A pilot randomized controlled trial of exercise to improve walking energetics among older adults with mobility limitation: The HealthySteps Study

by

Kristina J. Collins

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Name: **Kristina Collins**

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Title: **A pilot randomized controlled trial of exercise to improve walking energetics among older adults with mobility limitation: The HealthySteps Study**

Examining Committee: **Chair:** **Dr. Thomas Claydon**
Associate Professor

Dr. Dawn Mackey
Senior Supervisor
Assistant Professor

Dr. Angela Brooks-Wilson
Supervisor
Professor

Dr. Jennifer Schrack
Supervisor
Assistant Professor
Epidemiology and Center on Aging and Health
Johns Hopkins University

Dr. Kristin Campbell
External Examiner
Associate Professor
Department of Physical Therapy
University of British Columbia

Date Defended/Approved: July 11, 2017

Ethics Statement

The author, whose name appears on the title page of this work, has obtained, for the research described in this work, either:

a. human research ethics approval from the Simon Fraser University Office of Research Ethics

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Abstract

Mobility is a fundamental component of healthy aging; however, mobility limitation is a prevalent, energetically costly problem among older adults. We conducted a pilot randomized controlled trial to compare the effects of two, 12-week exercise interventions (timing and coordination, TC; aerobic walking, AW) to an active control (stretching and relaxation; SR) on outcomes related to mobility among community-dwelling older adults with mobility limitation (n=72). At 12 weeks, TC reduced mean energy cost of walking by 13-15% versus SR. Among those with high baseline cost, TC reduced mean energy cost by 20-26% versus SR. Reductions were maintained at 24-week follow-up. AW had no effect at 12 or 24 weeks. Fatigability, daily physical activity, endurance, physical function, and life-space mobility did not change with TC or AW versus SR at 12 or 24 weeks. In summary, 12 weeks of TC, but not AW, improved walking economy among older adults with mobility limitation.

Keywords: older adults; mobility; energy cost of walking; fatigability; exercise; randomized controlled trial

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List of Acronyms

AW	Outdoor Aerobic Walk Training
MVPA	Daily Moderate-to-Vigorous Physical Activity
RPE	Rating of Perceived Exertion
SR	Stretching and Relaxation Training
T0	Baseline
T1	12-Week Follow-Up
T2	24-Week Follow-Up
TC	Timing and Coordination of Gait Training
$\dot{V}O_2$	Rate of Oxygen Consumption
$\dot{V}O_2max$	Maximal Rate of Oxygen Consumption

Chapter 1. Introduction

1.1. Older Adult Mobility

Mobility is necessary to maintain independent functioning and autonomy, and it is fundamental to continued participation in processes that optimize health and well-being across the life-course (*Active Ageing: A Policy Framework*, 2002). For example, mobility is necessary to access commodities, make use of neighbourhood facilities, and participate in meaningful social, cultural, and physical activities. Mobility also promotes healthy aging as it relates to the basic human need of physical movement (Rantanen, 2013). Mobility is broadly defined as “the ability to move oneself (either independently or by using assistive devices for transportation) within environments that expand from one’s home, to the neighbourhood, and to regions beyond” (Webber, Porter, & Menec, 2010).

In this thesis, I investigate if targeted exercise training can reduce the energy cost of walking and improve markers of mobility among older adults. In Chapter 1, I provide a concise review of three research areas. Firstly, I introduce the determinants of older adult mobility, discuss the impact of mobility limitation on older adults, and highlight important risk factors for mobility limitation. Secondly, I examine age-related changes in gait and present a framework proposing that walking energetics underlie mobility loss. Thirdly, I discuss current and emerging interventions aimed to improve walking energetics. I close Chapter 1 by hypothesizing that exercise training can reduce the energy cost of walking and alleviate difficulty in walking, and contribute to positive changes in older adult mobility.

1.1.1. Determinants of Mobility

To conceptualize mobility, Webber and colleagues (Webber et al., 2010) have proposed a theoretical framework of mobility that takes an interdisciplinary approach that addresses the complexity of factors influencing mobility. Due to the broad definition of mobility, the framework includes five main categories of interrelated determinants that influence mobility throughout the life-course: cognitive, psychosocial, physical, environmental, and financial. It also emphasizes that gender, culture, and biography greatly impact the five determinants of mobility throughout an individual's life-course and across the life spaces in which they are mobile (Webber et al., 2010).

Cognitive Determinants. Cognitive determinants of mobility include such factors as mental status, memory, processing speed, and executive function (Webber et al., 2010). For example, deciding to go from one's home to the grocery store requires executive function to plan, organize, and complete the task; individuals with lower executive function may require assistance to help them plan their trip to the grocery store, whereas, those with higher executive function will be able to appropriately determine whether they will drive themselves or use another form of transportation. Mild cognitive impairment and dementia can also seriously challenge older adult mobility, especially when interacting with the environment outside of one's home (Webber et al., 2010).

Psychosocial Determinants. Psychosocial determinants are those factors that impact confidence, self-efficacy, mental health, social support, coping behaviours, and relationships that affect interest or motivation to be mobile (Webber et al., 2010). Expanding upon the example above, whether an older adult will travel to the grocery store can be influenced by their motivation for social interactions. It is more likely that an older adult will be mobile if there is a social component to their travel, whether it is routinely going shopping with a friend, or having a personal interaction with the grocery store cashier.

Physical Determinants. Physical determinants include reaction time, balance, biomechanics, vision and hearing impairments, pain, injury, chronic disease, and physical activity engagement (Webber et al., 2010). For example, pain while walking may discourage older adults from using active modes of transportation to travel to and shop at the grocery store or even getting outside of their home regularly.

Environmental Determinants. Environmental determinants include walkability, stairs, lighting, outdoor terrain, slippery surfaces, weather conditions, modes of transportation, density, safety, and geographical location of one's home to services (Webber et al., 2010). For example, the environment in which an individual interacts greatly influences the extent and frequency for an older adult to be mobile throughout their community. Sidewalks with smooth terrain and good lighting positively impact older adults’ mobility, as these conditions are perceived as safe and welcoming for older adults with impaired balance or physical limitations to participate in active transportation and maintain their mobility.

Financial Determinants. Financial determinants include income and economic resources (Webber et al., 2010). For example, older adults with higher incomes have access to more economic resources. If an older adult with high income requires assistance to travel to and from the grocery store, he/she can more easily hire in-home support to help, while another older adult with low income who requires assistance cannot afford to hire in-home care to help with transporting groceries to their home, therefore, limiting their mobility.

Gender, Culture, and Biography. Each determinant is largely affected by an individual’s experiences, opportunities, and behaviours based on their gender, culture, and biography (Webber et al., 2010). This framework recognizes these factors and how they influence mobility throughout the life-course. For example, mobility limitations are not equally distributed amongst those with and without a spouse; those without a spouse or partner have worse mobility (Umstattd Meyer, Janke, & Beaujean, 2014).

Life-Space. Life spaces are incorporated into the framework, such that as the levels of life-space expand from one’s home, to their neighbourhood, to their community and beyond, there are increasing factors, either in number or weight, that influence mobility (Webber et al., 2010). For example, at the level of one’s home, each determinant has fewer factors that contribute to overall mobility, as the home is a relatively known and stable setting; whereas, at the level of the community, the environment is constantly changing and this adds factors to each determinant that are of greater importance outside the home.

The determinants of mobility interact with each other to define an older adult’s mobility status. For example, if an older adult is both confident in their physical ability and physically capable of transporting themselves to the grocery store, then psychosocial and physical determinants would be positively influencing the individual’s ability and interest in being mobile beyond the confines of their home. The determinants, and the interactions between determinants, allows for the conceptualization of mobility in different contexts (Webber et al., 2010). The determinants of mobility connect interdisciplinary mobility research and emphasize the complex interactions between factors that impact mobility. As Webber's comprehensive framework of mobility outlines, the maintenance of mobility greatly influences how older adults engage with their surroundings and their ability to remain active and independent throughout their life course (Webber et al., 2010). In this thesis, I focus on testing the ability of exercise to improve physical determinants of mobility in older adults, including energy cost of walking, fatigability, physical activity, endurance, physical function, and life-space mobility.

1.1.2. Mobility Limitation

Over the past decade, mobility limitation (typically defined as self-reported difficulty walking one-quarter mile or climbing one flight of stairs without resting due to a health or physical problem) has been consistently reported by 30-40% of persons aged 65 years and older in Canada and USA (Fuller-Thomson, Yu, Nuru-Jeter, Guralnik, & Minkler, 2009; Shumway-Cook, Ciol, Yorkston, Hoffman, & Chan, 2005; Statistics Canada, 2006). However, because many older adults do not engage in regular volitional walking and are therefore not aware of their own difficulties, the actual prevalence is likely higher (Fried, Bandeen-Roche, Chaves, & Johnson, 2000; Simonsick et al., 2008). Moreover, the burden of mobility limitation is expected to grow significantly in the future. As in many developed countries, Canada's population is aging. In 2017, 16.9% (5.9 million) of Canadians are over the age of 65 (Statistics Canada, 2017). And by 2036, it is projected that older adults will account for approximately 23% of the Canadian population (Census, 2016). With this growing number of older adults, it is projected that the number and proportion of older adults with mobility limitation could nearly double by 2036 (Statistics Canada, 2006).

Mobility limitation is a precursor to more severe mobility disability, and increased dependence in activities of daily living and loneliness (Perissinotto, Stijacic Cenzer, & Covinsky, 2012; Verbrugge & Jette, 1994), entry into nursing homes (Foley et al., 1992), and mortality (Hirvensalo, Rantanen, & Heikkinen, 2000; Newman et al., 2006). With an aging population in Canada, addressing mobility limitations is an important public health concern, and additional research and action are imperative to combat mobility limitations and the associated consequences (Statistics Canada, 2006).

