal to no reported biomechanical benefit of pole use. One major limitation of this study was that the NW group was compared to a sedentary group, whereas more valid conclusions may have been generated had they compared NW to a conventional walking group. Similar findings were reported by Takeshima et al. (2013) who assessed the effects of NW compared to conventional walking and resistance band training on the functionality and static and dynamic balance of older adults. All exercise groups improved in functional capacity, however, like previous research (Parkatti et al., 2012), NW demonstrated the greatest change in a variety of functional measures (e.g. arm curls, chair stands, functional reach, etc.). This may be due to NW encompassing four main components of training (i.e. flexibility, strength, cardiovascular, and balance) as outlined by the American College of Sports Medicine (1998), thus suggesting sufficient physical benefits of NW. Further, like Parkatti et al. (2012), Takeshima et al. (2013) also found no biomechanical benefit, particularly in terms of static and dynamic balance, although this may simply be due to poorer initial balance of this particular group.

Finally, Figueiredo et al. (2013) completed 6-weeks of training with two separate groups, one performing NW and the second performing conventional walking. Defined by distance travelled with the 6MWT, the authors report an improvement of 45m and 41m for NW and conventional walking, respectively. This coincides with previously reported findings towards improved functionality in older adults (Parkatti et al., 2012). However, dissimilar from Parkatti et al. (2012), NW training for healthy older adults revealed significant gait changes, namely an increase in gait speed of 0.14m/s, indicating a mild biomechanical effect of NW on older adult gait.

In summary, research has clearly demonstrated the physiological benefits of NW including increased caloric expenditure and oxygen consumption, with littleto no increase in heart rate. Moreover, in terms of a biomechanical assessment of NW gait, the majority of research has focused on young and middle aged adults, with little regard for older adult populations. In these studies on young adults, consistent findings of increased gait speed and stride length have been reported, however, mixed findings exist regarding lower extremity joint kinetics. Research supports all possible outcomes including a reduction in joint loading (Willson et al., 2001), no change in joint loading (Hansen et al., 2008) as well as increases (Hagen et al., 2011), lending to the idea that further research is required on this topic. In the few studies that have focused on older adults, the majority of studies have solely investigated spatial-temporal parameters, finding similar increases in gait speed and stride length. Data related to lower extremity joint loading is relatively non-existent, with only Parkatti et al. (2012) examine GRF, albeit from an asymmetry point of view.

To the best of our knowledge, investigation of postural alignment during NW, regardless of the population, has yet to be examined. Further, the majority of research reports on findings from young and middle aged adults, leaving gaps as to the effects of poles on elderly individuals.

Thus, studies based on examining the biomechanics of both gait and posture in older adults, and eventually those with orthopedic or neurological conditions, is of necessity.

Chapter III: Research Article

Nordic walking improves postural alignment and leads to a more normal gait pattern following 8 weeks of training in older adults

Christopher Dalton[1] and Julie Nantel[1]

[1]School of Human Kinetics, University of Ottawa, Ottawa, Canada

Correspondence concerning this article should be addressed to:
Julie Nantel
École des sciences de l'activité physique / School of Human Kinetics
Faculté des sciences de la santé / Faculty of Health Sciences
Université d'Ottawa / University of Ottawa
125 rue Université, MNT 353, K1N 6N5
jnantel@uottawa.ca
613-562-5800 ext. 4025

Abstract

The aim of this study was to investigate the impact of an 8-week Nordic walking (NW) intervention on older adult gait patterns and postural alignment. Twelve healthy older adults aged 60-80 years (8 female, 4 male) participated, all performing two 6 minute walk tests (1 with poles (WP), 1 without poles (NP)) and six 5m walk trials (3 WP, 3 NP) at pre- and post-testing. Gait and postural variables were compared between poling conditions (i.e. WP to NP) as well as prior to and following the intervention. With 8 weeks of practice, pole use resulted in various gait changes including: longer stride, faster gait, and increased power generation at the hip and power absorption at the knee. We conclude that an initial 8-week training period is necessary for novice NW in order to perfect technique and to promote a more natural, normal pattern following training.

Keywords: Nordic walking, gait, posture, older adults

1 Introduction

Between 2001 and 2011, Canada experienced a 27% increase in the population aged 65 years and older (Federation of Canadian Municipalities, 2013), equalling roughly 14% of the total Canadian population, which is estimated to increase to nearly 25% by 2036 (Statistics Canada, 2012). With advancing age comes an increased likelihood and prevalence of fall incidences, many of which lead to functional decline and physical activity restrictions (Rubenstein, 2006; Scheffer et al., 2008; Becker et al., 2013). However, physical activity has proven effective in falls prevention and has demonstrated the potential for improved muscle strength, postural balance, flexibility, and gait (Gillespie et al. 2003; Kannus et al., 2005).

Nordic walking (NW) has gained popularity in recent years due to its potential benefits towards physical health and fitness. NW involves the use of specially designed poles, which could enhance postural stability, postural alignment, and reduce the loads placed on the lower extremities during gait (Willson et al., 2001; Hansen et al. 2008; Hagen et al., 2011). Current research in NW supports benefits including increased oxygen consumption and increased caloric expenditure due to greater number of muscles involved relative to conventional walking (Rodgers et al., 1995; Porcari et al., 1997; Shim et al.. 2013). Also, existing evidence, primarily obtained from young and middle aged adults over single test sessions, suggests that NW may result in anything from a significant reduction in joint loading (Willson et al., 2001) to no difference (Hansen et al., 2008) to a significant increase (Hagen et al., 2011).

More recently, Figueiredo et al. (2013) and Becker et al. (2013) investigated the effect of NW in older adults and have shown promising, yet small effects regarding gait patterns following training when walking with poles (WP). In two groups of healthy older adults undergoing either structured or unstructured training, Becker et al. (2013) demonstrated that unstructured training, specifically, results in both increased gait velocity and stride length. Figueiredo et al. (2013) concur with these results finding increased gait speed following 6 weeks of training with frail older adults. These results suggest that regardless of the presence of frailty or disability, NW may present beneficial effects towards older adult gait patterns. However, when looking at joint loading during NW, very little evidence exists in older adult populations. Parkatti et al. (2012) have examined the vertical and horizontal ground reaction forces (GRF) in older adults when walking WP as well as in a sedentary older adult group. They reported no differences in GRF following 9 weeks of training, however, it is not possible to ascertain an understanding of the lower extremity joint loading as the GRF data was rather used to interpret the lower extremity asymmetry within the NW and sedentary groups.

Due to the above studies largely addressing spatial-temporal gait characteristics and addressing only the symmetry of the GRF, more in depth biomechanical analyses as well as assessment of the effect of NW training should be considered in order to better understand the impact of NW on gait in older adults. The aim of this study was two-fold. First, we wish to determine the initial effect of NW poles on various spatial-temporal (i.e. gait velocity, stride length, cadence, and double and single support phases) and kinetic (i.e. lower extremity joint power generation and absorption) parameters as well as on postural alignment in older adults. And second, we wish to investigate the effect of an 8 week intervention on these same gait and postural characteristics in older adults.

2 Methods

2.1 Participants

A sample of seventeen healthy older adults (mean age: 68 ± 6.8 years, 12 female, 5 male) were initially included in this study. Due to an inability to complete the required Nordic walking intervention, 5 participants dropped out, resulting in a total of 12 participants (mean age: 68 ± 6.4 year, 8 female, 4 male) for data analysis. Dropouts occurred for two specific reasons: 1) a medical condition/injury or 2) a family emergency, as opposed to due to the activity itself. Of these 12 individuals, 2 report engaging in vigorous intensity physical activity (e.g. jogging/running) on a weekly basis, 7 in moderate intensity activity (e.g. bicycling, weight training), and 3 in light intensity activity (e.g. casual walking). All participants were community-dwelling older adults, recruited from a local area walking group and through word of mouth and were screened for study eligibility. Inclusion criteria included: 55-80 years of age, novice to Nordic walking (NW), with no neurological conditions (e.g. Parkinson's disease), cognitive impairments, or cardiac conditions, as well as no previous injury or surgery affecting gait and upper extremity range of motion (ROM), all of which were assessed using various questionnaires (Appendix A-D). As the study was comprised of mainly walking tasks, participants who were unable to walk unaided (i.e. without a cane or walker) were also excluded from the study. The study was approved by the University of Ottawa's institutional review board and each participant provided their written informed consent prior to study commencement.

2.2 Nordic Walking Instruction

Each participant was given a set of Nordic walking poles provided by Nordixx Canada and instructed to adjust the poles to an optimal length relative to their height, corresponding to approximately 65% of body height according to Nordixx Canada guidelines. Instructions were as follows: 1) stand tall, 2) place the pole tip in front of the toes, 3) place the elbow and forearm next to the body, and 4) lengthen the poles so the elbow forms a 90° angle. Poles were then securely tightened and boot tips were appropriately angled backward.

Following pole setup, poling instructions were provided using 4 basic steps in order to minimize the amount of information provided and to ensure complete understanding of technique. These steps are as follows:

Step 1: Participants placed the poles behind the back and stood upright with the chest tall and the shoulders relaxed.

Step 2: Participants placed the pole tips behind them with their arms hanging at their sides and hands open, and began walking slowly with minimal arm swing for approximately 100 metres with the poles simply dragging on the ground behind them.

Step 3: Then, participants were instructed to walk faster, allowing for a natural reciprocal arm-leg swing to occur. Participants were asked to visualize bringing their arm up as if they were to shake hands with someone.

Step 4: Finally, as the arm swung forward, participants gently grasped the handles and applied a force against the ground. With each arm swing, the poles are now lifted slightly off the ground and firmly planted with each subsequent stride to help propel the body forward.

During this time, any questions were addressed and continuous feedback regarding form was provided by a certified Nordic pole walking instructor (C.D.). After instruction, participants practiced walking with the poles for about 30 minutes or until they expressed a readiness to begin the testing protocol.

2.3 Tasks and Training Intervention

Specific anthropometric measurements (i.e. height, weight, inter-Anterior Superior Iliac Spine (ASIS) distance, left and right leg lengths, knee widths, ankle widths, shoulder offsets, elbow width, wrist widths, and hand thicknesses) (Appendix E) were performed to aid in the 3-dimensional reconstruction of each trial with the Vicon full body plug-in gait model.

Both pre-intervention and post-intervention testing involved completion of two trials of a 6 Minute Walk Test (6MWT) at a comfortable self-selected speed, along a 25-metre walkway, once with poles and once without poles. Following this, each participant was asked to perform 6 walking trials, three WP and three NP, along a 5-metre walkway with two force platforms inset within it, in order to quantify both gait kinematics and kinetics. WP trials and NP trials for both the 6MWT and the 5-metre walking trials were performed in a randomized order to control for order effect.

Between pre- and post-testing, participants completed an independent 8-week NW intervention, twice per week for one hour each session. A minimum of 12 out of 16 sessions was required for data inclusion, which was accounted for through physical activity logs (Appendix F) to be completed by each participant following each session. Each session included: 1) a 5-10 minute warm-up involving dynamic movements (e.g. leg swings, pole kayaking (See Appendix F)), 2) 45 minutes of NW, and 3) a 5-10 minute cool down involving static stretches (See Appendix F).

2.4 Data Collection and Analysis

Postural alignment and spatial-temporal gait characteristics were quantified using an APDM accelerometry system (APDM, Oregon, USA) collecting at 128 Hz and comprised of 6 monitors placed on the wrists, ankles, lumbar spine (L5), and trunk. Calculated through APDM algorithms, spatial-temporal measures (i.e. stride length, gait speed, cadence, double support time, and single support time), trunk ROM, and peak trunk velocities in all 3 planes were extracted for each trial. Values for all test variables were collected over 3 trials and averaged for statistical analysis. Motion was also recorded using a reflective infrared motion capture system with eight 3-dimensional cameras (Vicon, Oxford, UK) collecting at 100 Hz along with 2 Kistler

(Kistler, Winterthur, Switzerland) force platforms embedded in the walkway, each collecting at 1000 Hz. Vicon was used specifically to quantify postural alignment, spatial-temporal, kinematic and kinetic gait characteristics. Thirty-nine retro reflective markers (14mm) were placed on specific anatomical landmarks according to a full body plug-in gait model (Vicon, Oxford, UK) (Figure 1). Analog data was filtered using a zero lag fourth-order Butterworth filter with a cut-off frequency of 10 Hz. Marker trajectories were filtered using a Woltring filtering routine with a 15mm predicted MSE value.

Spatial-temporal characteristics were obtained using Vicon Polygon (Vicon, Oxford, UK). Postural alignment, defined as the range of motion of the trunk, in the sagittal and frontal planes were calculated using the position of the markers placed at C7 and a virtual marker at the middle point between the right and left Posterior Superior Iliac Spine (PSIS) markers. Finally, peak ankle, knee, and hip muscle power, were quantified for each trial using data collected from the 2 Kistler (Kistler, Winterthur, Switzerland) force platforms. Each trial was exported as an ASCII file and using macro functions in Microsoft Excel, peak power and moment of force values were extract. Based on percentages previously reported by Winter (1991) as to when each peak (e.g. A1, A2, K1, K2, etc.) occurs during a single gait cycle, each macro function was written to specifically extract these variables.