Several clinical and epidemiological studies have been conducted to assess an array of risk factors for mobility decline (Stuck et al., 1999). Overall, the findings of these studies have revealed that age-related decline in mobility is multifactorial in which demographic and lifestyle factors, health status, and physiological and psychological functioning contribute to observed changes in mobility over time. Demographic factors that are associated with increased risk for mobility limitations are advanced age, female sex, low socioeconomic status, and income level. Higher education is associated with a reduced risk of mobility decline (Brown & Flood, 2013; Shumway-Cook et al., 2005; Stuck et al., 1999). Lifestyle factors linked to mobility decline are low levels of physical activity, current or former smoking, and no or heavy drinking, such that low- to moderate-alcohol consumption is associated with greater mobility (Brown & Flood, 2013; Shumway-Cook et al., 2005; Stuck et al., 1999). Health status is a strong predictor of mobility decline among older adults. Multiple comorbidities are risk factors for mobility limitations, including blood pressure (e.g., hypertension), cardiovascular (e.g., angina, heart failure, and stroke), gastrointestinal, hematological, metabolic (e.g., diabetes), musculoskeletal (e.g., arthritis, hip fracture or broken bones, and joint or back pain), neurologic, pulmonary diseases, and cancer (Brown & Flood, 2013; Ferrucci et al., 2000; Shumway-Cook et al., 2005; Stenholm, Shardell, Bandinelli, Guralnik, & Ferrucci, 2015; Stuck et al., 1999). Additionally, cognitive and visual impairments, poor or fair self-rated health, multiple medication use, and a history of falls are associated with increased risk for mobility decline. Normal body mass index is protective against mobility limitations. Psychosocial functioning, including anxiety, depression, and social isolation are risk factors for mobility decline (Stuck et al., 1999).

1.2. Age-Related Changes in Walking Energetics

With age, the physical determinants of mobility change. The Baltimore Longitudinal Study of Aging found that the ability to maintain a fast gait speed over moderate distances declines with age (Schrack, Simonsick, & Ferrucci, 2013). Gait speed and energy cost of walking have a U-shaped relationship, at which preferred walking speed in healthy adults is located at the minimum energy cost (Zarrugh, Todd, & Ralston, 1974). The relationship holds for individuals with abnormal gait; however, the curve is shifted upward or to the left, which demonstrates that walking is more energetically costly and slower for older adults with impaired gait (VanSwearingen &

Studenski, 2014). With age, peak walking energy and maximum energy expenditure decline with age (Schrack et al., 2013). In addition, the energy cost of walking rises progressively with aging, meaning older adults use more energy to walk a given distance at a given speed compared to young adults (Schrack et al., 2013). Among healthy young adults, walking at preferred speed averages approximately 0.15 mL O_2/kg/m, whereas, older adults with difficulty walking may use up to two times this energy to walk at preferred speed (VanSwearingen et al., 2009; Waters & Mulroy, 1999). These changes suggest that walking becomes slow and less economical with increasing age.

In addition, as maximum energy expenditure declines and the energy cost of walking increases, the energy available for productive and essential activity becomes progressively smaller (Schrack, Zipunnikov, Simonsick, Studenski, & Ferrucci, 2016). Young and healthy individuals perform most activities of daily living at a workload well below their maximum energetic capacity and can sustain such activity for a prolonged period (Ferrucci et al., 2016). With age, overall compression and downward shift of available energy reduces this capacity substantially, and even the most basic tasks can challenge energetic limits. As a consequence, walking can be physiologically demanding for older adults, occupying up to 90% of reserve aerobic capacity (Fiser et al., 2010), likely contributing to high perceived fatigability during walking (Fiser et al., 2010; Richardson, Glynn, Ferrucci, & Mackey, 2015).

The mechanisms that contribute to an increase in the energy cost of walking among older adults are not clearly understood – it is most likely a combination of multiple factors, including impaired aerobic capacity and metabolic processes and movement inefficiencies that result from age-related changes in gait biomechanics and movement control. Movement inefficiencies have been widely studied among aging populations. Biomechanics, in particular the kinematics and kinetics, of gait change over time. Older adults often experience decreased gait speed, reduced hip, knee, ankle, pelvic and trunk range of motion, and reduced ankle and knee power. (Aboutorabi, Arazpour, Bahramizadeh, Hutchins, & Fadayevatan, 2015). Increased trunk flexion, less hip and knee extension in mid- to late-stance, reduced ankle dorsiflexion angle at heel-strike, and decreased ankle plantarflexion and power during toe-off are associated with aging (Wert, Brach, Perera, & VanSwearingen, 2010). In addition, changes in movement control of gait are observed among older adults, such that stride length, cadence, and gait symmetry decrease, and stride width and step time increase. This is to say that the timing of steps is disrupted, as there are increases in double-support time, stance time, reduced rate of forward momentum, and loss of rhythm while transitioning from stance to swing phases (Wert et al., 2010). These factors appear to interact and result in alterations to the timing and coordination of gait with age, which coincide with alterations in the energy cost of walking.

1.2.1. Energetic Pathway to Mobility Loss

An emerging body of evidence supports the hypothesis that high energy requirements for daily activities, such as walking, play a central role in the development of mobility limitation among older adults (Fiser et al., 2010; Schrack, Simonsick, & Ferrucci, 2010b; Schrack et al., 2013; VanSwearingen et al., 2009). Schrack and colleagues (Schrack et al., 2010b) contend that, as the energy required for usual walking approaches maximum energy expenditure, thus inducing fatigue, compensation strategies, such as reducing walking speed, are used to ensure individuals remain within the limits of their energetic boundaries. Simply, they hypothesize that the high energy cost of walking contributes to high fatigability, which negatively impacts mobility. Fatigability is recognized as a major source of activity limitation, such that older adults opt to walk more slowly or walk less to minimize feelings of fatigue (Eldadah, 2010; Fiser et al., 2010; Gill, Desai, Gahbauer, Holford, & Williams, 2001; Vestergaard et al., 2009). This compensatory strategy can lead to reduced physical activity and, in turn, endurance, physical function, and mobility decline because of deconditioning.

This hypothesis stresses the importance of older adults retaining the ability to perform essential activities, such as walking, at a moderate or submaximal level to maintain mobility. Schrack and colleagues (Schrack et al., 2010b) postulate that interventions that reduce the energy cost of walking could decrease fatigability, and thereby may increase daily physical activity, endurance, physical function, and life-space mobility. Below, I will briefly outline the relevance and measurement of these concepts, as they are key outcomes in my thesis.

Energy Cost of Walking. Energy cost, commonly referred to as metabolic cost, energy expenditure, or energy consumption, measures the rate of physiological work, as determined by the amount of metabolic energy consumed or ATP used, by a specific motor task (VanSwearingen & Studenski, 2014). It is defined by 1) the rate of oxygen delivered through the blood to the skeletal muscles, and 2) the rate of oxygen extracted and used by the muscles (G. A. Brooks, Fahey, & Baldwin, 2000). A widely used proxy measure for the energy cost of walking is the rate of oxygen consumption ($\dot{V}O_2$) measured over a given distance at a constant submaximal speed. After several minutes working at a constant load, $\dot{V}O_2$ reaches a level sufficient to meet the energy demands of the tissue and the energy cost plateaus to achieve a steady state condition (Waters & Mulroy, 1999). In relation to the above hypothesis, the ability to perform functional tasks, such as walking, is linked to energy expenditure. For example, if the energy cost of an activity exceeds a certain threshold, the activity may be performed at a lower intensity or it may not be completed at all (Schrack, Simonsick, Chaves, & Ferrucci, 2012). In this paradigm, high energy cost of walking can have profound negative implications on an individual's overall mobility status.

Fatigability. Fatigability describes how fatigued an individual is in relation to performance of a defined activity with a specific intensity, volume, and frequency (Eldadah, 2010). This outcome normalizes subjective measures of fatigue in relation to performing a standardized activity to control for self-pacing and allow for meaningful comparisons between individuals (Eldadah, 2010; Simonsick, Schrack, Glynn, & Ferrucci, 2014). Fatigability has recently emerged as a construct to systematically measure fatigue, which is commonly reported among many older adults (Simonsick et al., 2014). Reports have shown that higher fatigability is associated with greater frequency of global fatigue symptoms, such as unusual tiredness and lower energy levels, and worse physical performance (Simonsick et al., 2016). Longitudinal investigations of fatigability measures are still needed to determine the usefulness in predicting relevant health outcomes (Simonsick et al., 2014). Fatigability has been linked to walking energetics; thereby, reducing the energy cost of walking may reduce fatigability among older adults (Richardson et al., 2015).

Daily Physical Activity. Daily physical activity is "any bodily movement produced by the skeletal muscles that requires energy expenditure" (Canadian Society of Exercise Physiology, 2012). Physical activity is a modifiable behavioural risk factor that is an important determinant for health, fitness, and daily functioning throughout the life course (Colley et al., 2011). Walking is the most common form of physical activity amongst older adults, which makes it critical for the maintenance of functional independence. Low levels of daily physical activity are associated with mortality and many age-related health conditions (Mackey et al., 2011; Schrager, Schrack, Simonsick, & Ferrucci, 2014). Daily physical activity is linked to energy availability (Schrager et al., 2014); thus, reducing the energy cost of walking increases available energy, which facilitates increases in daily physical activity.

Physical Function. Physical function is the ability to perform mobility tasks and activities of daily living that are essential for maintaining independence and autonomy (Brach, VanSwearingen, Newman, & Kriska, 2002). Performance based physical measures are typically used to assess physical function, which can include balance tasks, ability to stand-up from a chair, and leg strength assessments. A reduction in the energy cost of walking has been associated with greater physical function amongst older adults with mobility impairments (Wert et al., 2010).