List of Operation Definitions

1. *Stride Length:* Distance covered in an average step measured from the heel strike of one foot to the next heel strike of the same foot (or toe-off to toe-off)
2. *Gait Speed:* Pace at which an individual walks between two points
3. *Cadence:* The rate of walking, measured as the number of steps per minute

4. *Single Support Time:* Phase of the gait cycle in which the mass of the body is supported by only one lower limb
5. *Double Support Time:* Phase of the gait cycle in which both feet are on the ground.
6. *A1 Ankle Power Absorption:* A region of negative power during mid-stance of the gait cycle, resulting in eccentric activity of the ankle plantarflexors (i.e. calf muscles)
7. *A2 Ankle Power Generation:* A region of positive power at pre-swing of the gait cycle, resulting in concentric activity of ankle plantarflexors
8. *K1 Knee Power Absorption:* A region of negative power during the loading response of the gait cycle, resulting in eccentric activity of the knee extensors (i.e. quadriceps)
9. *K2 Knee Power Generation:* A region of positive power during mid-stance of the gait cycle, resulting in concentric activity of the knee extensors
10. *K3 Knee Power Absorption:* A region of negative power at pre-swing of the gait cycle, resulting in eccentric activity of the knee extensors, specifically the rectus femoris
11. *K4 Knee Power Absorption:* A region of negative power at terminal swing of the gait cycle, resulting in eccentric activity of the knee flexors (i.e. hamstrings)
12. *H1 Knee Power Generation:* A region of positive power during the loading response of the gait cycle, resulting in concentric activity of the hip extensors (i.e. glutes)
13. *H2 Knee Power Absorption:* A region of negative power during mid-stance of the gait cycle, resulting in eccentric activity of the hip flexor musculature
14. *H3 Knee Power Generation:* A region of positive power at pre-swing of the gait cycle, resulting in concentric activity of the hip flexor musculature

15. *Moment of Force:* Defined as the product of the distance from one point to the point of an applied force acting on a body. As per power generation and absorption, moments of force correspond to the various stages of the gait cycle.
16. *Sagittal Trunk Range of Motion (Alignment):* Defines the movement of the trunk in the anterior-posterior direction (i.e. flexion-extension)
17. *Frontal Trunk Range of Motion (Alignment):* Defines the movement of the trunk in the medial-lateral direction (i.e. side-to-side)
18. *Horizontal Trunk Range of Motion (Alignment):* Defines the movement of the trunk in terms of rotation

2.5 Statistics

Group means were assessed for normality using Shapiro-Wilks test for normality. Spatial-temporal, kinematic, and kinetic measures were compared between pole conditions (WP vs. NP) and between time points (pre- and post-intervention) using Two-Way Repeated Measures (RM) ANOVAs to account for main and interaction effects between conditions and time points. Statistical level of significance was set at $P < 0.05$. Holm-Sidak pairwise multiple comparison procedures were performed when necessary.

3 Results

Statistical analysis of pre-testing involved assessment of 17 individuals, however, following the training program, only 12 participants were included in the final analysis. Despite the dropouts, the results of 17 subjects have been included as a subsection to demonstrate that even with the loss of 5 participants throughout the entirety of the study, statistical power was not lost. A second section follows demonstrated the statistical results of the 12 subjects who completed both pre- and post-testing.

3.1 Spatial-Temporal Gait Analysis

Means and standard deviations for the following parameters are presented in Table 1.

3.1.1 Stride Length

Paired t-tests for pre-test data (n=17) revealed significantly longer stride lengths with poles (WP) compared to no poles (NP), both when assessed over a longer time period (6MWT) (P <0.001) and over a shorter duration (~5s) (P <0.01).

A two-way repeated measures (RM) ANOVA for the pre-post assessment (n=12) of the 6MWT indicated a significant main effect for pole condition (F(1,11) = 31.009, P <0.001). With the 5m walk trials, a two-way RM ANOVA also indicated a significant main effect for pole condition (F(1,11) = 11.414, P = 0.006). Regardless of walking duration, stride length was found to be significantly longer WP compared to NP both before and following the training period.

3.1.2 Gait Speed

Paired t-tests for pre-test data revealed significantly slower gait speeds WP compared to NP, both when assessed with the 6MWT (P <0.001) and with 5m walk trials (P <0.05).

A two-way RM ANOVA for the pre-post assessment (n=12) of the 6MWT revealed a significant main effect for pole condition, which was superseded by a time-pole interaction effect (F(1,11) = 12.957, P = 0.001). Holm-Sidak post hoc procedures showed a significantly slower gait speed WP compared to NP during pre-testing (P <0.001) as well as a strong trend towards an increase in gait speed WP during post-testing compared to pre-testing (P = 0.058). With the 5m walk trials, a two-way RM ANOVA indicated a main effect for time (F(1,11) = 6.932, P = 0.023), indicating a faster gait speed during post-testing compared to pre-testing, both with and without poles.

3.1.3 Cadence

Paired t-tests for pre-test data revealed significantly smaller cadence WP compared to NP, both when assessed with the 6MWT (P <0.001) and with the 5m walk trials (P <0.001).

A two-way RM ANOVA for the pre-post assessment (n=12) of the 6MWT revealed a significant main effect for pole condition, which was superseded by a time-pole interaction effect (F(1,11) = 16.311, P = 0.002). Holm-Sidak pairwise multiple comparison procedures showed a smaller cadence WP compared to NP during pre-testing (P< 0.001) and post-testing (P = 0.001), and a larger cadence WP during post-testing compared to pre-testing (P = 0.021). The 5m walk trials demonstrated similar results in which a two-way RM ANOVA indicated main effects for time and for pole condition, which were both superseded by a time-pole interaction effect (F(1,11) = 15.758, P = 0.002). Holm-Sidak post hoc analysis exhibited a smaller cadence WP compared to NP during pre-testing (P <0.001) and post-testing (P = 0.005) as well as a larger cadence WP during post-testing compared to pre-testing (P <0.001).

3.1.4 Double Support Time

Paired t-tests for pre-test data revealed significantly longer double support time WP compared to NP, both when assessed with the 6MWT (P <0.001) and with 5m walks (P <0.01).

A two-way RM ANOVA for pre-post assessment (n=12) of the 6MWT revealed a significant main effect for pole condition, which was superseded by a time-pole interaction effect (F(1,11) = 8.664, P = 0.013). Holm-Sidak post hoc analysis revealed a longer double support time WP during pre-testing (P <0.001). A two-way RM ANOVA for the 5m walk trials indicated significant main effects for time (F(1,11) = 7.485, P = 0.019) and for pole condition (F(1,11) = 5.009, P = 0.046). Double support time was significantly longer WP compared to NP (pre- and post-) and was shorter during post-testing compared to pre-testing (WP and NP).

3.1.5 Single Support Time

Single support time was only assessed with the 5m walk trials. Paired t-tests for pre-test data revealed a significantly longer single support time WP compared to NP ($P < 0.001$).

A two-way RM ANOVA for pre-post assessment ($n=12$) of the 5m walk trials indicated main effects for both time and for pole condition, which were superseded by a time-pole interaction effect ($F(1,11) = 12.692$, $P = 0.005$). Holm-Sidak post hoc analysis demonstrated a longer single support time WP compared to NP during pre-testing ($P < 0.001$) and post-testing ($P < 0.001$) as well as a shorter single support time WP during post-testing compared to pre-testing ($P < 0.001$).

3.2 Lower Extremity Joint Peak Power Analysis

Means and standard deviations for the following parameters are presented in Table 2.

3.2.1 Hip Power Generation/Absorption

Representative peak hip power profiles, both WP and NP and pre- and post-intervention, are presented in Figure 2.

H1 (Heel contact/loading response):

Paired t-tests for pre-test data revealed a significantly smaller peak hip power generation WP compared to NP, due to the concentric contractions of the hip extensors (e.g. glutes and hamstrings) for H1 during the loading phase ($P < 0.05$).

A two-way RM ANOVA of pre-post assessment ($n=12$) indicated a main effect for pole condition ($F(1,11) = 10.614$, $P = 0.008$). Peak hip power generation by the hip extensors during the loading response was significantly smaller WP compared to NP before and after the intervention. No difference was found for time.

H2 (Mid-stance):

No statistically significant change was found for peak hip power absorption by the eccentric activity of the hip flexors at H2.

H3 (Pre swing):

Paired t-tests for pre-test data revealed a significantly smaller peak hip power generation WP compared to NP, due to the concentric contractions of the hip flexors for H3 or “pull-off” of the gait cycle ($P < 0.01$).

A two-way RM ANOVA for pre-post assessment ($n=12$) indicated main effects for both time ($F(1,11) = 6.272$, $P = 0.029$) and pole condition ($F(1,11) = 7.003$, $P = 0.023$). Peak hip power generation by the hip flexors at H3 was significantly smaller WP compared to NP (pre- and post-) as well as greater during post-testing compared to pre-testing (WP and NP).

3.2.2 Knee Power Generation/Absorption

Knee power profiles, both WP and NP and pre- and post-intervention, are presented in Figure 3.

K1 (Heel contact/loading response):

Paired t-tests for pre-test data revealed a significantly lower peak knee power absorption WP compared to NP, due to the eccentric activity of the knee extensors (i.e. quadriceps) for K1 during the loading response ($P < 0.05$).

A two-way RM ANOVA for pre-post assessment ($n=12$) indicated a main effect for time ($F(1,11) = 7.929$, $P = 0.017$). Peak knee power absorption due to the quadriceps was significantly greater during post-testing compared to pre-testing, both WP and NP. No difference was found for pole condition.

K2 (Mid-stance):

No statistically significant change was found for peak knee power generation by the concentric activity of the knee extensors for K2.

K3 (Pre swing):

Paired t-tests for pre-test data revealed a significantly lower peak knee power absorption WP compared to NP, due to the eccentric contraction of the knee extensors, primarily the rectus femoris for K3 (P <0.001).

A two-way RM ANOVA for pre-post assessment (n=12) indicated a main effect for pole condition (F(1,11) = 12.656, P = 0.004). Peak knee power absorption by the rectus femoris was significantly lower WP compared to NP during both pre- and post-testing. No difference was found for time.

K4 (Terminal swing):

Paired t-tests for pre-test data revealed a significantly lower peak knee power absorption WP compared to NP, due to the eccentric contractions of the knee flexors (i.e. hamstrings) for K4 terminal swing (P <0.001).

A two-way RM ANOVA for pre-post assessment (n=12) indicated a significant main effect for pole condition, which was superseded by a time-pole interaction effect (F(1,11) = 12.938, P = 0.004). Holm-Sidak post hoc analysis revealed lower peak knee power absorption by the hamstrings WP compared to NP as well as a larger peak knee power absorption during post-testing WP compared to pre-testing WP.

3.2.3 Ankle Power Generation/Absorption

No statistically significant change was found for peak ankle power absorption for A1 (mid-/terminal stance) or for peak knee power generation for A2 (pre swing) by the ankle plantarflexors (i.e. triceps surae).

3.3 Lower Extremity Joint Moments of Force

Means and standard deviations for the following parameters are presented in Table 3.

3.3.1 Hip Moments of Force

H1 (Heel contact/loading response):

Paired t-tests for pre-test on data of the initial 17 subjects revealed a significantly smaller moment of force about the hip WP compared to NP, due to the concentric activity of the hip extensors for H1 ($P < 0.05$).

A two-way RM ANOVAs did not reveal any statistically significant changed either WP compared to NP or from pre-testing to post-testing.

H2 (Mid-stance):

No statistically significant change was found for the moment of force by the eccentric activity of the hip flexors for H2.

H3 (Pre swing):

Paired t-tests for pre-test on data of the initial 17 subjects revealed a significantly smaller moment of force about the hip WP compared to NP, due to the concentric activity of the hip flexors for H3 ($P < 0.05$).

A two-way RM ANOVA for pre-post assessment (n=12) demonstrated a main effect for pole condition ($F(1,11) = 4.676$, $P = 0.05$). This hip moment of force was found to be significantly smaller WP compared to NP, both before and following the intervention.

3.3.2 Knee Moments of Force

K1 (Heel contact/loading response):

Paired t-tests for pre-test data revealed a significantly smaller moment of force about the knee WP compared to NP, due to the eccentric activity of the knee extensors for K1 ($P < 0.001$).

A two-way RM ANOVA for pre-post assessment (n=12) indicated a significant time-pole interaction effect ($F(1,11) = 7.434$, $P = 0.02$). Holm-Sidak post hoc analysis revealed a smaller moment of force about the knee joint WP compared to NP during pre-testing only ($P < 0.001$) and a greater moment of force during post-testing WP compared to pre-testing WP ($P = 0.002$).

K2 (Mid-stance):

Paired t-tests for pre-test on data of the initial 17 subjects revealed a significantly smaller moment of force about the knee WP compared to NP, due to the concentric activity of the knee extensors for K2 ($P < 0.01$).

A two-way RM ANOVA revealed only a trend towards a time-pole interaction effect ($P = 0.062$), but otherwise did not reveal any statistically significant change either WP compared to NP or from pre-testing to post-testing.

K3 (Pre swing):

No statistically significant change was found for the moment of force by the eccentric activity of the knee extensors for K3.

K4 (Terminal swing):

Paired t-tests for pre-test data revealed a significantly smaller moment of force about the knee WP compared to NP, due to the eccentric activity of the knee flexors for K4 ($P < 0.001$).

A two-way RM ANOVA for pre-post assessment (n=12) indicated a significant time-pole interaction effect ($F(1,11) = 9.187$, $P = 0.01$). Holm-Sidak post hoc tests indicated a smaller moment of force about the knee joint WP compared to NP during pre-testing only ($P < 0.001$) and a greater moment of force during post-testing WP compared to pre-testing WP ($P = 0.008$).

3.3.3 Ankle Moment of Force

No statistically significant change was found for the moments of force for A1 (mid-/terminal stance) or for A2 (pre swing) due to the eccentric and concentric activity of the ankle plantarflexors (i.e. triceps surae).

3.4 Postural (Trunk) Analysis

Means and standard deviations for trunk range of motion are presented in Table 4.

3.4.1 Trunk Range of Motion (ROM)

Paired t-tests for pre-test data did not reveal any statistical significance for trunk ROM in any of the 3 planes of motion, either when assessed over a longer time period or over a shorter duration.

A two-way RM ANOVA for pre-post assessment (n=12) did not reveal any statistical significance for trunk ROM in any of the 3 planes of motion when assessed over a longer time period. However, when assessed over a shorter walking duration, a two-way RM ANOVA for trunk ROM in the anterior-posterior (AP) direction indicated a significant main effect for pole condition (F(1,11) = 10.832, P = 0.007). Trunk ROM in the AP was significantly smaller WP compared to NP. No difference was found for time. No significant change was found for trunk ROM in the medial-lateral (ML) direction.

3.4.2 Trunk Velocity

No statistically significant change was found for trunk velocity in any of the 3 planes of motion.

4 Discussion

The present study determined the effectiveness of Nordic walking poles towards improving the gait patterns, namely spatial-temporal and kinetic measures, and the postural alignment of healthy older adults. Moreover, we assessed the effect of an independent 8-week long NW intervention on gait and postural alignment and compared differences between walking with and without poles following the 8-week practice period.

4.1 Spatial-Temporal Characteristics

Gait speed was significantly slower during pre-intervention testing with poles (WP) compared to walking without poles (NP), particularly when assessed with the 6MWT (i.e. long duration). This may be explained by the relative novelty of NW to this group as they had limited to no experience with such exercise. Therefore, the reduced gait speed may be a direct result of greater attention being directed towards learning the poling technique. However, with sufficient practice as part of the 8-week intervention, gait velocity (+0.16m/s for long and +0.09m/s for short durations) increased WP during post-testing compared to pre-testing. This particular increase in speed is dissimilar to results by Becker et al. (2013) who conducted a study on healthy older adults using both structured and unstructured training programs. Following the unstructured program, they found a decrease in gait speed and increase in stride length, while no changes were seen with the structured training. They concluded that the decrease in speed may have been due to participants focusing on the poling technique (i.e. reciprocal arm swing), thereby decreasing velocity. The difference between studies may be primarily due to the fact our participants were given a concise tutorial on the proper poling technique that aimed at minimizing the amount of information participants were required to process. Also, participants' moderate physical activity levels as well as the relative youth of our group (68 ± 6.4 years) compared to that of Becker et al. (2013) (84.5 ± 9.5 years) may further explain these discrepancies.

The increase in gait speed post-intervention is instead similar to results by Figueiredo et al. (2013) who found significant increases in gait speed WP following 6-weeks of training in a group of frail elderly adults. As suggested by Figueiredo et al. (2013), the poles may act to transmit force against the ground and thus aid in effectively propelling the body forward. This, along with the promotion of proper gait rhythm with the poles, and the overall increase in confidence in pole use with 8 weeks of practice, may appropriately explain the gait speed increase post-intervention. Additionally, inclusion of EMG for both the arms and legs could assist in determining whether or not power was transferred to the poles. Moreover, Langlois et al. (1997) stipulate that a gait speed of 0.8-1.2 m/s can be considered the minimum standard pace required for safe ambulation for older adults. With an average of 0.79 m/s following training, participants in Figueiredo et al. (2013) failed to reach this standard. However, our group exceeded this minimum standard, WP and NP both before and following intervention, which suggests an important implication that our participants may have been at lower risk of falls. Further, the increase in speed WP post training might indicate that participants gained confidence walking with the poles, thereby allowing them to walk faster.

Further, in line with previous research, using poles led to significantly longer stride length, (Willson et al., 2001; Hansen et al., 2008; Becker et al., 2013), but also to an increased time spent in double support. Maki (1997) suggests that a reduction in stride length, a slower gait speed, and a prolonged double support time are indicative of gait changes associated with fear of falling. However, as our study demonstrates a longer stride and faster walking speed WP following training, along with this increase in double support time following acclimation to the poles, we believe that our results may instead demonstrate an improvement in confidence as all participants report feeling more stable WP. Thus, with improved confidence and the added external support when using poles compared to without, participants are better able to take a longer step and increase their pace without the fear of falling or loss of confidence in their gait and balance.

4.2 Gait Kinetics and Posture

Peak hip power generation at initial heel contact (H1) and pre-swing (H3) were smaller when WP compared to NP during both pre- and post-testing. This is indicative of smaller concentric muscle activity of the hip extensors (H1) and hip flexors (H3) when walking with poles. However, the 8 weeks of training resulted in greater power generation of the hip flexors (H3) compared to pre-intervention testing WP. This increase in H3 power generation during post-testing may be directly related to the increase in gait velocity as the majority of power measures are directly related to gait speed, including power generation at pre-swing (Lelas et al. 2003). In our study, H3 power generation increased once participants were comfortable with the poles (i.e. once walking faster). However, the hip flexor power generation still remained smaller WP compared to NP in post-training. This could be due to the increase in gait speed also seen NP following the training. Alternatively, the extra support provided by the poles could have allowed participants to use this power generation solely to pull the leg forward rather than also controlling the forward progression of the trunk. Indeed, walking with poles did improve postural alignment of the trunk in the sagittal direction both before and after the intervention. However, this was found only during short duration gait activities (i.e. 5m walk), as we found no such evidence during the 6MWT. This suggests that pole walking has the potential to improve postural alignment, which could lead to a more efficient pulling strategy at the hip level for the swing phase of gait. However, due to factors such as fatigue or not directing an appropriate amount of attention to the technique, maintaining this posture over a long period of time appears difficult. Yet with proper acquisition of the skill and a more rigorous intervention program, postural improvements over a longer duration may be possible.

Knee power absorption was reduced at pre-swing (K3) when walking WP compared to NP, both before and after 8 weeks of training. This eccentric knee extensor contraction is employed to prevent the knee joint from collapsing during the push-off phase (A2) and to prepare for knee extension (Winter, 1991). It is important to note that the hip flexor activity at H3 peaks slightly prior to the peak of eccentric activity by the quadriceps (K3) (~60% of gait cycle). Winter (1991) proposed that a biarticular muscle may act on adjacent joints, whereby power generation may occur at one joint while power absorption may occur at the other. This may explain the reduction found at K3, wherein pole use results in greater generation of energy at one end (i.e. hip joint) to assist in initiating leg swing and consequently less energy absorption at the other (i.e. knee joint). Therefore, at this stage, power output WP is primarily aimed at gait progression rather than at preventing collapse of the knee joint.

During the loading response (K1), knee extensors are employed as shock absorbers to decelerate the body segments (LaStayo et al., 2003) and to control knee flexion (Winter, 1991). No significant differences were found during pre-testing in comparing WP to NP, however, when comparing pre-testing WP to post-testing WP, K1 knee power absorption increased following the training period. The increased absorption post-intervention suggests that as participants gain confidence in the poling technique, they may rely to a greater degree and thus more appropriately on their quadriceps to control knee flexion during the loading response.

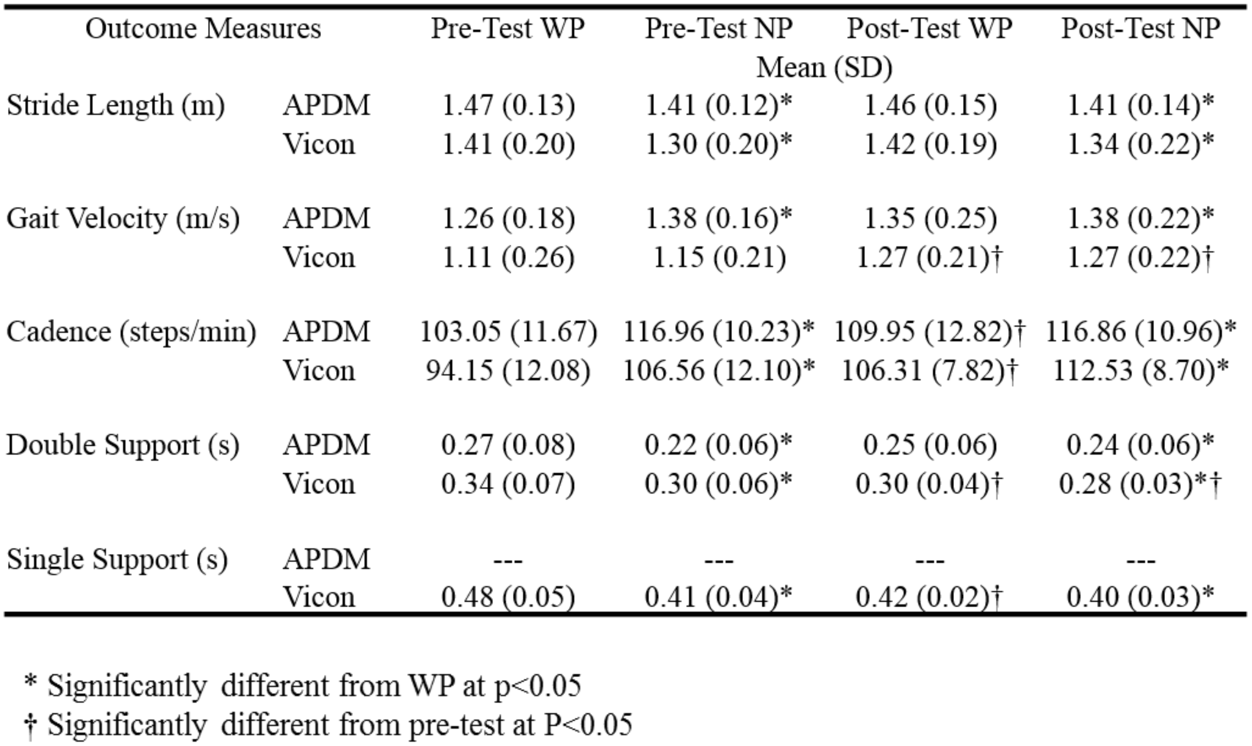
Knee flexor power absorption at terminal swing (K4) was found to be smaller WP compared to NP during pre-intervention testing only. Following training WP, we also found a significant increase in power absorption (K4) compared to pre-testing WP. This eccentric activity of the knee flexors is mainly employed to decelerate the swinging leg and prepare for heel contact with the ground (Winter, 1991). Therefore, as they acclimate to the poles, participants might transition from relying heavily on the poles during this crucial phase of the gait cycle to converting back to a more normal gait pattern, thereby relying primarily on the eccentric activity of the knee flexors.

Finally, although we did find a slight increase in peak ankle power generation at “push-off” (A2) for both walking conditions after training, this did not reach statistical significance. This highlights that our group, when walking both with and without poles, modified their gait patterns principally at the hip and knee level rather than at the ankle. This is in line with previous studies reporting hip strategies to compensate for age-related decreased ankle plantarflexor power generation (Winter et al., 1990; Judge et al., 1996; DeVita & Hortobagyi, 2000; Cofré et al., 2010). Since power generation at the ankle is an important component of forward progression, as participants get more comfortable walking with the poles, emphasis could be put on increasing the contribution of the plantarflexors during the push-off phase.

5 Conclusions

Eight weeks of training, walking WP resulted in an increased stride length and faster gait speed to go along with increased power generation at the hip (at pre-swing (H3)) and power absorption at the knee (during the loading response (K1) and at terminal swing (K4)). An initial 8-week training period such as this appears necessary for novice older adult NW even when already physically active, in order to gain familiarity with the poles and ultimately perfect the technique itself. As evidenced by the various changes in gait pattern WP, this 8-week program resulted in a shift towards a more natural gait pattern and improved posture following the intervention, with a longer stride length, greater power generation and absorption, and more upright postural alignment. To continue to improve gait further and reap the additional benefits of NW (e.g. strength), a regimented and more rigorous routine may be utilized following this acquisition period. Additionally, although not tested in this study, a longer acquisition period may be warranted for frail older adults due to increased muscular weakness and potential for difficulty performing the activity. Therefore, the use of poles will assist in engaging a larger proportion of muscles, both in the upper and lower body, ultimately aiding in the maintenance of the functional well-being of frail older adults. Finally, although a dual task was not assessed in this study, the introduction of new equipment such as the poles might increase the level of attention needed to perform locomotor activities. Therefore, these activities should initially be performed in a safe environment in order to remove external distractions. This may include not walking on uneven surfaces, wearing proper clothing/attire, walking in properly lit environments, and avoiding crowded areas.

Tables



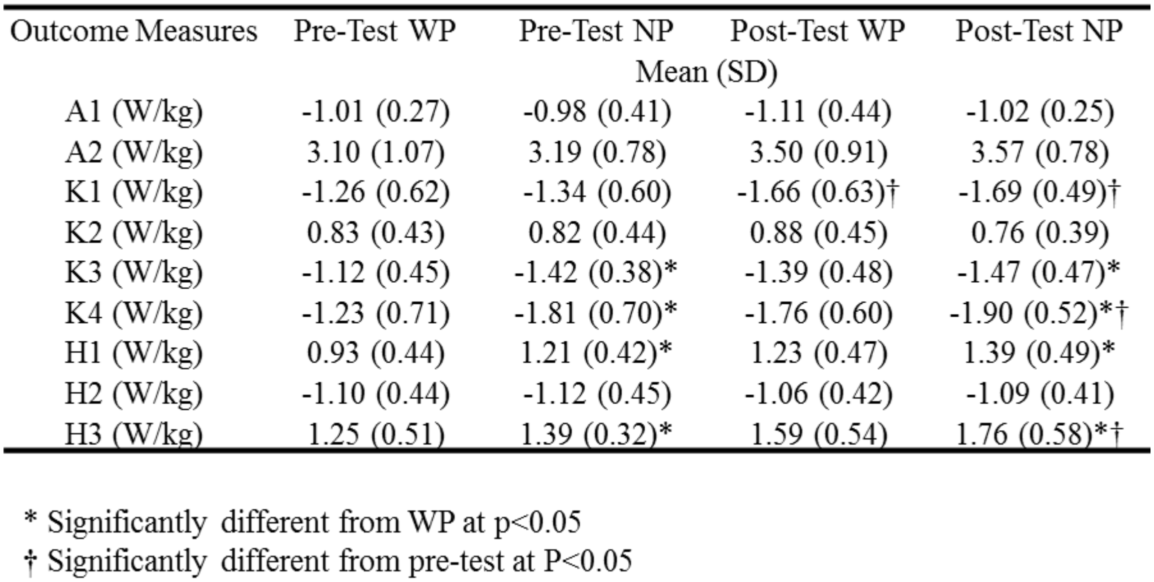
Outcome Measures		Pre-Test WP	Pre-Test NP	Post-Test WP	Post-Test NP
		Mean (SD)			
Stride Length (m)	APDM	1.47 (0.13)	1.41 (0.12)*	1.46 (0.15)	1.41 (0.14)*
	Vicon	1.41 (0.20)	1.30 (0.20)*	1.42 (0.19)	1.34 (0.22)*
Gait Velocity (m/s)	APDM	1.26 (0.18)	1.38 (0.16)*	1.35 (0.25)	1.38 (0.22)*
	Vicon	1.11 (0.26)	1.15 (0.21)	1.27 (0.21)†	1.27 (0.22)†
Cadence (steps/min)	APDM	103.05 (11.67)	116.96 (10.23)*	109.95 (12.82)†	116.86 (10.96)*
	Vicon	94.15 (12.08)	106.56 (12.10)*	106.31 (7.82)†	112.53 (8.70)*
Double Support (s)	APDM	0.27 (0.08)	0.22 (0.06)*	0.25 (0.06)	0.24 (0.06)*
	Vicon	0.34 (0.07)	0.30 (0.06)*	0.30 (0.04)†	0.28 (0.03)*†
Single Support (s)	APDM	---	---	---	---
	Vicon	0.48 (0.05)	0.41 (0.04)*	0.42 (0.02)†	0.40 (0.03)*

* Significantly different from WP at $p<0.05$

† Significantly different from pre-test at $P<0.05$

Table 1. Spatial-temporal results

Mean spatial-temporal gait characteristics comparing with poles (WP) and without poles (NP), both before and following an 8-week Nordic walking (NW) training intervention. These are the averages of the group gathered from both motion capture systems, representing gait as recorded over different durations and distance (i.e. APDM for long duration (6 minutes) and Vicon for short duration (5m)).