Endurance. Endurance is a measure of aerobic fitness, or the capacity to do work, which is predictive of morbidity and mortality among older adults (VanSwearingen & Studenski, 2014). Endurance is often quantified by the maximal rate of oxygen consumption ($\dot{V}O_2max$), which approximates the maximal amount of energy that can be expended within a day (Schrack et al., 2010b). However, it is difficult to assess endurance in older adults using a maximal exercise test because of safety concerns outlined by exercise testing guidelines, required oversight by medical professionals, and high equipment costs (Simonsick, Montgomery, Newman, Bauer, & Harris, 2001). Instead, extended overground walking tests have been used to assess endurance in community dwelling older adults (Newman et al., 2006). Although reducing the energy cost of walking will not directly impact endurance, lowering the energy cost of walking can increase the energy available to complete daily physical activities that conditions older adults to improve their endurance.

Life-Space Mobility. Traditional performance-based measures of mobility assess the ability to complete functional tasks at a given point in time. In contrast, life-space mobility incorporates the extent, frequency, and independence of movement within the environment over a period of time (Mackey et al., 2014). The Life-Space Assessment (Stalvey, Owsley, Sloane, & Ball, 1999) is a novel tool that measures an individual's mobility in relation to 1) the distance they move from their home to beyond their city 2) the frequency of movement per week, and 3) whether the movement is completed independently. In accordance with the energetic pathway to mobility loss hypothesis, energy is diverted toward the essential systems that maintain homeostatic regulation due to reduced available energy with age. Since skeletal muscles demand high amounts of energy, decreased mobility develops to allow for greater energy utilization toward the regulation of homeostasis (Schrack et al., 2010b). With this reasoning, reducing the energy cost of walking would allow for more movement and the ability to move throughout one's environment and increase life-space mobility measurements.

1.3. Interventions to Modify Walking Energetics

1.3.1. Impairment-Based Training

Traditionally, exercise interventions have been implemented to mitigate lower limb impairments related to walking difficulty (Brach & VanSwearingen, 2013). These multifactorial interventions that focus on impairments associated with age-related changes include strength, flexibility, and endurance training, with the primary goal to improve the physiologic capacity of the body systems involved in movement, and the secondary goal to relieve walking difficulty. By this notion, resistance training is used to increase the size and quality of lower limb muscle fibers, which enhances muscular strength and power (Liu & Latham, 2009). Stretching is used to increase joint range of motion, which increases muscle length or modifies proprioception of the lower limbs to improve joint functioning in the lower limbs. Endurance training is used to enhance delivery and extraction of oxygen to muscle fibers, which improves exercise tolerance for sustained movement during walking. Although standard exercise interventions that target deficiencies in strength, flexibility, and endurance have led to improvements in physical function, they do not appear to reduce the energy cost of walking (Mian et al., 2007; VanSwearingen et al., 2009). An impairment-based intervention approach that improves the capacity of the body may not be an optimal strategy to directly improve walking difficulty because this type of training does not update how the body should utilize its increased capacity for movement (Brach & VanSwearingen, 2013). Rather, training that aims to reduce the energy cost of walking and incorporates goal-oriented motor skill training may have a greater effect on reducing functional walking difficulties among older adults.

1.3.2. Motor Skill Training

Timing & Coordination of Gait Training

Walking is a highly skilled motor task, acquired through motor learning, which requires complex interactions between the motor system, sensory, control, and cognitive functions (VanSwearingen & Studenski, 2014). Walking integrates the locomotor pattern of stepping with the cyclic biomechanical phases of gait, while managing the postural demands to keep the body in an upright position in a smooth, automatic, and efficient manner. Developed by physical therapists, timing and coordination of gait training is based on task-oriented motor skill training (Brach & VanSwearingen, 2013; VanSwearingen & Studenski, 2014). Timing and coordination of gait training targets correcting biomechanical and neuromuscular deficits in the activation of stepping patterns, and aims to integrate these patterns with postures involved in each phase of the gait cycle. It does this by using task-oriented, progressive stepping and walking tasks, and treadmill-paced practice (VanSwearingen, Perera, Brach, Wert, & Studenski, 2011). The stepping and walking tasks provide recent and relevant movement experiences in walking, which informs the neural circuity that the capacity of the body's systems have changed and they need to be updated in order for older adults to select a correct motor plan (V. B. Brooks, 1986). The goal is to train the older adult to select an appropriate motor plan for a given walking task that minimizes the neural, muscle, and joint motion requirements to successfully complete the task (Brach & VanSwearingen, 2013; Brach et al., 2015; V. B. Brooks, 1986). With each movement experience, more information is gained and adjustments are made to the motor plan selection for various changes in limb positions, muscle activation, and postural control (Brach & VanSwearingen, 2013).

Four components of task-oriented motor skill training were included in the development of the timing and coordination of gait training program (Brach & VanSwearingen, 2013): defined movement goal; move to gain knowledge; practice to refine and develop a repertoire of motor plans; and challenges to select the optimal motor plan. These components provide different movement experiences which allow the body to learn and adapt to task demands.

1. *Defined movement goal.* Defining the goal of the task limits the degrees of freedom and increases the likelihood that the appropriate neuromuscular

circuitry will be activated to generate the desired motor sequence of muscles and movements (Brach & VanSwearingen, 2013). Having a defined goal for step initiation in gait, such as ‘step across’, initiates forward momentum within the gait cycle. It does not require older adults to consciously focus their attention on recruiting specific muscles or timing the movement series; rather, by stepping across, the center of mass automatically accelerates forward to continue the gait cycle.

2. *Movement to gain knowledge.* Movement through different muscle activation patterns, which requires the smooth transition between agonist and antagonist muscle groups within the gait cycle, facilitates experience and movement-related feedback of the locomotor pattern of walking (Brach & VanSwearingen, 2013). Moving through different stepping patterns, such as ‘step backward and across’ prior to stepping forward and across, provides the experience of smoothly moving the body’s center of mass without asking an older adult to consciously think about weight shifting and progression.

3. *Practice to refine and develop a repertoire of motor plans.* Accurate practice of the selected motor plan drives experience-dependent changes in neural connectivity (Brach & VanSwearingen, 2013). First, experience with a given task is required to select an accurate motor plan. Second, repetition is needed to become skilled at the task. Repeating the same stepping and walking patterns during multiple training sessions promotes skilled movement. Once the mover becomes skilled, the stepping and walking patterns are incorporated into modified tasks at subsequent sessions, promoting refinement of the motor skill acquisition.

4. *Challenges to select the optimal motor plan.* Challenges to the accuracy, amplitude, and direction of movement enhances motor skill acquisition (Brach & VanSwearingen, 2013). The overall goal is to promote problem-solving and to focus on the movement goal of the task, which minimizes attention on the specific task components. By introducing challenges in a controlled setting, the motor program is able to enhance its ability to recognize, select, and modify motor plans to accomplish tasks encountered in daily life. Walking in

an oval path or walking past another individual are tasks that add variability to the motor program and promote the expansion of motor skill.

Throughout each component, feedback of successful task performance enhances motor skill outcomes, as the individual's neuromuscular system is rewarded, which reinforces the motor plan selection (VanSwearingen & Studenski, 2014).

Timing and coordination of gait training has been implemented in two randomized control trials (Brach et al., 2015; Brach, VanSwearingen, Perera, Wert, & Studenski, 2013; VanSwearingen et al., 2009, 2011). In the first study, among older adults selected for slow and variable gait, 12 weeks of one-to-one physical therapist instructed timing and coordination training reduced the energy cost of walking by 15% (0.10 mL of O_2/kg/m) compared to a standard exercise group (VanSwearingen et al., 2009). Furthermore, among those with high baseline energy cost (>median across all participants), the timing and coordination of gait training reduced the energy cost of walking by 0.15 mL of O_2/kg/m compared to the standard exercise group. In the second study, among older adults with subclinical gait dysfunction, 12 weeks of timing and coordination of gait training increased the number of participants who had a normal energy cost of walking, although the mean energy cost of walking was not reduced over the intervention compared to the standard exercise group (Brach et al., 2013).

In addition to reductions in the energy cost of walking, timing and coordination of gait training has been reported to increase walking confidence, gait speed, and motor control during walking tasks, and decrease self-reported disability compared to standard exercise (Brach et al., 2013; VanSwearingen et al., 2009). Timing and coordination of gait training has also improved double support time variability, the time spent with two feet in contact with the ground, and led to greater improvements in the smoothness of walking, both markers of motor skill, compared to standard exercise (Brach et al., 2015). It is important to note that walking endurance also increased in both the timing and coordination group and the standard exercise group, but no significant differences were observed between groups (Brach et al., 2013). Physical function, physical activity, and lower-extremity functioning have also been assessed in subsequent studies; however, no differences were found between pre- and post-measurements. Definitive trials are still needed to assess these outcomes (Brach et al., 2013; VanSwearingen et al., 2011).

1.4. Thesis Objectives

1.4.1. Rationale

The population of older adults in Canada will almost double in the next 20 years; therefore, the prevention and treatment of age-related mobility limitation is a major clinical and public health priority. Although there have been promising findings from previous trials of task-oriented motor skill training, it remains unknown whether a reduction in energy cost can be sustained following timing and coordination of gait training cessation, and there has been limited investigation of the intervention effects on fatigability, daily physical activity, endurance, physical function, and mobility. Moreover, the effectiveness of the timing and coordination of gait training intervention has not been reported when delivered in small-group settings by certified fitness instructors to community-dwelling older adults. Such a delivery mechanism would be more scalable and cost effective than the one-to-one physical therapist led training used in the past.

Alternatively, aerobic conditioning and walking practice may improve walking energetics. Aerobic exercise improves oxidative metabolism in the active muscles and practice is a fundamental component of motor learning to enhance motor skill. Thus, the regular practice of walking may also improve gait efficiency, but no randomized controlled trial to date has assessed the effect of aerobic walking on the energy cost of walking.