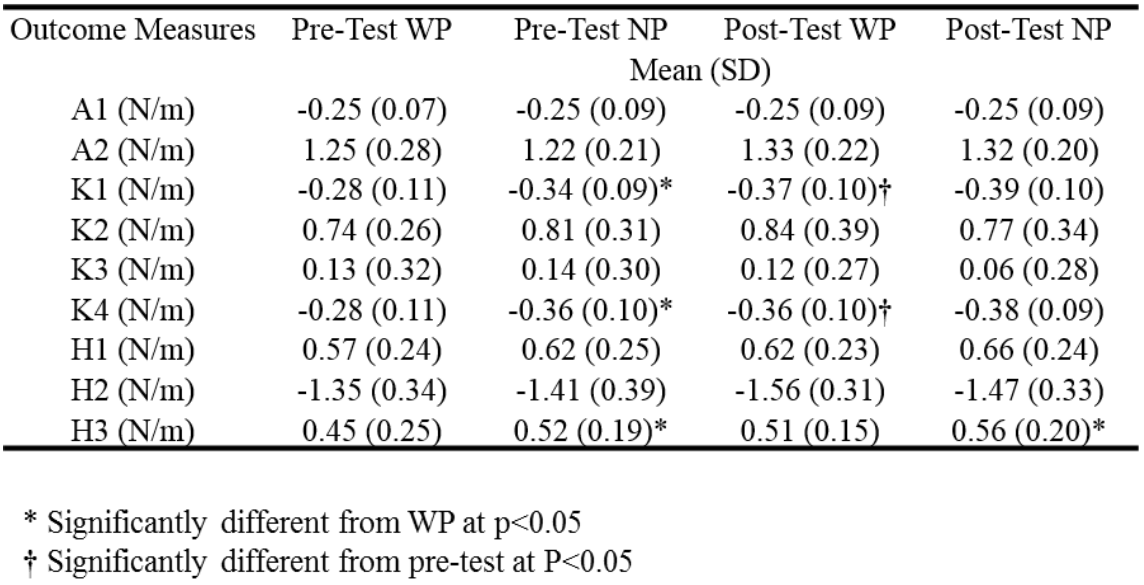


Outcome Measures	Pre-Test WP	Pre-Test NP	Post-Test WP	Post-Test NP
		Mean (SD)		
A1 (W/kg)	-1.01 (0.27)	-0.98 (0.41)	-1.11 (0.44)	-1.02 (0.25)
A2 (W/kg)	3.10 (1.07)	3.19 (0.78)	3.50 (0.91)	3.57 (0.78)
K1 (W/kg)	-1.26 (0.62)	-1.34 (0.60)	-1.66 (0.63)†	-1.69 (0.49)†
K2 (W/kg)	0.83 (0.43)	0.82 (0.44)	0.88 (0.45)	0.76 (0.39)
K3 (W/kg)	-1.12 (0.45)	-1.42 (0.38)*	-1.39 (0.48)	-1.47 (0.47)*
K4 (W/kg)	-1.23 (0.71)	-1.81 (0.70)*	-1.76 (0.60)	-1.90 (0.52)*†
H1 (W/kg)	0.93 (0.44)	1.21 (0.42)*	1.23 (0.47)	1.39 (0.49)*
H2 (W/kg)	-1.10 (0.44)	-1.12 (0.45)	-1.06 (0.42)	-1.09 (0.41)
H3 (W/kg)	1.25 (0.51)	1.39 (0.32)*	1.59 (0.54)	1.76 (0.58)*†

* Significantly different from WP at $p<0.05$
† Significantly different from pre-test at $P<0.05$

Table 2. Lower extremity joint peak power generation/absorption

Mean peak power generation and absorption (W/kg) in the sagittal plane at the ankle, knee, and hip joints as measured during specific gait events (i.e. loading, mid-stance, push-off, terminal swing). Positive values represent power generation (and concentric muscles activity). Negative values represent power absorption (and eccentric muscle activity).

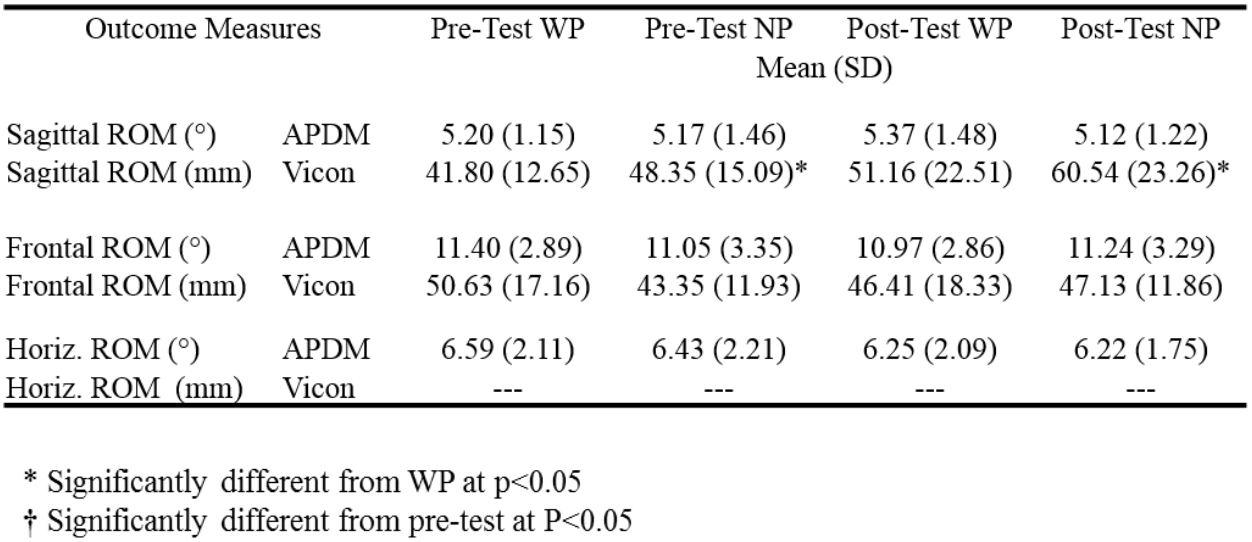


Outcome Measures	Pre-Test WP	Pre-Test NP	Post-Test WP	Post-Test NP
	Mean (SD)			
A1 (N/m)	-0.25 (0.07)	-0.25 (0.09)	-0.25 (0.09)	-0.25 (0.09)
A2 (N/m)	1.25 (0.28)	1.22 (0.21)	1.33 (0.22)	1.32 (0.20)
K1 (N/m)	-0.28 (0.11)	-0.34 (0.09)*	-0.37 (0.10)†	-0.39 (0.10)
K2 (N/m)	0.74 (0.26)	0.81 (0.31)	0.84 (0.39)	0.77 (0.34)
K3 (N/m)	0.13 (0.32)	0.14 (0.30)	0.12 (0.27)	0.06 (0.28)
K4 (N/m)	-0.28 (0.11)	-0.36 (0.10)*	-0.36 (0.10)†	-0.38 (0.09)
H1 (N/m)	0.57 (0.24)	0.62 (0.25)	0.62 (0.23)	0.66 (0.24)
H2 (N/m)	-1.35 (0.34)	-1.41 (0.39)	-1.56 (0.31)	-1.47 (0.33)
H3 (N/m)	0.45 (0.25)	0.52 (0.19)*	0.51 (0.15)	0.56 (0.20)*

* Significantly different from WP at $p<0.05$
† Significantly different from pre-test at $P<0.05$

Table 3. Lower extremity joint moments of force

Mean peak moments of force (N/m) in the sagittal plane at the ankle, knee, and hip joints as measured during specific gait events (i.e. loading, mid-stance, push-off, terminal swing).



Outcome Measures		Pre-Test WP	Pre-Test NP	Post-Test WP	Post-Test NP
		Mean (SD)			
Sagittal ROM (°)	APDM	5.20 (1.15)	5.17 (1.46)	5.37 (1.48)	5.12 (1.22)
Sagittal ROM (mm)	Vicon	41.80 (12.65)	48.35 (15.09)*	51.16 (22.51)	60.54 (23.26)*
Frontal ROM (°)	APDM	11.40 (2.89)	11.05 (3.35)	10.97 (2.86)	11.24 (3.29)
Frontal ROM (mm)	Vicon	50.63 (17.16)	43.35 (11.93)	46.41 (18.33)	47.13 (11.86)
Horiz. ROM (°)	APDM	6.59 (2.11)	6.43 (2.21)	6.25 (2.09)	6.22 (1.75)
Horiz. ROM (mm)	Vicon	---	---	---	---

* Significantly different from WP at p<0.05

† Significantly different from pre-test at P<0.05

Table 4. Postural range of motion

Mean postural range of motion comparing with poles (WP) and without poles (NP), both before and following an 8-week Nordic walking (NW) intervention. There are the averages of the group gathered from both motion capture systems, representing gait as recorded over different durations and distances (i.e. APDM for long duration (6 minutes) and Vicon for short duration (5m)).

Figures

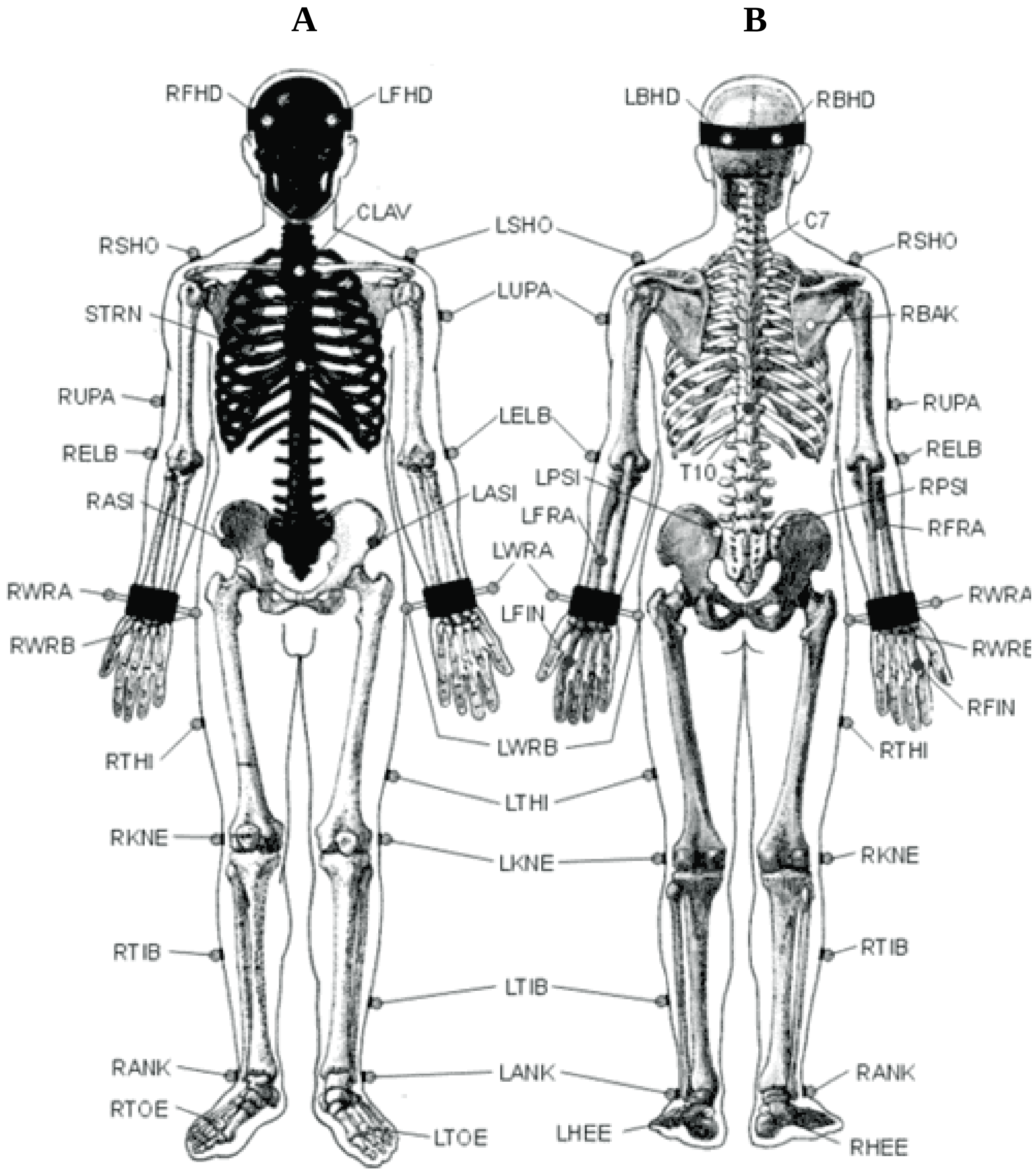


Figure 1. Plug-in gait marker set

Anterior (A) and posterior (B) views of the full body marker set used during Vicon analysis