1.4.2. Objective

The objective of my thesis was to test the hypothesis that two independent, 12-week, twice-weekly small-group exercise programs (timing and coordination; aerobic walking) could reduce the energy cost of walking and fatigability, and increase daily physical activity, endurance, physical function, and life-space mobility among community-dwelling older adults with mobility limitation, relative to an active control (stretching and relaxation).

In my thesis, I use data from the HealthySteps Study, a pilot randomized control trial of exercise training in older adults with mobility limitations. In Chapter 2, I describe the design and methods of the study. In Chapter 3, I report the effects of the exercise interventions on the study's primary and secondary outcomes. Finally, in Chapter 4, I discuss the findings, limitations, and future directions of this research.

Chapter 2. Methods

2.1. Study Design

We conducted a three-arm, 12-week, pilot randomized controlled trial of exercise among older adults with mobility limitation who were able to ambulate independently (ClinicalTrials.gov #NCT01740505). Participants were assessed at three time points: baseline (T0); 12-weeks (end of intervention phase, T1); 24-weeks (end of maintenance phase, T2). The trial was approved by the Research Ethics Boards at Simon Fraser University and Vancouver Coastal Health Research Institute, and was conducted at the Centre for Hip Health and Mobility in Vancouver, British Columbia, from February to November 2013. All participants provided written informed consent.

2.2. Recruitment

Recruitment was primarily focused on newspaper, poster, and email advertisement in the Vancouver and Burnaby area. Newspapers targeted were the Vancouver Courier, Vancouver Sun, Coffee News, Black Press, Burnaby Now, and Royal City Record. Posters were displayed in the Vancouver General Hospital corridors and common areas, such as entrance bulletins, elevators, and cafeterias, at community centers and libraries in both Vancouver and Burnaby, and at local grocery stores. Posters were also listed on websites, including Craigslist, Backpage, and Kijiji. In addition, email advertisements were sent to all Vancouver General Hospital staff. Incentives were listed on advertisements, which highlighted participants would receive free exercise classes and functional assessments, and would be paid $20 for each assessment completed.

2.3. Participants

Community-dwelling men (n=19) and women (n=53) were recruited from the Vancouver area from February to April 2013. Individuals that met the following criteria during telephone screening were eligible for inclusion: 1) ≥65 years; 2) living independently in the community; 3) reported mobility limitation, defined as any difficulty walking one quarter mile (i.e., 2-3 blocks) outside on level ground or climbing one flight of stairs (i.e., 10 steps) without resting due to a health or physical problem (Simonsick et al., 2008); 4) able to walk without assistance of a device or another person; and 5) willing to be randomized to one of three intervention groups. Similar to past research (Richardson et al., 2015), we excluded those who presented with any of the following: 1) history of medical conditions that might alter gait energetics or the ability to safely complete treadmill walking tests or exercise classes, which included hip fracture or stroke in past 12 months, cerebral hemorrhage in past 6 months, heart attack, angioplasty, or heart surgery in past 3 months, chest pain during walking in past 30 days, current treatment for shortness of breath or a lung condition, usual or excessive aching, stiffness, or pain in lower limbs and joints while walking, 2) participation in an exercise trial in past 6 months, 3) reported walking for ≥30 minutes, twice per week at a self-identified moderate-to-vigorous intensity, 4) were unable to wear an armband activity monitor continuously for one week because of left arm disability, participation in a water-based activity more than once per week, or household use of supplemental oxygen, or 5) did not speak, write, or understand English fluently. During telephone screening, we assessed exercise readiness with the PAR-Q (Canadian Society of Exercise Physiology, 2002); individuals who answered 'yes' to any of the questions were advised to discuss their answers with their physician.

Following telephone screening, eligible participants were mailed a package containing additional study information, informed consent form, and letter to be signed by their physician indicating their appropriateness to participate in an exercise training program. They were also asked to attend a 60-minute in-person information session which provided details about the intervention groups and randomization and concluded with the provision of written informed consent. **Figure 1** shows participant flow through the study stages (Schulz, Altman, & Moher, 2010).

2.4. Measures

2.4.1. Descriptive Measures

Height was measured with a wall-mounted Harpenden stadiometer, and weight was measured with a standard balance beam digital scale (both SECA model 2841300109). Body mass index was calculated as weight (kg) divided by the square of height (m^2). Grip strength of both hands was measured with a handheld dynamometer

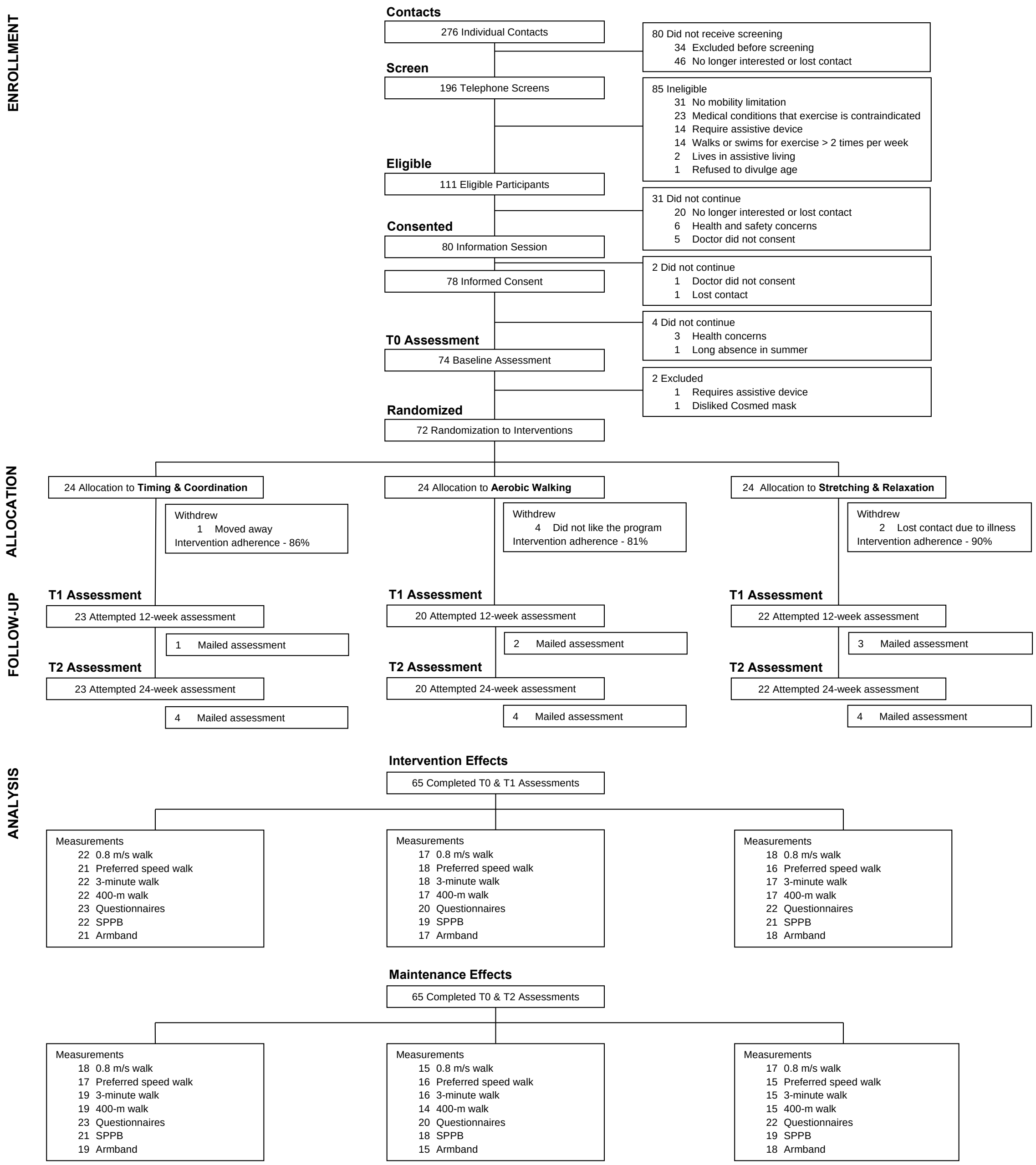

Figure 1 Flow diagram of participants. T0 indicates baseline, T1 indicates 12-week follow-up, and T2 indicates 24-week follow-up.

Average adherence was calculated by excluding the seven participants that withdrew from the HealthySteps Study between T0 and T1. Average adherence for the participants that attended at least one intervention class was 84% for TC, 75% for AW, and 84% for SR.

(Jamar Plus Digital Hand Dynamometer). Global cognitive function was assessed with the Mini Mental State Examination (Folstein, Folstein, & McHugh, 1975; Teng & Chui, 1987). Racial background, smoking history, alcohol use, previous physician diagnoses of medical conditions, and self-rated health were ascertained by standard questionnaires developed by the HealthySteps Study research personnel. Depressive symptoms were assessed with the 20-item Center for Epidemiologic Studies Depression Scale (CES-D) (Radloff, 1977).

Primary Outcome Measure

Energy Cost of Walking. We determined the mean energy cost of walking (mL/kg/m) during three submaximal walking tests (two treadmill, one overground) by measuring the rate of oxygen consumption ($\dot{V}O_2$) in mL/min via open circuit indirect calorimetry with a portable metabolic system (Cosmed K4b^2, Cosmed, Rome, Italy) (Schrack, Simonsick, & Ferrucci, 2010a). Prior to testing, the Cosmed was warmed-up for a minimum of 20 minutes, and the O_2 and CO_2 analyzers were calibrated using reference gases of known concentrations according to the manufacturer's instructions. Participants were ineligible for walking tests if blood pressure was > 180/110 mmHg, or resting heart rate was > 120 bpm. Wearing a light weight (<3.5 lbs) portable metabolic monitor, such as the Cosmed K4b^2, does not impact gait characteristics of older adults with mobility limitation (Wert, Vanswearingen, Perera, Studenski, & Brach, 2016).

After being outfitted with the Cosmed, participants sat for two minutes to adapt to the equipment. Prior to beginning the two treadmill tests, participants were given time to become familiar with treadmill walking before data was collected. Participants then walked at sub-maximal intensity for 5 minutes at 0.8 m/s and 6-meter overground preferred speed on a motor-driven treadmill (0° incline). The standard speed of 0.8 m/s was chosen to maximize participant inclusion at a speed that was not uncomfortably slow for participants (Richardson et al., 2015). Next, participants walked for 3 minutes on an overground course (20-meter per segment, 40 meters per lap) with the instruction to "walk at your usual pace without overexerting yourself", which has application to everyday walking. Indirect calorimetry measures of oxygen consumption during overground walking have high test-retest reliability in older adults with mobility limitation (Wert, VanSwearingen, Perera, & Brach, 2015). Five-minute rest breaks were provided between each walking test to minimize fatigue.

To calculate mean $\dot{V}O_2$ during steady state for each test, the beginning minutes of breath-by-breath data were discarded to allow participants to adjust to the workload and reach stable $\dot{V}O_2$, the remaining data were averaged. If the 5-minute test was completed, we discarded the first 3 minutes of data and averaged over the final 2 minutes of data. If the participant or examiner chose to end the test early (such that test duration was between 3 and 5 minutes), we discarded the first 2 minutes of data and averaged over the remaining minutes. If the 3-minute overground test was completed, we discarded the first 2 minutes of data and averaged over the final 1 minute. If the treadmill or overground test duration was less than 3 minutes, we investigated the data on a case-by-case basis to determine if the participant reached a stable rate of oxygen consumption. After averaging, mean $\dot{V}O_2$ was converted to mean energy cost of walking per distance unit (mL/kg/m) using the participant's measured weight (kg) and average walking speed (m/s) (Richardson et al., 2015).

2.4.2. Secondary Outcome Measures

To understand the range of effects that exercise training may have on older adults with mobility limitation, we assessed secondary outcomes related to the World Health Organization International Classification of Functioning, Disability, and Health (World Health Organization, 2002) domains of activity, defined as execution of a task or action by an individual, and participation, defined as involvement in a life situation. Activity outcomes included fatigability, endurance, and physical function, and participation outcomes included daily physical activity and life-space mobility.

Fatigability. We assessed fatigability using three different measures. Perceived fatigability, defined as self-reported fatigue in relation to a standardized task (Eldadah, 2010), was assessed by the Borg Rating of Perceived Exertion (RPE) Scale from 6-20 (Borg, 1982) at the end of the three walking tests (0.8 m/s and 6-m overground preferred speed treadmill tests and the 3-minute overground test) (Richardson et al., 2015). Performance deterioration, defined as decrements in performance during objective tests of physical function, was assessed via a 400-meter, 20-meter per segment, overground walk (Simonsick et al., 2014). Participants were instructed to "walk as quickly as you can, without running, at a pace you can maintain" (Newman et al., 2006; Simonsick, Fan, & Fleg, 2006). We identified participants with performance deterioration if they did not attempt the 400-meter walk, did not complete the 400-meter walk, or had ≥6.5% decline in pace between the second and ninth laps of the 400-meter walk (Simonsick et al., 2014). The Pittsburgh Fatigability Scale assessed physical fatigability (Glynn et al., 2015); participants rated their physical fatigue from 0 ('No Fatigue') to 5 ('Extreme Fatigue') in relation to 10 activities of a specified intensity and duration. We calculated the Physical Fatigability Score (range 0-50) by summing the ratings for the activities (Glynn et al., 2015).

Daily Physical Activity. We measured daily physical activity using a SenseWear Pro Armband (Bodymedia Inc., Pittsburgh, PA) worn for 7 days following each assessment (Jakicic et al., 2004; Mackey et al., 2011). Mean time (mins/day) spent in moderate-to-vigorous physical activity (MVPA, 3-6+ METs), mean number of steps per day, and mean daily energy expenditure (kilocalories/day) were calculated over a minimum of 5 valid wear days (wear time > 90% of 24 hours). We also measured self-reported occupational, household, and leisure physical activities over the past 7 days using the Physical Activity Scale for the Elderly (PASE) (Washburn, Smith, Jette, & Janney, 1993). We scored the questionnaire by multiplying the amount of time spent in each type of activity (hours per 7 days) by the corresponding intensity weight and summing across all activities; for possible scores ranging from 0 to about 400 (Washburn et al., 1993).

Endurance. We measured endurance as the time (minutes) to complete the 400-meter, 20-meter per segment, overground walk described above with the instruction to "walk as quickly as you can, without running, at a pace you can maintain" (Newman et al., 2006; Simonsick et al., 2006), as described above.

Physical Function. We implemented the Short Physical Performance Battery (SPPB) to assess: standing balance, preferred gait speed over 6 meters, and ability and time to complete five repeated chair stands (Guralnik, Ferrucci, Simonsick, Salive, & Wallace, 1995). Standing balance was assessed by having participants hold three positions (side-by-side, semi-tandem, and tandem) for 10 seconds. Participants then completed two timed 6-meter walks at preferred speed. Lastly, participants were timed while they completed five repeated chair stands as fast as they could. Inability to perform any individual component of the battery resulted in a score of 0, while completion of the maneuver resulted in a score of 1 to 4 based on the time to completion. We summed the component scores to obtain an aggregate score from 0 to 12 (Guralnik et al., 1995). In addition, gait speed was assessed on a 3-minute overground course. Participants were instructed to “walk at your usual pace without overexerting yourself”, as described above.

Life-Space Mobility. We conducted the Life-Space Assessment (Peel et al., 2005) to examine the extent, frequency, and independence of movement during four weeks prior to assessment across five levels of life-space (1=outside bedroom, 2=outside home, 3=neighbourhood, 4=town, 5=outside town). The Life-Space Questionnaire was scored by multiplying the life-space level (1-5), by a value for independence (1=use of another person with or without equipment, 1.5=use of equipment only, 2=no assistance) by a value for frequency (1=less than 1 time/week, 2=1-3 times/week, 3=4-6 times/week, 4=daily), then summing across five life-space levels; composite scores range from 0 (restricted to one’s bedroom on a daily basis) to 120 (travels out of one’s town without assistance on a daily basis) (Peel et al., 2005). We also identified participants who had restricted life-space, defined as confinement to one’s neighbourhood if assistance was not used (Mackey et al., 2014; Stalvey et al., 1999).

2.5. Randomization

Randomization of participants was performed after T0 assessments were complete. The randomization sequence was computer generated and concealed by a research assistant until interventions were assigned. Participants were randomized and enrolled by the research assistant, in 1:1:1 ratio.

2.6. Sample Size

We calculated that 22 participants per group were required to yield statistical power of 0.80 to detect a clinically meaningful 15% reduction in the energy cost of walking between the exercise and control groups with a two-sided alpha of 0.05 and 20% loss to follow-up over 12 weeks. We estimated baseline mean energy cost of walking on a treadmill at 0.8 m/s with 0° incline would be between 0.25 and 0.30 mL/kg/m with SD of 0.06 mL/kg/m based on data from community-dwelling adults aged 70-89 years in the Study of Energy and Aging Pilot (Richardson et al., 2015).

2.7. Interventions

Participants were scheduled for two, small-group (eight or fewer participants), 60-minute classes per week for 12 weeks from May to July 2013. Classes were led by certified fitness instructors who received in-person training specific to three possible interventions: timing and coordination of gait training (TC), outdoor aerobic walk training (AW), and stretching and relaxation training (SR). All classes involved a 10-minute warm-up, 40 minutes of intervention-specific content, and 10-minute cool down. Summaries of the interventions are included below. Participants were not permitted to attend classes for which they were not assigned. When a participant missed two consecutive classes, follow-up phone calls were made to provide support and encourage continued adherence. Participants were not blinded to their assigned intervention; however, they were instructed not to describe their group assignment with others who were also participating in the study. To ensure consistent program delivery throughout the study, quality assurance assessments were conducted by the project coordinator every four weeks to correct inconsistencies in intervention protocol. Following intervention end, all participants were encouraged to continue exercising on their own over the following 12 weeks, and were given a handout with examples of home exercises and a list of exercise programs within their communities.

2.7.1. Timing and Coordination of Gait Training (TC)

The TC program was adapted from a motor skill training program developed by investigators at the University of Pittsburgh (Brach & VanSwearingen, 2013; Brach et al., 2015, 2013; VanSwearingen et al., 2009, 2011). The program incorporated four elements of task-oriented motor skill training (Brach & VanSwearingen, 2013): (1) a defined movement goal, (2) movement to gain knowledge of muscles and postures, (3) practice to correct errors in movement by developing and adjusting motor plans, and (4) challenges to select the optimal motor plan. The TC program specifically used stepping and walking patterns to promote timing and coordination within the gait cycle. Progression for stepping and walking tasks was accomplished by increases in the speed, amplitude, and accuracy of performance. Object manipulation (e.g., bouncing a ball), and the introduction of more complex tasks that combined these aspects (e.g., walking past other people while bouncing a ball) were incorporated. Participants also completed approximately 10-15 minutes of treadmill walking at preferred pace in each class to reinforce rhythmic stepping. Brief increases in speed (i.e., 30-60 seconds at 10% increased speed) were used to reinforce timing of gait, but were not intended to increase endurance or raise perceived effort (**Figure 2**).

Figure 2 Timing and Coordination of Gait Training

Figure 3 Outdoor Aerobic Walk Training.

2.7.2. Outdoor Aerobic Walk Training (AW)

The AW program focused on outdoor walking in surrounding neighbourhoods. Participants were instructed to gradually progress walking intensity over the intervention period to a target Borg RPE of 14-15 (Borg, 1982), corresponding to ‘hard’. To further guide intensity, participants were instructed to use a simple “talk” test (Levine et al., 2008) and to initially walk at a pace they could talk comfortably without effort and gradually progress to a pace at which conversation required more effort. Accordingly, the walking routes increased in distance and incorporated more slopes as the intervention period progressed (**Figure 3**).