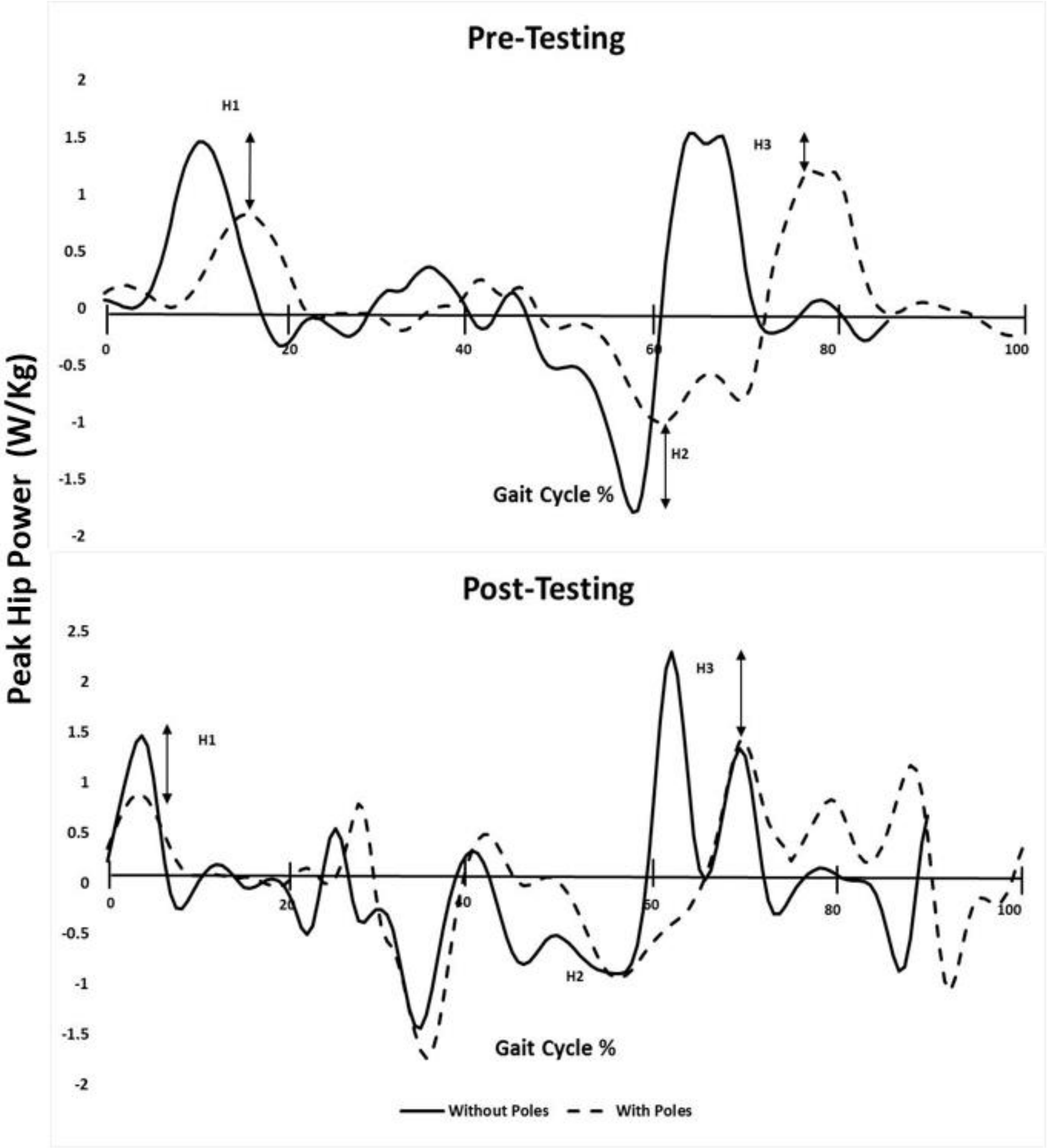


Figure 2. Peak hip power profile

Representative results of hip power profiles (W/kg) during pre-intervention and post-intervention testing, both with poles and without poles.

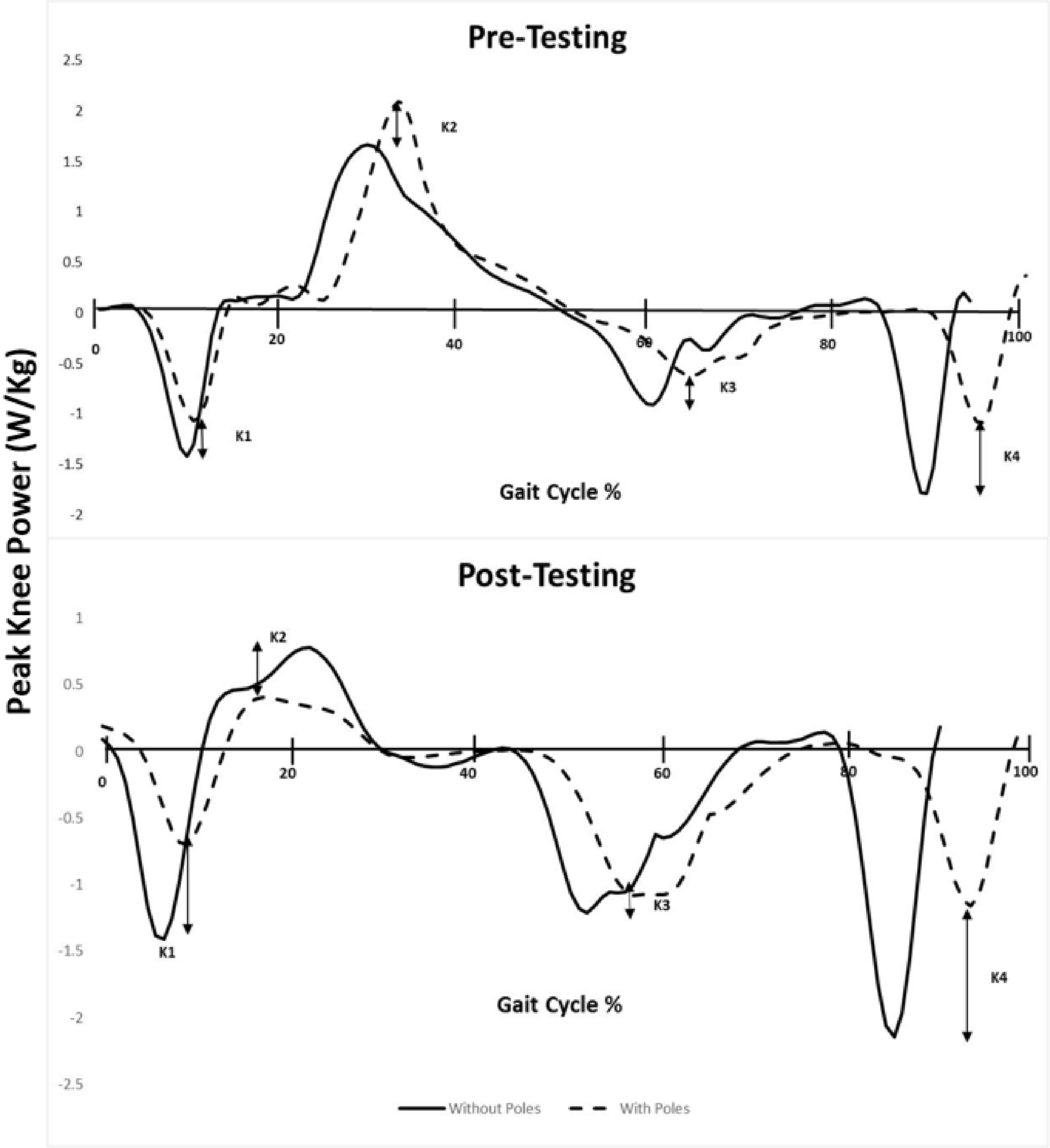


Figure 3. Peak knee power profile

Representative results of knee power profiles (W/kg) during pre-intervention and post-intervention testing, both with and without poles.

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Chapter IV: General Discussion

The objective of the present study was two-fold: 1) to establish the initial effect of NW on older adult gait, specifically spatial-temporal (i.e. gait speed, stride length, cadence, double support time) and kinetic (moments of force, power generation/absorption) parameters as well as postural alignment and trunk stability in older adults, and 2) to establish the effect of an 8-week NW intervention, and thus prolonged practice, on these same variables in older adults. First, we hypothesized an increase in gait velocity, stride length, cadence, and single support time, along with decreased double support time during pole use compared to without and during post- compared to pre-testing. Second, we postulated an initial increase in the moments of force and power generation/absorption WP compared to NP followed by a further increase in these same measures during post-intervention testing (i.e. following 8 weeks of training). Lastly, we expected to see an improvement (i.e. a smaller ROM) in trunk ROM towards a more erect, upright position WP compared to NP as well as during post- relative to pre-testing.

1 Spatial-Temporal Characteristics

During pre-testing, the initial effect of NW on gait speed was largely dependent upon the walk duration and the distance walked. During the 5m walk, no difference in gait speed was found when comparing WP to NP, however, the 6MWT appropriately distinguished between WP and NP, demonstrating a slower gait speed WP relative to NP. The initial reduction in gait speed during the 6MWT may primarily be explained by participants being newly exposed to NW, as they had only minimal to no exposure to the activity. Therefore, upon acquiring the poling technique, greater attention is likely devoted to the technical aspects of NW, such as the cyclical movement of the poles as well as to the proper planting technique, which may have resulted in the subsequent decreased gait speed. Additionally, due to this novelty, participants may have initially been more conservative and cautious regarding their gait speed during pole use. Despite this, following the 8-week intervention and with sufficient practice time, a significant increase in speed over a short duration (+0.09m/s) (P = 0.023) as well as a trend (P = 0.058) towards increased gait speed over a long duration (+0.16m/s) were found during post-testing compared to pre-testing WP. Likely, these increases are attributable to the training itself, potentially due to improvements in NW technique and/or physiological function, although neither was tested.

The increased gait speed post-test is similar to findings by both Willson et al. (2001) and Figueiredo et al. (2013). Willson et al. (2001) assessed various gait parameters between NW and conventional walking in healthy young adults. They report greater speed WP compared to NP, but conclude that prolonged practice may be of importance for assessment beyond a brief time period. Moreover, Figueiredo et al. (2013) found significant increases in gait speed following a 6-week intervention in a group of frail older adults. The authors conclude that the poles may act to transmit force against the ground, aiding in propelling the body forward through each gait cycle along with promoting proper gait rhythm. Therefore, our larger gait speed post-training may be due to proper transmission of force as well as promotion of suitable gait rhythm following prolonged practice. However, as the poles themselves were not instrumented, it is impossible to fully confirm whether proper force transmission is responsible for this change in gait speed. And inclusion of EMG on the muscles of the arms and legs may also aid in determining whether or not some power was transferred to the poles.

Additionally, although only subjectively reported, participants continually stated that they felt more stable and overall, more self-confident in their gait and balance with pole use, which suggests safer ambulation when walking with poles. Langlois et al. (1997) report that a gait speed of 0.8-1.2m/s is the minimum required velocity necessary for safe older adult ambulation.

With a 0.79m/s average following their 6 week unstructured training, subjects in Figueiredo et al. (2013) did not reach this level. But rather, our group met or exceeded this minimum WP and NP before and after training, indicating an important association that this group was at a lower risk for falls.

Our results also differ from those of Becker et al. (2013), who examined healthy older adults using single session structured and unstructured training programs. Following the unstructured training, the authors found a decrease in gait speed and increased stride length, while no changes were evident during structured training. They conclude that contrary to their results in the structured program, this decreased gait speed may have been a result of participants focusing heavily on the poling technique (i.e. dual tasking effect), often leading to improper pole placement without correction. Therefore, it is possible that contrary to results by Becker et al., (2013), the increased speed at post-testing could further be due to our concise tutorial on poling technique, which was designed to minimize the information participants were required to process. Also, moderate physical activity levels and a younger average age in our group (68 ± 6.4 years) relative to Becker et al. (2013) (84.5 ± 9.5 years) may further explain this variance between studies.

Both the 6MWT and 5m walk, regardless of time component (before or after the intervention), resulted in a significantly longer stride length when comparing WP to NP. As Figueiredo et al. (2013) previously proposed for gait speed, this increase may be a direct result of the force transmitted by the poles against the ground, aiding in propelling and driving the body forward. Past research by Willson et al. (2001) on young adults also demonstrated a significant increase in stride length when walking with poles compared to conventional gait, reporting an average increase in stride length of 0.20 m WP compared to NP in healthy young adults.

However, once again, they suggest the necessity for assessment following prolonged practice to develop a more adequate representation of NW gait. Becker et al. (2013) examined older adults and reported a significant average increase of 0.05 m WP compared to NP following a single unstructured practice period. The discrepancy in stride length improvement between WIllson et al. (2001) and Becker et al. (2013) may be explained by the age group difference between the studies. Indeed, the significant but smaller stride length change in Becker et al. (2013) may be due to the age related decreased muscle strength and subsequent reduction in power generation by older adults relative to the younger adults in Willson et al. (2001). However, overall and in line with our results, stride length increases WP compared to NP.

Further, Winter (1991) reports that older adults do not constitute an entirely homogenous group and that parameters, particularly cadence, may vary from study to study and be dependent upon fitness levels and levels of physical degeneration. In this study, the changes in cadence WP may simply be explained by its relationship with gait speed, rather than with its dependence on or relation to levels of fitness and degeneration. During both gait activities at pre-testing, as gait speed decreases WP compared to NP, so too does cadence. Similarly, during post-intervention testing, cadence significantly increases WP for both long and short duration gait activities, following suit with the increase in gait velocity at these times. Alternatively, Winter (1991) reports “as cadence and velocity of walking increase, both stance and swing times decrease” and vice versa. This inverse relationship may explain our findings regarding double support time. During pre-testing, the 6MWT and 5m walk first revealed an increase in double support time WP to coincide with decreased gait velocity and cadence WP. Further, with the 5m walk, we also found decreased double support time following the intervention, both WP and NP, to coincide with increased gait speed and cadence, further supporting this inverse relationship.