Figure 4 Stretching and Relaxation Training.

2.7.3. Stretching and Relaxation Training (SR)

The SR program served as an active control to account for potential effects related to traveling to the training center, social interactions, and changes in lifestyle secondary to study participation. Each class involved full-body stretching, range-of-motion activities, and relaxation techniques for which there was no available evidence to suggest an effect on the energy cost of walking or other outcomes (**Figure 4**).

2.8. Assessments

Descriptive measures and outcomes were assessed within a 3-4 week time frame at baseline (T0), 12 weeks (intervention end, T1), and 24 weeks (12 weeks after intervention end to measure maintenance of intervention effects, T2). Outcome assessors were blinded to intervention assignments at T0, but not at T1 or T2. For participants who could not attend T1 or T2 assessments, an assessment booklet was mailed to complete on their own; these participants did not complete the physical measurements that research personnel assessed on-site (e.g., walking tests, SPPB).

2.9. Statistical Analysis

Normally distributed continuous variables were summarized as mean (standard deviation [SD]), and categorical variables as count [N] (percent [%]). We compared continuous primary and secondary outcomes between the exercise (TC, AW) and control (SR) groups using an analysis of covariance model with Tukey multiple comparisons procedure. Results are reported as mean (95% confidence interval [CI]). We analyzed 1) the *intervention effects* by comparing T1 measurements between exercise (TC, AW) and control (SR) groups, adjusting for T0 measurements, and 2) the *maintenance effects* by T2 measurements between exercise and control groups, adjusting for T0 measurements. Categorical secondary outcomes were analyzed using odds ratios to compare between the exercise (TC, AW) and control (SR) groups at T1 and T2. Results are reported as odds ratios [OR] (95% CI).

We conducted multiple analyses to gain a complete understanding of the intervention effects. First, we performed standard intention-to-treat analysis for each outcome. Second, we repeated the analysis, including baseline age and MVPA as covariates, as age influences study outcome and baseline MVPA values were slightly unequal between groups. Third, we completed as-treated analyses by restricting to participants with ≥ 85% class adherence (≥21/24 classes). Fourth, we conducted two sets of subgroup analyses: 1) for the energy cost of walking outcomes, we divided participants into high and low baseline energy cost groups based on the overall median baseline energy cost, similar to past research (VanSwearingen et al., 2009), and 2) for all outcomes, we classified participants based on presence or absence of osteoarthritis (OA) because a large proportion of participants (61%) reported OA at baseline, and we hypothesized that OA may affect responsiveness to the interventions. We examined these subgroups to determine if those with high baseline energy cost and those without OA had greater intervention and maintenance effects.

The alpha level was set at 0.05 for intention-to-treat and as-treated analyses, and at 0.20 for subgroup analyses. We did not adjust the p-value for multiple endpoints since a Type II error is of greater concern than a Type I error in pilot studies (Schoenfeld, 1980).

Chapter 3. Results

3.1. Flow of Participants and Intervention Adherence

Of 196 individuals screened by telephone, 111 were eligible to participate in the study, and 80 attended an on-site information session (**Figure 1**). Baseline assessments were completed for 74 participants, of which 72 were randomized to intervention groups. Average intervention adherence was 86% (86% for TC, 81% for AW, and 90% for SR). Seven participants withdrew from the study, while 65 (90%) completed the T1 and T2 assessments.

3.2. Participant Characteristics

At baseline, participants had a mean age of 74.2 (SD: 6.6) years, and were predominantly white (67%) women (74%), with 61% reporting OA, and mean BMI within the obese range (30.2, SD: 6.3 kg/m^2). Participants had mean 3-minute gait speed of 0.9 (SD: 0.2) m/s and mean energy cost of walking on the 0.8 m/s treadmill walk of 0.260 (SD: 0.052) mL/kg/m. Participant characteristics were well balanced across intervention groups (**Table 1**). Marginal differences were observed in MVPA between groups at baseline (TC: 81 (SD: 82) minutes, AW: 67 (SD: 85) minutes, SR: 48 (SD: 44) minutes) (**Table 5**).

3.3. Primary Outcome

At T0, for the primary outcome, 66 participants completed the 0.8 m/s treadmill walk test, 66 completed the preferred speed treadmill walk test, and 68 completed the 3-minute overground walk test (**Table 2**). At T1, 57 participants completed the 0.8 m/s treadmill walk test, 55 completed the preferred speed treadmill walk test, and 57 completed the 3-minute overground walk test (**Table 2**). At T2, 50 completed the 0.8 m/s treadmill walk test, 48 completed the preferred speed treadmill walk test, and 50 completed the 3-minute overground walk test (**Table 2**).

Table 1 Summary of baseline participant characteristics (n=72).

Characteristic	Timing & Coordination (n=24)	Aerobic Walking (n=24)	Stretching & Relaxation (n=24)	Total (n=72)
Sex (Female), N (%)	17 (70.8)	18 (75.0)	18 (75.0)	53 (73.6)
Age (years), mean (SD)	73.6 (6.3)	74.4 (6.8)	74.7 (6.9)	74.2 (6.6)
Race, N (%)				
White	16 (66.7)	17 (70.8)	15 (62.5)	48 (66.7)
Chinese	4 (16.7)	4 (16.7)	3 (12.5)	11 (15.3)
Other	4 (16.7)	3 (12.5)	6 (25.0)	13 (18.1)
Good/Excellent Self-Rated Health, N (%)	14 (58.3)	8 (33.3)	11 (45.8)	33 (45.8)
Teng Mini Mental (/100), mean (SD)	90.0 (9.6)	93.3 (4.8)	89.9 (9.1)	91.1 (8.2)
CESD Scale ≥16*, N (%)	2 (8.3)	3 (12.5)	5 (20.8)	10 (13.9)
Smoking Status, N (%)				
Never	15 (62.5)	13 (54.2)	13 (54.2)	41 (56.9)
Current	1 (4.2)	1 (4.2)	0 (0.0)	2 (2.8)
Past	8 (33.3)	10 (41.7)	11 (45.8)	29 (40.3)
<1 Alcoholic Drink/week, N (%)	18 (75.0)	12 (50.0)	18 (75.0)	48 (66.7)
Medical History, N (%)				
Myocardial Infarction	1 (4.2)	4 (16.7)	2 (8.3)	7 (9.7)
Congestive Heart Failure	1 (4.2)	2 (8.3)	0 (0.0)	3 (4.2)
Stroke	3 (12.5)	3 (12.5)	2 (8.3)	8 (11.1)
Peripheral Vascular Disease	1 (4.2)	1 (4.2)	0 (0.0)	2 (2.8)
Chronic Obstructive Lung Disease	1 (4.2)	5 (20.8)	6 (25.0)	12 (16.7)
Osteoarthritis	15 (62.5)	15 (62.5)	14 (58.3)	44 (61.1)
Depression	7 (29.2)	2 (8.3)	4 (16.7)	13 (18.1)
Cancer	4 (16.7)	9 (37.5)	10 (41.7)	23 (31.9)
Fallen in Last 12 Months	9 (37.5)	7 (29.2)	8 (33.3)	24 (33.3)
1 time	4 (16.7)	3 (12.5)	3 (12.5)	10 (13.5)
2+ times	5 (20.8)	4 (16.7)	5 (20.8)	14 (19.4)
Height (cm), mean (SD)	160.7 (9.5)	163.3 (11.7)	160.6 (9.2)	161.5 (10.1)
Weight (kg), mean (SD)	76.9 (18.9)	80.1 (23.0)	81.7 (20.7)	79.6 (20.7)
Body Mass Index (kg/m^2)	29.6 (5.8)	29.6 (6.3)	31.5 (6.8)	30.2 (6.3)
Grip Strength, mean (SD)				
Right (kg)	26.0 (11.5)	26.3 (10.3)	23.3 (7.7)	25.2 (9.9)
Left (kg)	24.9 (12.2)	24.1 (10.5)	21.2 (7.2)	23.4 (10.2)

* Centre for Epidemiologic Studies Depression (CESD) Scale ≥16 is suggestive of depressive symptoms

Table 2 Flow of participants through the energy cost of walking tests (n=72).

	Timing & Coordination (n=24)	Aerobic Walking (n=24)	Stretching & Relaxation (n=24)	Total (n=72)
T0 Assessment				
Eligible for Walk Tests, N (%)	24 (100.0)	24 (100.0)	24 (100.0)	72 (100.0)
Treadmill Walk - Speed: 0.8 m/s, N (%)				
Attempted Test	22 (91.7)	23 (95.8)	22 (91.7)	67 (93.1)
Included in Analysis	22 (91.7)	23 (95.8)	21 (87.5)	66 (91.7)
Treadmill Walk - Speed: 6-m Overground Preferred Speed, N (%)				
Attempted Test	23 (95.8)	23 (95.8)	24 (100.0)	70 (97.2)
Included in Analysis	23 (95.8)	23 (95.8)	20 (83.3)	66 (91.7)
Overground Walk - Speed: Preferred Speed, N (%)				
Attempted Test	24 (100.0)	24 (100.0)	24 (100.0)	72 (100.0)
Included in Analysis	24 (100.0)	23 (95.8)	21 (87.5)	68 (94.4)
T1 Assessment				
Withdrew from Study, N (%)	1 (4.2)	4 (16.7)	2 (8.3)	7 (9.7)
Mailed Assessment, N (%)	1 (4.2)	2 (8.3)	3 (12.5)	6 (8.3)
Treadmill Walk - Speed: 0.8 m/s, N (%)				
Attempted Test	22 (100.0)	18 (100.0)	18 (94.7)	58 (98.3)
Included in Analysis	22 (100.0)	17 (94.4)	18 (94.7)	57 (96.6)
Treadmill Walk - Speed: 6-m Overground Preferred Speed, N (%)				
Attempted Test	21 (95.5)	18 (100.0)	16 (84.2)	55 (93.2)
Included in Analysis	21 (95.5)	18 (100.0)	16 (84.2)	55 (93.2)
Overground Walk - Speed: Preferred Speed, N (%)				
Attempted Test	22 (100.0)	18 (100.0)	18 (94.7)	58 (98.3)
Included in Analysis	22 (100.0)	18 (100.0)	17 (89.5)	57 (96.6)
T2 Assessment				
Mailed Assessment	4 (16.7)	4 (16.7)	4 (16.7)	12 (16.7)
Treadmill Walk - Speed: 0.8 m/s, N (%)				
Attempted Test	18 (94.7)	15 (93.8)	17 (94.4)	50 (94.3)
Included in Analysis	18 (94.7)	15 (93.8)	17 (94.4)	50 (94.3)
Treadmill Walk - Speed: 6-m Overground Preferred Speed, N (%)				
Attempted Test	17 (89.5)	16 (100.0)	15 (83.3)	48 (90.6)
Included in Analysis	17 (89.5)	16 (100.0)	15 (83.3)	48 (90.6)
Overground Walk - Speed: Preferred Speed, N (%)				
Attempted Test	19 (100.0)	16 (100.0)	17 (94.4)	52 (98.1)
Included in Analysis	19 (100.0)	16 (100.0)	15 (83.3)	50 (94.3)

Included in Analysis	Participant completed at least 3 minutes of walking test
T0	Baseline
T1	12-week follow-up
T2	24-week follow-up

Energy Cost of Treadmill Walking at 0.8 m/s.

At T1, TC reduced the mean energy cost of walking at 0.8 m/s by 15% compared to SR (adjusted mean difference = -0.040, 95% CI = -0.070, -0.009 mL/kg/m, p=0.008) (**Table 3, Figure 5 - Top**). Results were consistent after adjusting for baseline age and MVPA (p=0.018), and restricting to adherence ≥85% (n=29, p=0.025). In subgroup analyses, TC reduced mean energy cost by 20% compared to SR (adjusted mean difference= -0.062, 95% CI= -0.125, 0.001 mL/kg/m, p=0.055) among n=18 with high baseline cost (>median = 0.251 mL/kg/m), but had no effect among n=19 with low baseline cost (p=0.997) (**Table 9**). There was no evidence of effect modification based on OA status.

The intervention group differences at T1 were maintained at T2, with a 13% reduction in the mean energy cost of walking at 0.8 m/s for TC compared to SR (adjusted mean difference = -0.033, 95% CI = -0.060, 0.005 mL/kg/m, p=0.016) (**Table 3, Figure 5 - Bottom**). At T2, results were consistent after adjusting for baseline age and MVPA (p=0.009), and restricting to adherence ≥85% (n=27, p=0.028). In subgroup analyses, TC reduced mean energy cost by 16% compared to SR (adjusted mean difference = -0.044, 95% CI = -0.097, 0.009 mL/kg/m, p=0.160) among n=15 with high baseline cost (>median = 0.246 mL/kg/m), but had no effect among n=18 with low baseline cost (p=0.997) (**Table 9**). TC also reduced mean energy cost by 18% compared to SR (adjusted mean difference = -0.049, 95% CI = -0.099, 0.0005 mL/kg/m, p=0.053) among n=16 without OA, but had no effect among n=19 with OA (p=0.769).

AW had no effect on the mean energy cost of walking at 0.8 m/s compared to SR at T1 (p=0.549) or T2 (p=0.359) (**Table 3**). Results were unchanged at T1 and T2 after adjusting for baseline age and MVPA, restricting to adherence ≥85%, and stratifying based on baseline energy cost (**Table 9**) and OA status.

Energy Cost of Treadmill Walking at Preferred Speed.

Similarly, TC reduced the mean energy cost of walking at preferred speed by 13% compared to SR at T1 (adjusted mean difference = -0.032, 95% CI = -0.065, 0.001 mL/kg/m, p=0.058) (**Table 3, Figure 6 - Top**). In subgroup analyses, TC reduced mean energy cost by 26% compared to SR (adjusted mean difference = -0.065, 95% CI = -0.128, -0.002 mL/kg/m, p=0.038) among n=18 with high (>median = 0.237) baseline cost, but had no effect among n=18 with low baseline cost (p=0.998) (**Table 9**). Reductions in the mean energy cost of walking at preferred speed were maintained at T2, with a 14% reduction in the mean energy cost of walking at preferred speed for TC compared to SR (adjusted mean difference = -0.035, 95% CI = -0.066, -0.003 mL/kg/m, p=0.031) (**Table 3, Figure 6 - Bottom**). Results were consistent after adjusting for baseline age and MVPA (p=0.024), and restricting to adherence ≥85% (n=31, p=0.025).

AW had no significant effect on mean energy cost compared to SR at T1 (p=0.670) or T2 (p=0.765) (**Table 3**). Results were unchanged at T1 and T2 after adjusting for baseline age and MVPA, restricting to adherence ≥85%, and stratifying based on baseline energy cost (**Table 9**) and OA status.

Energy Cost of Overground Walking at Preferred Speed.

No significant differences were found at T1 (TC-SR: p=0.983, AW-SR: p=0.644) or T2 (TC-SR: p=0.969, AW-SR: p=0.659) between the exercise and control groups for the 3-minute overground walk test at preferred speed (**Table 3**). In subgroup analyses, those with high compared to low baseline energy cost of walking in TC had a larger reduction in energy cost compared to SR at both T1 and T2 (**Table 9**).

3.4. Secondary Outcomes

Compared to SR, neither TC nor AW exercise interventions led to statistically significant changes in measures of fatigability (**Table 4**), daily physical activity (**Table 5**), endurance (**Table 6**), physical function (**Table 7**), or life-space mobility (**Table 8**) at T1 or T2 based on intention-to-treat, as treated, and subgroup analyses for baseline energy cost (**Table 9**) and OA status. Despite these statistically non-significant findings, we observed two trends among the secondary outcomes. First, there was a trend toward a 10% increase in 3-minute gait speed for TC compared to SR at T1 (adjusted mean difference = 0.10, 95% CI = -0.01, 0.21 m/s, p=0.074) (**Table 7**). Second, TC increased MVPA by 22 minutes/day compared to SR at T2 (95% CI = -5.1, 50.0, p=0.129) (**Table 5**).

Table 3 **Energy cost of walking outcomes. Group comparisons are reported as mean difference (95% CI) based on ANCOVA analyses.**

	Mean (95% CI)			Mean Difference (95% CI)	
	Timing & Coordination (TC)	Aerobic Walking (AW)	Stretching & Relaxation (SR)	TC-SR	AW-SR
Treadmill at 0.8 m/s (mL/kg/m)					
T0	0.266 (0.248, 0.285)	0.265 (0.238, 0.292)	0.248 (0.227, 0.270)	---	---
T1	0.236 (0.220, 0.252)	0.263 (0.228, 0.298)	0.255 (0.225, 0.284)	---	---
T1*	0.227 (0.210, 0.244)	0.252 (0.233, 0.272)	0.267 (0.248, 0.285)	-0.040 (-0.070, -0.009) p = 0.008	-0.014 (-0.047, 0.018) p=0.549
T1**	0.227 (0.208, 0.245)	0.252 (0.232, 0.272)	0.267 (0.246, 0.288)	-0.040 (-0.074, -0.006) p=0.018	-0.015 (-0.050, 0.021) p=0.580
T2	0.238 (0.223, 0.253)	0.255 (0.224, 0.286)	0.255 (0.234, 0.276)	---	---
T2*	0.229 (0.213, 0.245)	0.245 (0.228, 0.263)	0.262 (0.246, 0.278)	-0.033 (-0.060, -0.005) p=0.016	-0.017 (-0.046, 0.013) p=0.359
T2**	0.228 (0.212, 0.243)	0.246 (0.229, 0.262)	0.262 (0.246, 0.279)	-0.035 (-0.062, -0.008) p=0.009	-0.017 (-0.045, 0.012) p=0.334
Treadmill at Preferred Speed (mL/kg/m)					
T0	0.253 (0.233, 0.272)	0.243 (0.217, 0.270)	0.244 (0.217, 0.272)	---	---
T1	0.216 (0.200, 0.232)	0.238 (0.205, 0.270)	0.238 (0.201, 0.275)	---	---
T1*	0.214 (0.197, 0.232)	0.234 (0.214, 0.253)	0.246 (0.225, 0.267)	-0.032 (-0.065, 0.001) p=0.058	-0.012 (-0.047, 0.022) p=0.670
T1**	0.214 (0.197, 0.231)	0.233 (0.215, 0.251)	0.237 (0.217, 0.258)	-0.024 (-0.056, 0.009) p=0.187	-0.004 (-0.037, 0.029) p=0.943
T2	0.217 (0.196, 0.238)	0.242 (0.198, 0.285)	0.240 (0.209, 0.270)	---	---
T2*	0.213 (0.196, 0.230)	0.238 (0.219, 0.256)	0.247 (0.227, 0.267)	-0.035 (-0.066, -0.003) p=0.031	-0.010 (-0.043, 0.024) p=0.765
T2**	0.211 (0.194, 0.228)	0.238 (0.220, 0.255)	0.246 (0.227, 0.265)	-0.035 (-0.065, -0.004) p=0.024	-0.008 (-0.039, 0.023) p=0.805