Maki (1997) postulates that shorter stride, slower gait speed, and prolonged double support time are typical age-related gait modifications, all of which correlate with fear of falling. However, following prolonged exposure to the poles, our participants, despite showing a prolonged double support time (for 6MWT) WP, had a longer stride and faster speed. Therefore, our results may not necessarily indicate an association with fear of falling. Instead, these changes along with the participants' subjective reports of greater stability WP may be indicative of improved confidence during ambulation. Thus with the potential improvement in self-confidence, participants may be more comfortable and better suited to taking a larger step and increasing their speed, without any detrimental repercussions (e.g. fear of falling, loss of balance). However, since improved confidence was reported informally and strictly subjectively, a more formal confidence scale (e.g. Likert scale) could have allowed for better quantification of the relationship between confidence and stride length, gait speed, and double support time.

Finally, as assessed only over 5m, single support time decreased WP post-intervention, coinciding with increased speed and cadence during this time. This can again be simply explained by the inter-dependence between the spatial-temporal gait characteristics as previously proposed by Winter (1991). Further, it is possible that the added external support of the poles aided in their confidence. By always having one pole in contact with the ground during single leg stance, it may have provided a sense of continuous double support, allowing them to direct less attention to postural stability during the single support phase and more attention to stepping further and faster.

2 Gait Kinetics and Posture

Hip muscle peak power generation were smaller during the loading response (H1) and at pre-swing (H3) when walking WP compared to NP during both pre- and post-testing, indicative of less concentric muscle activity of the hip extensors (H1) and of the hip flexors (H3). Yet, following 8 weeks of training, walking WP resulted in a significant increase in power generation at pre-swing, representative of an increase in concentric activity of the hip flexors compared to pre-testing WP. The majority of power measures, including hip power generation at these two phases of the gait cycle, are closely associated with speed (Lelas et al., 2003). In our study, with the initial acquisition of the poling technique (i.e. pre-testing), gait speed was slower WP compared to NP, although not significantly. Even so, the decreased pace may have directly contributed to the reductions found for H1 and H3 power generation of the hip extensors and flexors, respectively. Similarly during post-testing, with efficiency and understanding of the poling technique, increased speed likely aided in generating increased power at pre-swing and again demonstrated the close relationship between these two measures. However, it is also likely that walking without poles generated greater power at pre-swing due to the additional increase in speed seen NP following training. Alternatively, the extra support provided by the poles could have allowed participants to allocate greater power generation towards exclusively pulling the leg forward rather than participants having to simultaneously control the forward progression of the trunk and the swing of the leg.

These results, namely during the loading response (H1), differ from those by Willson et al. (2001). In comparing NW to conventional walking in healthy young adults, they found no differences between walking with and without poles. However, the difference between these results and ours could be primarily attributed to the population included, as different age groups (i.e. young vs. old) typically employ different strategies for power generation throughout the gait cycle. Indeed, it has been reported that young adults mostly employ an ankle strategy to generate power through push-off (A2). Therefore, it would not be expected to see an increase in hip power in Willson et al. (2001), whereas our study falls more in line with past research demonstrating a hip strategy with advancing age (Wilson et al., 1990; Judge, Davis, & Õunpuu, 1996; Cofré et al., 2010).

Further, both before and after the intervention, walking with poles aided in improving postural alignment of the trunk in the sagittal plane (anterior-posterior: AP). However, this was found solely during short duration gait events (i.e. 5m walk), as we found no such evidence of improved alignment during the 6MWT. Although only found over the 5m walk trials, the improvement in sagittal range of motion aids in presenting two implications: 1) there is potential for improving postural alignment with pole use and 2) improved posture has the potential to lead to a more efficient pulling strategy at the hip level for leg swing during gait. However, potentially due to factors including fatigue and insufficient attention allocation to the poling technique, maintaining this improved posture over a long period appears difficult. And yet with proper acquisition of the skill and a more rigorous intervention program, postural improvements over a longer duration may be possible.

Power absorption by the knee extensors at pre-swing (K3) is utilized primarily to control knee flexion during push-off at the ankle (A2) (Winter, 1991). Winter (1991) states that a biarticular muscle has the potential to act on adjacent joints (e.g. hip and knee joints), resulting in power generation (i.e. concentric contraction) at one joint and power absorption (i.e. eccentric contraction) at the next. Knee power absorption and hip power generation at pre-swing (K3 and H3) employ common biarticular muscles (e.g. recuts femoris), in addition to the similar timing of these power phases as the concentric hip flexor activity for H3 peaks just prior to the eccentric activity of the quadriceps for K3 (~60% of a typical gait cycle). In our study, knee power absorption for K3 was found to be significantly reduced during pole use compared to conventional walking, during both pre- and post-testing. The actions of the biarticular muscle, in this instance the rectus femoris, as well as the well-timed power generation and absorption about the hip and knee may explain this reduction. During pole use, regardless of prolonged practice, older adults produce a greater degree of power generation from the hip joint (pull off), for the primary purpose of initiating the swing phase of gait. Consequently, however, pole use could result in a lesser degree of power absorption at the knee joint, which is meant to aid in preventing the knee joint from collapsing. Thus, for older adults novice to NW, muscle power output appears to be primarily tasked with assisting in gait progression rather than in preventing collapse of the knee joint. Complementarily, A2 power generation WP was smaller compared to NP, although not significantly. This may also help to explain the reduction WP for K3 in which our participants push less from the ankle and pull more from the hip, and thus require less control at the knee joint.

During the loading response (K1), knee extensors are employed as shock absorbers to decelerate the body segments (LaStayo et al., 2003) and to control knee flexion (Winter, 1991). In comparing WP to NP during pre-testing, no differences were found in knee power absorption for K1. This lack of change between walking conditions may be primarily due to the novelty of NW and an inability to completely and appropriately acquire the skill itself. Due to limited exposure to the poles prior to initial testing, participants may simply require greater pole familiarization in order to employ the poles in the manner that is expected. This fact is evidenced when comparing pre-testing WP to post-testing WP, where K1 knee power absorption significantly increased following training and familiarization with the poling technique. As participants gain confidence in the skill and begin taking longer strides at a faster pace, they may be able to rely to a greater degree and more appropriately on their quadriceps to control knee flexion during the loading response.

Finally, at terminal swing (K4), knee power absorption of the knee flexors (i.e. hamstrings) was smaller WP compared to NP, solely during pre-testing. Further, following 8 weeks of training, a significant increase in power absorption for K4 was found relative to pre-testing WP. At this stage of the gait cycle, the eccentric activity of the knee flexors is mainly used to decelerate the swinging leg and prepare for initial heel contact (Winter, 1991). Therefore, as older adults become acclimated to the poles, they may transition from heavy reliance on the poles during the critical phase of the gait cycle to a more natural gait pattern, relying largely on the knee flexors.

To coincide with the muscle power alterations with NW, the moments of force about the hip and knee joints are also altered. In our study, with certain decreases in power generation or absorption come subsequent decreases in the moment of force about that particular joint, and vice versa. Specifically, a reduction in moment of force was found for K4 (i.e. terminal swing), H1 (i.e. loading response), and H3 (i.e. pull-off) during pole use compared to conventional walking at both pre- and post-testing. Further, following training WP, increases for K1 (i.e. loading response), K4, H1, and H3 were found compared to pre-testing WP. Our results differ from those of Hansen et al. (2008) as well as Steif et al. (2008). Hansen et al. (2008) report no significant changes in the knee and hip extensor and flexor moments during pole use, broadly concluding that NW does not reduce the joint loading of the lower extremity joints. Further, Stief et al. (2008) report an increased knee extensor moment during the loading response with pole use, primarily attributing this to a longer stride length, and demonstrating no biomechanical benefit of NW. Despite this, our study opposes our original hypothesis of increased moments of force about the lower extremity joints as we found a significant reduction in the joint loading of the lower extremities, defined by the reduced knee flexor and hip flexor and extensor moments found during NW. And further, even with increased moments of force following training, reduced joint loading is still supported due to the fact that K1, K4, H1, and H3 values for moment of force were all smaller WP during post-testing compared to NP during post-testing.

Finally, although we did find a slight increase in peak ankle power generation at “push-off” (A2) for both walking conditions after training, this did not reach statistical significance. This highlights that our group, when walking both with and without poles, modified their gait patterns principally at the hip and knee level rather than at the ankle. This is in line with previous studies reporting hip strategies to compensate for age-related decreased ankle plantarflexor power generation (Winter et al., 1990; Judge et al., 1996; DeVita & Hortobagyi, 2000; Cofré et al., 2010). Since power generation at the ankle is an important component of forward progression, as participants get more comfortable walking with the poles, emphasis could be put on increasing the contribution of the plantarflexors during the push-off phase with NW training.

One limitation of this study includes the lack of a control group (e.g. young adults) in order to compare our results against baseline measures. Even with participants essentially acting as their own controls and generating baseline measures to compare against, another group to compare to may provide better understanding of the effect of NW on gait and posture. Another limitation is the independent nature of the training program. A more rigorous and regimented one-on-one intervention could be used, which may further elucidate greater NW advantages due to the constant feedback and correction of technique over this 8-week period. Should this be feasible, it would be of added value to implement into the study methods.

Chapter V: Conclusions

In conclusion, an 8-week training intervention has the potential to improve both the gait patterns and postural alignment of healthy older adults. This was largely evidenced by a longer stride length, an increase in gait speed, increases in lower extremity joint power generation and absorption and a more upright postural alignment. The use of walking poles demonstrates an overall shift toward a more normal gait pattern and posture. From this, it can be recommended that an initial 8-week training program, or acquisition period, is necessary to gain an appropriate understanding of the poling technique and reap the associated benefits, even for those older adults who are healthy and relatively active. Further, although not directly tested in this study, two further general recommendations should be considered when performing NW. First, due to difficulty performing the task as well as due to muscular weakness, frail older adults may require a longer acquisition period to properly develop the technique and obtain the benefits as they pertain to gait patterns and postural alignment. And second, due to the introduction of new equipment and the potential dual task effect, an increase of attentional resources may be allocated to the secondary activity (i.e. pole manipulation) at the expense of walking itself. Therefore, NW should initially be performed in a safe environment under safe conditions in order to remove any external distractions. To be exact, this may include: avoiding uneven and slippery surfaces, wearing proper clothing/shoes, walking in well-lit environments, and avoiding large crowds.

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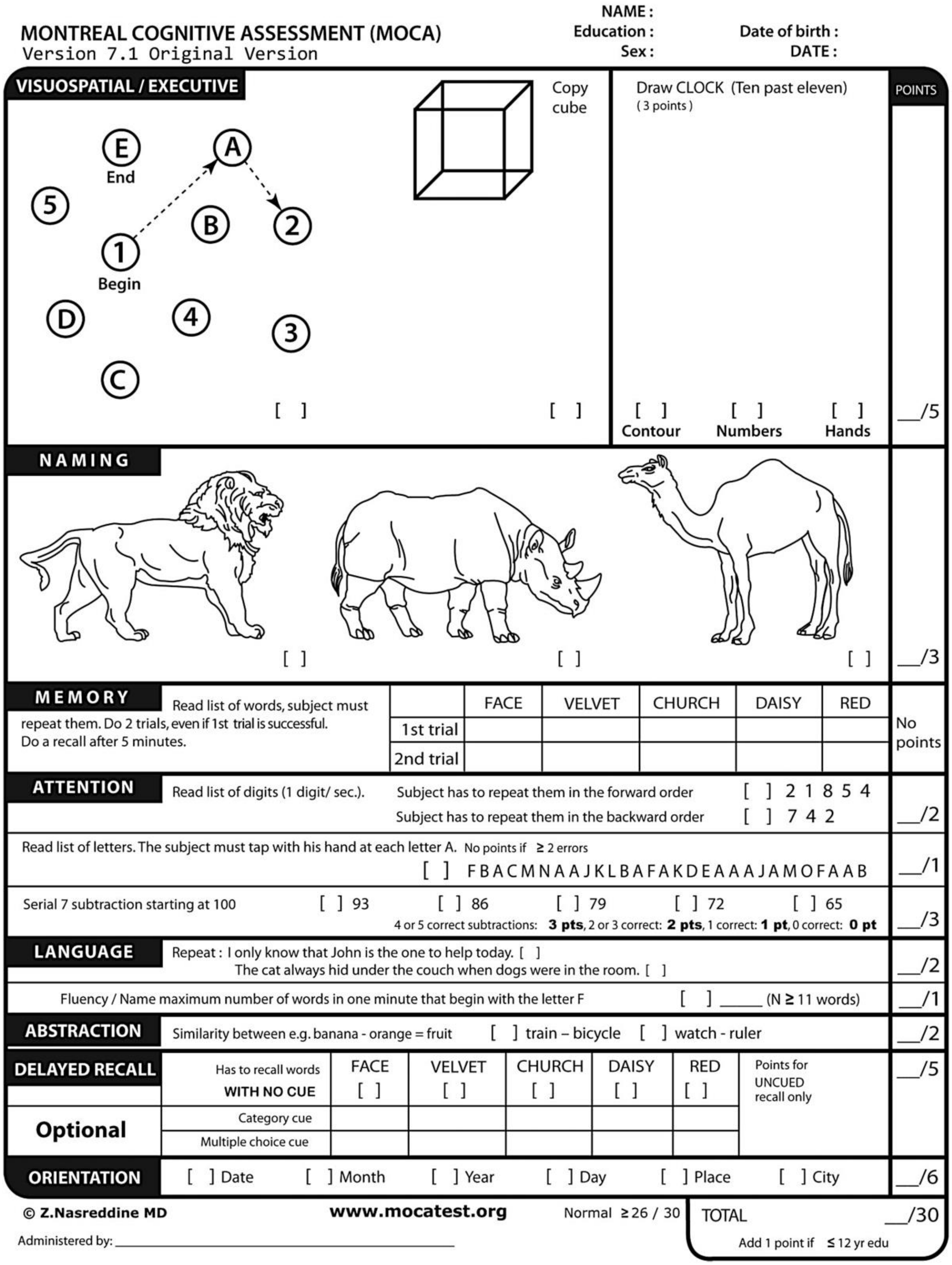
Appendix A
Montreal Cognitive Assessment (MoCA)



MONTREAL COGNITIVE ASSESSMENT (MOCA)
Version 7.1 Original Version

NAME :
Education :
Sex :
Date of birth :
DATE :

VISUOSPATIAL / EXECUTIVE — POINTS

[ ]

Copy cube [ ]

Draw CLOCK (Ten past eleven) (3 points)
[ ] Contour [ ] Numbers [ ] Hands __/5

NAMING

[ ] [ ] [ ] __/3

MEMORY Read list of words, subject must repeat them. Do 2 trials, even if 1st trial is successful. Do a recall after 5 minutes.

	FACE	VELVET	CHURCH	DAISY	RED
1st trial					
2nd trial					

No points

ATTENTION Read list of digits (1 digit/ sec.).
Subject has to repeat them in the forward order [ ] 2 1 8 5 4
Subject has to repeat them in the backward order [ ] 7 4 2 __/2

Read list of letters. The subject must tap with his hand at each letter A. No points if ≥ 2 errors
[ ] F B A C M N A A J K L B A F A K D E A A A J A M O F A A B __/1

Serial 7 subtraction starting at 100 [ ] 93 [ ] 86 [ ] 79 [ ] 72 [ ] 65
4 or 5 correct subtractions: **3 pts**, 2 or 3 correct: **2 pts**, 1 correct: **1 pt**, 0 correct: **0 pt** __/3

LANGUAGE Repeat : I only know that John is the one to help today. [ ]
The cat always hid under the couch when dogs were in the room. [ ] __/2

Fluency / Name maximum number of words in one minute that begin with the letter F [ ] _____ (N ≥ 11 words) __/1

ABSTRACTION Similarity between e.g. banana - orange = fruit [ ] train – bicycle [ ] watch - ruler __/2

DELAYED RECALL	Has to recall words **WITH NO CUE**	FACE [ ]	VELVET [ ]	CHURCH [ ]	DAISY [ ]	RED [ ]	Points for UNCUED recall only	__/5
Optional	Category cue							
	Multiple choice cue							

ORIENTATION [ ] Date [ ] Month [ ] Year [ ] Day [ ] Place [ ] City __/6

© Z.Nasreddine MD **www.mocatest.org** Normal ≥26 / 30 TOTAL __/30
Add 1 point if ≤ 12 yr edu
Administered by: ______________________________

Montreal Cognitive Assessment (MoCA)

Administration and Scoring Instructions

Time to administer the MoCA is approximately 10 minutes. The total possible score is 30 points; a score of 26 or above is considered normal.

1. Alternating Trail Making:

Administration: The examiner instructs the subject: *"Please draw a line, going from a number to a letter in ascending order. Begin here* [point to (1)] *and draw a line from 1 then to A then to 2 and so on. End here* [point to (E)]."

Scoring: Allocate one point if the subject successfully draws the following pattern: 1 −A- 2- B- 3- C- 4- D- 5- E, without drawing any lines that cross. Any error that is not immediately self-corrected earns a score of 0.

2. Visuoconstructional Skills (Cube):

Administration: The examiner gives the following instructions, pointing to the **cube**: *“Copy this drawing as accurately as you can, in the space below”.*

Scoring: One point is allocated for a correctly executed drawing.

- Drawing must be three-dimensional
- All lines are drawn
- No line is added
- Lines are relatively parallel and their length is similar (rectangular prisms are accepted)

A point is not assigned if any of the above-criteria are not met.

3. Visuoconstructional Skills (Clock):

Administration: Indicate the right third of the space and give the following instructions: *“Draw a* **clock.** *Put in all the numbers and set the time to 10 after 11”.*

Scoring: One point is allocated for each of the following three criteria:

- Contour (1 pt.): the clock face must be a circle with only minor distortion acceptable (e.g., slight imperfection on closing the circle);
- Numbers (1 pt.): all clock numbers must be present with no additional numbers; numbers must be in the correct order and placed in the approximate quadrants on the clock face; Roman numerals are acceptable; numbers can be placed outside the circle contour;
- Hands (1 pt.): there must be two hands jointly indicating the correct time; the hour hand must be clearly shorter than the minute hand; hands must be centred within the clock face with their junction close to the clock centre.

A point is not assigned for a given element if any of the above-criteria are not met.

4. Naming:

Administration: Beginning on the left, point to each figure and say: *“Tell me the name of this animal”.*

Scoring: One point each is given for the following responses: (1) camel or dromedary, (2) lion, (3) rhinoceros or rhino.

5. Memory:

Administration: The examiner reads a list of 5 words at a rate of one per second, giving the following instructions: *"This is a memory test. I am going to read a list of words that you will have to remember now and later on. Listen carefully. When I am through, tell me as many words as you can remember. It doesn't matter in what order you say them".* Mark a check in the allocated space for each word the subject produces on this first trial. When the subject indicates that (s)he has finished (has recalled all words), or can recall no more words, read the list a second time with the following instructions: *"I am going to read the same list for a second time. Try to remember and tell me as many words as you can, including words you said the first time."* Put a check in the allocated space for each word the subject recalls after the second trial.

At the end of the second trial, inform the subject that (s)he will be asked to recall these words again by saying, *"I will ask you to recall those words again at the end of the test."*

Scoring: No points are given for Trials One and Two.

6. Attention:

Forward Digit Span: Administration: Give the following instruction: *"I am going to say some numbers and when I am through, repeat them to me exactly as I said them"*. Read the five number sequence at a rate of one digit per second.

Backward Digit Span: Administration: Give the following instruction: *"Now I am going to say some more numbers, but when I am through you must repeat them to me in the backwards order."* Read the three number sequence at a rate of one digit per second.

Scoring: Allocate one point for each sequence correctly repeated, (N.B.: the correct response for the backwards trial is 2-4-7).

Vigilance: Administration: The examiner reads the list of letters at a rate of one per second, after giving the following instruction: *"I am going to read a sequence of letters. Every time I say the letter A, tap your hand once. If I say a different letter, do not tap your hand".*

Scoring: Give one point if there is zero to one errors (an error is a tap on a wrong letter or a failure to tap on letter A).

Serial 7s: Administration: The examiner gives the following instruction*: "Now, I will ask you to count by subtracting seven from 100, and then, keep subtracting seven from your answer until I tell you to stop."* Give this instruction twice if necessary.

Scoring: This item is scored out of 3 points. Give no (0) points for no correct subtractions, 1 point for one correction subtraction, 2 points for two-to-three correct subtractions, and 3 points if the participant successfully makes four or five correct subtractions. Count each correct subtraction of 7 beginning at 100. Each subtraction is evaluated independently; that is, if the participant responds with an incorrect number but continues to correctly subtract 7 from it, give a point for each correct subtraction. For example, a participant may respond "92 – 85 – 78 – 71 – 64" where the "92" is incorrect, but all subsequent numbers are subtracted correctly. This is one error and the item would be given a score of 3.

7. Sentence repetition:

Administration: The examiner gives the following instructions: *"I am going to read you a sentence. Repeat it after me, exactly as I say it* [pause]*:* ***I only know that John is the one to help today****."* Following the response, say: *"Now I am going to read you another sentence. Repeat it after me, exactly as I say it [pause]:* ***The cat always hid under the couch when dogs were in the room****."*

Scoring: Allocate 1 point for each sentence correctly repeated. Repetition must be exact. Be alert for errors that are omissions (e.g., omitting "only", "always") and substitutions/additions (e.g., "John is the one who helped today;" substituting "hides" for "hid", altering plurals, etc.).

8. Verbal fluency:

Administration: The examiner gives the following instruction: *"Tell me as many words as you can think of that begin with a certain letter of the alphabet that I will tell you in a moment. You can say any kind of word you want, except for proper nouns (like Bob or Boston), numbers, or words that begin with the same sound but have a different suffix, for example, love, lover, loving. I will tell you to stop after one minute. Are you ready? [Pause] Now, tell me as many words as you can think of that begin with the letter F.* [time for 60 sec]. *Stop."*

Scoring: Allocate one point if the subject generates 11 words or more in 60 sec. Record the subject's response in the bottom or side margins.

9. Abstraction:

Administration: The examiner asks the subject to explain what each pair of words has in common, starting with the example: *"Tell me how an orange and a banana are alike"*. If the subject answers in a concrete manner, then say only one additional time: *"Tell me another way in which those items are alike".* If the subject does not give the appropriate response (fruit), say, *"Yes, and they are also both fruit."* Do not give any additional instructions or clarification.

After the practice trial, say*: "Now, tell me how a train and a bicycle are alike"*. Following the response, administer the second trial, saying: *"Now tell me how a ruler and a watch are alike".* Do not give any additional instructions or prompts.

Scoring: Only the last two item pairs are scored. Give 1 point to each item pair correctly answered. The following responses are acceptable:

Train-bicycle = means of transportation, means of travelling, you take trips in both;

Ruler-watch = measuring instruments, used to measure.

The following responses are **not** acceptable: Train-bicycle = they have wheels; Ruler-watch = they have numbers.

10. Delayed recall:

Administration: The examiner gives the following instruction*: "I read some words to you earlier, which I asked you to remember. Tell me as many of those words as you can remember."* Make a check mark for each of the words correctly recalled spontaneously without any cues, in the allocated space.

Scoring: Allocate 1 point for each word recalled freely without any cues.

Optional: Following the delayed free recall trial, prompt the subject with the semantic category cue provided below for any word not recalled. Make a check mark (3) in the allocated space if the subject remembered the word with the help of a category or multiple-choice cue. Prompt all non-recalled words in this manner. If the subject does not recall the word after the category cue, give him/her a multiple choice trial, using the following example instruction, *"Which of the following words do you think it was, NOSE, FACE, or HAND?"*

Use the following category and/or multiple-choice cues for each word, when appropriate:

FACE: category cue: part of the body multiple choice: nose, face, hand

VELVET: category cue: type of fabric multiple choice: denim, cotton, velvet

CHURCH: category cue: type of building multiple choice: church, school, hospital

DAISY: category cue: type of flower multiple choice: rose, daisy, tulip

RED: category cue: a colour multiple choice: red, blue, green

Scoring: No points are allocated for words recalled with a cue. A cue is used for clinical information purposes only and can give the test interpreter additional information about the type of memory disorder. For memory deficits due to retrieval failures, performance can be improved with a cue. For memory deficits due to encoding failures, performance does not improve with a cue.

11. Orientation:

Administration: The examiner gives the following instructions*: "Tell me the date today".* If the subject does not give a complete answer, then prompt accordingly by saying: *"Tell me the [year, month, exact date, and day of the week]."* Then say: *"Now, tell me the name of this place, and which city it is in."*

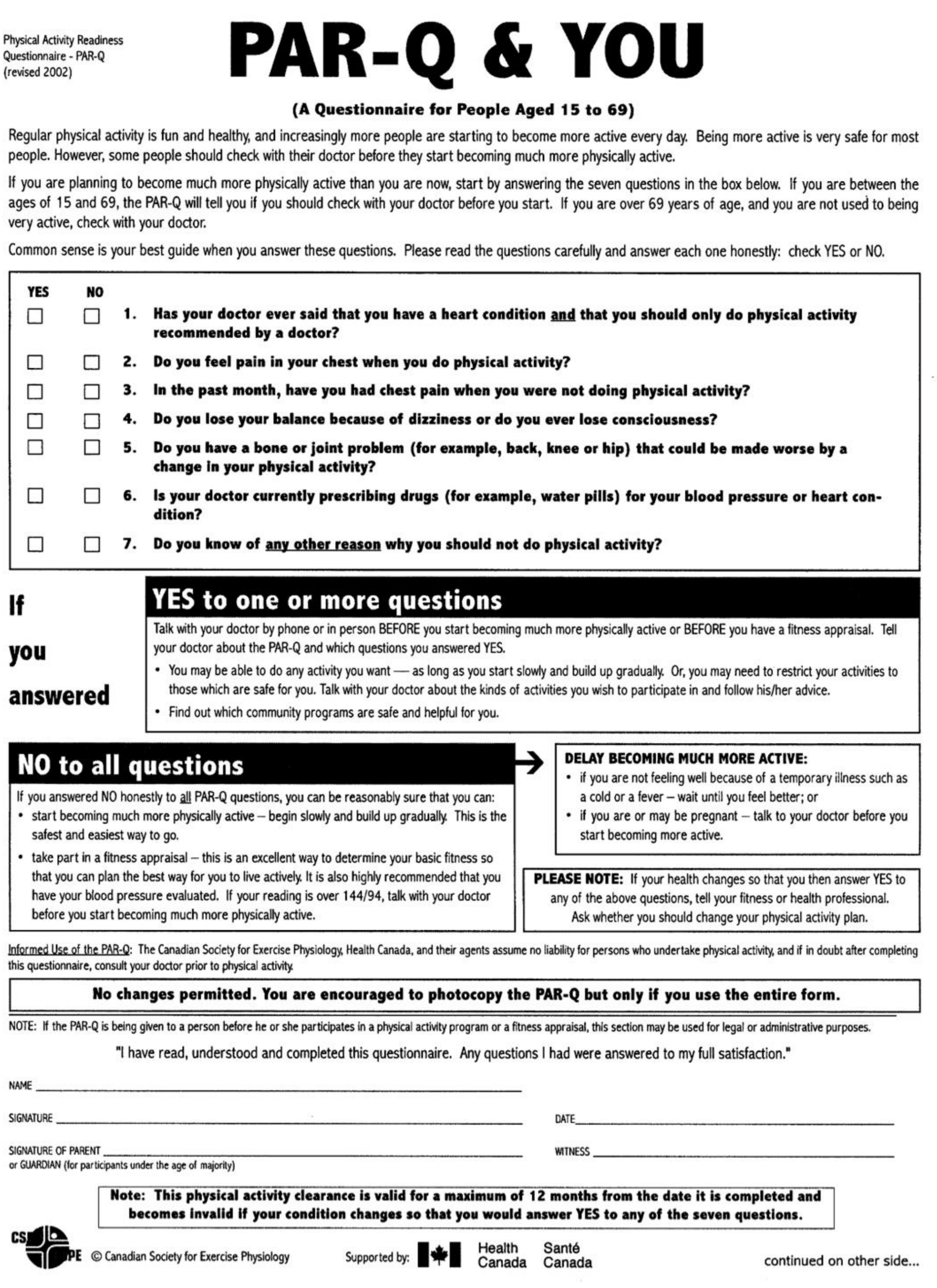
Scoring: Give one point for each item correctly answered. The subject must tell the exact date and the exact place (name of hospital, clinic, office). No points are allocated if subject makes an error of one day for the day and date.

<u>TOTAL SCORE:</u> Sum all subscores listed on the right-hand side. Add one point for an individual who has 12 years or fewer of formal education, for a possible maximum of 30 points. A final total score of 26 and above is considered normal.

Reference:

Nasreddine, Z. S., Phillips, N. A., Bédirian, V., Charbonneau, S., Whitehead, V., Collin, I., … Chertkow, H. (2005). The Montreal Cognitive Assessment, MoCA: a brief screening tool for mild cognitive impairment. *Journal of the American Geriatrics Society*, *53*(4), 695–699.

Appendix B
Physical Activity Readiness Questionnaire (PAR-Q)



Physical Activity Readiness
Questionnaire - PAR-Q
(revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	**NO**	
☐	☐	**1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?**
☐	☐	**2. Do you feel pain in your chest when you do physical activity?**
☐	☐	**3. In the past month, have you had chest pain when you were not doing physical activity?**
☐	☐	**4. Do you lose your balance because of dizziness or do you ever lose consciousness?**
☐	☐	**5. Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?**
☐	☐	**6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
☐	☐	**7. Do you know of any other reason why you should not do physical activity?**

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

→ **DELAY BECOMING MUCH MORE ACTIVE:**

- if you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- if you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME ______________________________

SIGNATURE ______________________________ DATE ______________________

SIGNATURE OF PARENT ______________________________ WITNESS ______________________
or GUARDIAN (for participants under the age of majority)

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

Supported by: Health Canada Santé Canada

continued on other side...

Appendix C
General Health and Physical Activity Questionnaires

General Health Questionnaire	
Gender	
Date of Birth (YYYY/MM/DD)	
Height	
Weight	
Health Concerns:	
Injury/Surgery	
Neurological Condition	
Cardiac Condition	
Other (diabetes, hypertension)	
Comments:	

Physical activity level for the elderly and physical activity barriers

How physically active are you?

(Check one answer on each line)

Rapa 1

Does this accurately describe you?

1	I rarely or never do any physical activity	Yes ☐ ☐ No
2	I do some **light** or **moderate** physical activities, but not every week.	Yes ☐ ☐ No
3	I do some **light** physical activity every week.	Yes ☐ ☐ No
4	I do **moderate** physical activities every week, but less than 30 minutes a day or 5 days a week.	Yes ☐ ☐ No
5	I do **vigorous** physical activities every week, but less than 20 minutes a day or 3 days a week.	Yes ☐ ☐ No
6	I do 30 minutes or more a day of **moderate** physical activities, 5 or more days a week.	Yes ☐ ☐ No
7	I do 20 minutes or more a day of **vigorous** physical activities, 3 or more days a week.	Yes ☐ ☐ No

Rapa 2

1	I do activities to increase muscle **strength**, such as lifting weights or calisthenics, once a week or more.	Yes ☐ ☐ No
2	I do activities to improve **flexibility**, such as stretching or yoga, once a week or more.	Yes ☐ ☐ No

<u>What prevents you from participating in physical activities?</u>

i. Cost
ii. Transportation problems
iii. Activities not available in the area
iv. Location not physically accessible
v. Location is too far
vi. Health condition limitation
vii. Time of activities not suitable
viii. Don’t want to go alone
ix. Personal or family responsibilities
x. Language related reasons
xi. Too busy
xii. Afraid of concerns about safety
xiii. Other (specify)

Appendix D
Postural stability and Falls Questionnaire (Adapted from Ashburn et al. 2008)

Definition of a fall : 'An event that results in a person coming to rest unintentionally on the ground or other lower level, not as the result of a major intrinsic event (individual) or overwhelming hazard'.

1. **Please indicate how many times you fell in the last 3months.** ___________________

   In the last year. ___________________

2. **How often do you fall :**
   0 Never
   1 Very rarely - about once a month
   2 Rarely - about once a week
   3 Often - about once a day
   4 Always - whenever walking
3. **Please answer the following questions :**

Where were you when you fell?

____

What were you trying to do at the time?

____

What do you think caused you to fall?

____

How did you land?

____

What injuries did you sustain? How did you get up again?

____

What health care did you receive?

____

Are you worried or concerned that in the future you might fall?

____

As a result of this concern, have you stopped doing some things you used to do or liked to do?

____

Appendix E
Anthropometric Data Collection

SUBJECT ID #: ________________________________

General

Body mass (kg)		**Height (mm)**		**Inter-ASIS Distance (mm)**	

Measurements (mm)

Left		**Right**	
Leg Length		**Leg Length**	
Knee width		**Knee width**	
Ankle width		**Ankle width**	
Shoulder offset		**Shoulder offset**	
Elbow width		**Elbow width**	
Wrist width		**Wrist width**	
Hand thickness		**Hand thickness**	

SUBJECT ID #: ________________________________

General

Body mass (kg)		**Height (mm)**		**Inter-ASIS Distance (mm)**	

Measurements (mm)

Left		**Right**	
Leg Length		**Leg Length**	
Knee width		**Knee width**	
Ankle width		**Ankle width**	
Shoulder offset		**Shoulder offset**	
Elbow width		**Elbow width**	
Wrist width		**Wrist width**	
Hand thickness		**Hand thickness**	

Appendix F
Nordic Walking Guidelines & Physical Activity Log

WARM-UP: Perform simple dynamic stretches and breathing exercises; 5-10 minutes

COOL DOWN: Decrease walking speed. After walking, stretch upper and lower body to relax the muscles; 5-10 minutes

STRETCH: Stretch out as needed during the Nordic walking portion of the program

WATER: Keep hydrated throughout each session

***NOTE: If fatigued or experience pain or discomfort during exercise, stop the exercise immediately.

Date (DD/MM/YYYY):

Session Number:

Activity	Completed	Time	Comments
Warm-up	☐		
Nordic walking	☐		
Cool-down	☐		

1. How do you feel after walking today (Scale from 1-10: 1 = Exhausted; 10 = Great)?

1 2 3 4 5 6 7 8 9 10

2. Do you feel that you followed the proper poling technique outlined above?

3. Did you encounter any issues during your exercise session?

4. Are there any additional comments you would like to make regarding today’s session?

Warm-Up Exercises

Breathing Exercise

Stand upright with poles in front (as shown). Rotate upper body left and right, inhaling deeply as you rotate. Coming back to start, exhale thoroughly.

Repetitions: 15 reps per side

Heel Raises

Stand upright with arms straight. Use poles for balance. Slowly lift heels off ground, rising onto toes. Slowly lower heels back down.

Repetitions: 10-15 reps

Leg Swings

Stand upright with arms straight. Use poles for balance. Swing your right leg from side to side (as shown). Next, swing you left leg from side to side.

Repetitions: 10-15 reps per leg

Kayaking

Stand upright, holding the poles on each end (as shown). Begin “paddling” to the right by rotating your upper hand back and down and bring your lower hand up. Repeat to the other side.

Repetitions: 10-15 reps per side

Cool Down/Stretching

Quad (Thigh) Stretch

Use poles for balance. Lift your right foot towards your buttocks until you feel a stretch in the front of your thigh. Hold this position. Repeat on the left side.

Hold: 30 seconds

Hip Flexor Stretch

Use poles for balance. Take a long stride with right leg. Bend the front knee, tilt pelvis, and lean back until you feel a stretch in front of hip. Hold this position. Repeat on the left side.

Hold: 30 seconds

Adductor (Groin) Stretch

Use poles for balance. Shift your body weight to left side (bend your knee). Keep your right leg straight and foot flat. You should feel a stretch in your right inner thigh. Hold this position. Repeat on the left side.

Hold: 30 seconds

Forward & Side Bends

Hold poles above head with straight arms. For both, begin by standing upright. First, bend forward at the hips, lowering as best you can toward the ground. Second, bend sideways as best you can.

Hold: 5 seconds (10 reps/side)

Appendix G
Background Information and Consent Form

Effect of Nordic walking on gait patterns and postural control in older adults

Principal Investigator:

Chris Dalton, BSc HK, MSc (Candidate)
School of Human Kinetics
Faculty of Health Sciences
University of Ottawa
200 Lees Avenue, Room E053
Ottawa, Canada, K1S 5S9
Telephone: 613-562-5800 #7356

Co-Investigator/Thesis Supervisor:

Julie Nantel, PhD., Assistant Professor
School of Human Kinetics
Faculty of Health Sciences
University of Ottawa
125 rue Université, Pavillon Montpetit, MNT 353
Ottawa, Canada, K1N 6N5
Telephone: 613-562-5800 #4025 / Fax: (613) 562-5497

Background: You are invited to participate in the abovementioned research study conducted by Chris Dalton and Dr. Julie Nantel. Please read this *Information Sheet* and *Consent Form* carefully and ask as many questions as you like before deciding whether to participate in this research study.

Purpose: Postural control and alignment during gait are highly important with regards to mobility and independence. However, as we age, changes to posture and gait can lead to mobility-related disabilities as well as undesired incidences such as falls, which may in turn lead to declines in independence and autonomy.

The purpose of this research study is to better understand the effect of Nordic walking poles on alignment and control of posture in older adults as well as its impact on the ankle, knee and hip joints.

This study aims to enrol 15 participants aged 55 years of age and older.

Study Procedure: If you agree to participate in this study, you will be asked to attend two testing session at the Movement and Performance lab (Room E053, Lees Campus, University of Ottawa). These two sessions will take place pre and post to an 8-week exercise program. For these sessions, you will be asked to complete tasks that involve walking, both with and without the use of Nordic walking poles. The first task involves walking along a 5 metre walkway, repeating this task a total of 6 times (3 times with poles and 3 times without poles). The second task involves walking back and forth along a hallway for a total of 6 minutes, repeating this two times (1 time with poles and 1 time without poles). Also, as part of the pre-testing session, you will be asked to complete four short questionnaires about your perceived health related quality of life and mood, your balance, and your gait. The first session will take approximately 1.5-2 hours to complete. The second session will take approximately 1 hour to complete.

Further, in between the two testing sessions, participants will be asked to complete an 8-week Nordic walking program. The program is to be performed at a frequency of two times per week for approximately 1 hour per session over the 8 weeks. You will receive hands-on instruction regarding pole use from a certified Nordic pole walking instructor (Chris Dalton). You will be provided with a set of poles as well as folders containing warm-up and cool down exercises that are to be performed before and after each Nordic walking session. Also, you will be asked to complete a simple questionnaire after each session regarding how you felt and if there were any issues during the session.

Risks and Discomforts: The equipment used for movement analysis is non-invasive and the risks involved in participating in this experiment are minimal. That is, the risks are no greater than the risks experienced in everyday life. However, you might experience fatigue, as you will be asked to perform different motor tasks and maintain focused attention throughout the experiment. In attempt to ensure that you do not become fatigued, short pauses have been schedules between the tasks and longer/more frequent pauses can be taken upon request.

Benefits: While there are no direct benefits to you from participating in this study, this research is important to gain a greater understanding of the effect that the use of Nordic walking poles can have on our posture/postural control and our gait. Results from this research could lead to implementation of Nordic walking programs within rehabilitation and fitness settings as well as retirement communities. This could be important towards providing a simple and effective form of exercise for older adults and remain active into older age.

Study Costs: You will not be paid to take part in this research study. However, small compensations will be given in the form of a set of new Nordic walking poles to keep.

Anonymity and Confidentiality: All information and data collected are coded to maintain confidentiality. Specifically, raw data will be stored using an alphanumeric coding system so that no one will be able to identify you, as your name will not appear on these files. The data will be analyzed on password-protected computers that only the researchers directly involved in the study will have access to. Once analyze, the data will be kept in Room E053, Lees Campus, in locked filing cabinets and only the researchers directly involved in the study will have access to your data. No records bearing your name will leave the institution.

The data collected in this study will be published in scientific journals. The data will be kept for a period of 10 years post-publication and will subsequently be destroyed by the physical resources service of the University of Ottawa.

Voluntary Participation:

For the entire duration of the study, it is fully understood that you may refuse to participate or withdraw from the study at any time, without question. As well, you can ask the researcher any question about any part of the research being conducted at any time.

INFORMED CONSENT OF PARTICIPANT

Research involving human participants requires written consent of the participants.

I, ___________________________________, hereby volunteer to participate in the study entitled **"Effect of Nordic walking on gait patterns and postural control in older adults"**. I have read the information presented in the above background information and I had the opportunity to ask questions to the investigators. I understand that my participation in this study, or indeed any research, may involve risks that are currently unforeseen.

I recognize that there will be no direct benefit to me from my participation in this study.

I understand that if I have any questions regarding the study, I may contact Chris Dalton at 613-562-5800 ext. 7356 or Dr. Julie Nantel at 613-562-5800 ext. 4025. If I have any questions or complaints with regards to the ethical conduct of this study, I may contact the Protocol Officer for Ethics in Research, University of Ottawa, Tabaret Hall, 550 Cumberland Street, Room 154, Ottawa, ON, K1N 6N5, tel.: 613-562-5387, email: ethics@uottawa.ca.

I have been given a copy of this Background Letter and Consent Form for me to keep.

Signature of Participant: ____ Date:
.

Signature of Researcher: ____ Date:
.