	Mean (95% CI)			Mean Difference (95% CI)	
	Timing & Coordination (TC)	**Aerobic Walking (AW)**	**Stretching & Relaxation (SR)**	**TC-SR**	**AW-SR**
Overground at Preferred Speed (mL/kg/m)					
T0	0.215 (0.198, 0.232)	0.220 (0.196, 0.244)	0.244 (0.205, 0.283)	---	---
T1	0.207 (0.190, 0.223)	0.240 (0.191, 0.288)	0.236 (0.199, 0.274)	---	---
T1*	0.219 (0.198, 0.240)	0.237 (0.213, 0.260)	0.222 (0.198, 0.245)	-0.003 (-0.041, 0.035) p=0.983	0.015 (-0.025, 0.055) p=0.644
T1**	0.218 (0.196, 0.240)	0.236 (0.212, 0.260)	0.220 (0.195, 0.245)	-0.002 (-0.043, 0.039) p=0.992	0.016 (-0.026, 0.058) p=0.634
T2	0.214 (0.191, 0.237)	0.241 (0.183, 0.300)	0.233 (0.203, 0.263)	---	---
T2*	0.221 (0.195, 0.246)	0.243 (0.214, 0.271)	0.225 (0.197, 0.254)	-0.005 (-0.051, 0.041) p=0.969	0.017 (-0.031, 0.066) p=0.659
T2**	0.220 (0.193, 0.246)	0.244 (0.215, 0.272)	0.225 (0.196, 0.254)	-0.006 (-0.054, 0.042) p=0.951	0.018 (-0.031, 0.067) p=0.646

Treadmill at 0.8 m/s: TC: T0 (n=22), T1 (n=22), T2 (n=18); AW: T0 (n=23), T1 (n=17), T2 (n=15); SR: T0 (n=21), T1 (n=18), T2 (n=17)
Treadmill at Preferred Speed: TC: T0 (n=23), T1 (n=21), T2 (n=18); AW: T0 (n=23), T1 (n=18), T2 (n=16); SR: T0 (n=20), T1 (n=16), T2 (n=15)
Overground at Preferred Speed: TC: T0 (n=23), T1 (n=22), T2 (n=19); AW: T0 (n=23), T1 (n=18), T2 (n=16); SR: T0 (n=22), T1 (n=17), T2 (n=15)

T0 Baseline
T1 12-week follow-up
T2 24-week follow-up

* T0 adjusted
** T0, age, and MVPA adjusted

Table 4 **Fatigability outcomes. Group comparisons are reported as mean difference (95% CI) based on ANCOVA analyses unless otherwise stated.**

	Mean (95% CI)			Mean Difference (95% CI)	
	Timing & Coordination (TC)	Aerobic Walking (AW)	Stretching & Relaxation (SR)	TC-SR	AW-SR
RPE at End of Treadmill at 0.8 m/s (Borg Scale: 6-20)					
T0	11.3 (10.0, 12.6)	11.3 (10.1, 12.5)	12.6 (11.4, 13.9)	---	---
T1	11.5 (9.1, 12.2)	10.7 (9.1, 12.2)	12.2 (10.7, 13.6)	---	---
T1*	11.3 (10.3, 12.2)	10.8 (9.7, 11.8)	11.6 (10.6, 12.6)	-0.3 (-2.0, 1.4) p=0.892	-0.9 (-2.6, 0.9) p=0.460
T1**	11.3 (10.3, 12.3)	10.6 (9.6, 11.6)	11.4 (10.3, 12.4)	-0.1 (-1.8, 1.7) p=0.994	-0.8 (-2.5, 1.0) p=0.558
T2	10.9 (10.0, 11.7)	10.9 (9.3, 12.4)	11.8 (10.5, 13.2)	---	---
T2*	10.9 (10.0, 11.7)	10.9 (9.9, 11.8)	11.3 (10.5, 12.2)	-0.5 (-1.9, 1.0) p=0.717	-0.5 (-2.0, 1.1) p=0.759
T2**	10.7 (9.9, 11.6)	10.9 (9.9, 11.8)	11.3 (10.4, 12.2)	-0.6 (-2.1, 0.9) p=0.638	-0.4 (-2.0, 1.2) p=0.804
RPE at End of Treadmill at Preferred Speed (Borg Scale: 6-20)					
T0	12.8 (11.5, 14.1)	12.2 (11.1, 13.4)	13.4 (12.3, 14.5)	---	---
T1	12.5 (11.2, 13.8)	12.6 (11.2, 13.9)	12.6 (11.3, 14.0)	---	---
T1*	12.6 (11.4, 13.7)	12.6 (11.4, 13.7)	12.3 (11.1, 13.5)	0.2 (-1.8, 2.3) p=0.954	0.2 (-1.8, 2.3) p=0.957
T1**	12.6 (11.4, 13.8)	12.5 (11.3, 13.7)	12.3 (11.0, 13.6)	0.3 (-1.9, 2.4) p=0.952	0.2 (-2.0, 2.3) p=0.979
T2	12.7 (11.9, 13.5)	13.1 (11.7, 14.5)	12.1 (10.4, 13.8)	---	---
T2*	12.7 (11.5, 14.0)	12.7 (11.5, 13.9)	12.0 (10.8, 13.2)	0.7 (-1.4, 2.8) p=0.702	0.7 (-1.4, 2.8) p=0.688
T2**	12.6 (11.3, 14.0)	12.7 (11.5, 13.9)	12.0 (10.8, 13.2)	0.6 (-1.6, 0.9) p=0.775	0.7 (-1.3, 2.8) p=0.687

	Mean (95% CI)			Mean Difference (95% CI)	
	Timing & Coordination (TC)	**Aerobic Walking (AW)**	**Stretching & Relaxation (SR)**	**TC-SR**	**AW-SR**
RPE at End of Overground at Preferred Speed (Borg Scale: 6-20)					
T0	12.1 (10.9, 13.3)	11.7 (10.5, 12.9)	13.1 (12.0, 14.2)	---	---
T1	12.4 (11.4, 13.4)	11.7 (10.1, 13.2)	12.4 (11.3, 13.6)	---	---
T1*	12.5 (11.5, 13.5)	12.0 (10.9, 13.1)	12.0 (10.9, 13.1)	0.5 (-1.3, 2.3) p=0.814	-0.03 (-2.0, 1.9) p=0.999
T1**	12.6 (11.6, 13.6)	11.9 (10.8, 13.0)	11.8 (10.7, 13.0)	0.8 (-1.1, 2.6) p=0.569	0.04 (-1.9, 1.9) p=0.999
T2	12.5 (11.6, 13.3)	12.9 (11.6, 14.1)	12.5 (11.4, 13.5)	---	---
T2*	12.5 (11.6, 13.4)	13.1 (12.1, 14.1)	12.2 (11.3, 13.2)	0.3 (-1.3, 1.9) p=0.908	0.8 (-0.8, 2.5) p=0.458
T2**	12.5 (11.5, 13.4)	13.1 (12.0, 14.1)	12.2 (11.2, 13.3)	0.2 (-1.5, 1.9) p=0.946	0.8 (-0.9, 2.6) p=0.488
Pittsburgh Fatigability Scale: Physical Fatigability (Score: 0-50)					
T0	20.8 (17.4, 24.3)	22.8 (20.3, 25.4)	26.1 (23.6, 28.5)	---	---
T1	21.4 (18.0, 24.8)	20.3 (16.2, 24.4)	25.5 (21.8, 29.2)	---	---
T1*	22.9 (19.6, 26.1)	20.3 (16.9, 23.7)	24.0 (20.6, 27.3)	-1.1 (-6.9, 4.7) p=0.890	-3.7 (-9.4, 2.1) p=0.279
T1**	22.6 (19.4, 25.7)	19.9 (16.7, 23.1)	24.3 (21.0, 25.6)	-1.7 (-7.4, 3.9) p=0.737	-4.4 (-9.8, 1.1) p=0.139
T2	19.7 (16.5, 23.0)	20.6 (16.3, 24.9)	25.0 (21.5, 28.5)	---	---
T2*	21.1 (17.9, 24.3)	20.8 (17.5, 24.1)	23.4 (20.1, 26.8)	-2.3 (-8.1, 3.4) p=0.597	-2.6 (-8.3, 3.0) p=0.513
T2**	21.0 (17.9, 24.2)	20.8 (17.6, 23.9)	23.6 (20.3, 27.0)	-2.6 (-8.3, 3.1) p=0.523	-2.9 (-8.4, 2.7) p=0.432

	Mean (95% CI)			Mean Difference (95% CI)	
	Timing & Coordination (TC)	**Aerobic Walking (AW)**	**Stretching & Relaxation (SR)**	**TC-SR**	**AW-SR**
Performance Deterioration, N(%) - comparisons reported as odds ratios					
T0	14 (58.3)	13 (54.2)	16 (66.7)	---	---
T1	12 (54.5)	8 (44.4)	13 (68.4)	1.055 (0.364, 3.054) p=1.000	0.757 (0.241, 2.380) p=0.773
T2	8 (40.0)	7 (38.9)	8 (44.4)	1.143 (0.339, 3.850) p=1.000	1.077 (0.308, 3.762) p=1.000

RPE at End of Treadmill at 0.8 m/s	TC: T0 (n=22), T1 (n=22), T2 (n=18); AW: T0 (n=23), T1 (n=18), T2 (n=15); SR: T0 (n=22), T1 (n=18), T2 (n=17)
RPE at End of Treadmill at Preferred Speed	TC: T0 (n=21), T1 (n=21), T2 (n=16); AW: T0 (n=23), T1 (n=18), T2 (n=16); SR: T0 (n=23), T1 (n=16), T2 (n=15)
RPE at End of Overground at Preferred Speed	TC: T0 (n=24), T1 (n=22), T2 (n=19); AW: T0 (n=24), T1 (n=18), T2 (n=16); SR: T0 (n=24), T1 (n=18), T2 (n=17)
Pittsburgh Fatigability Scale: Physical Fatigability	TC: T0 (n=24), T1 (n=23), T2 (n=23); AW: T0 (n=24), T1 (n=20), T2 (n=21); SR: T0 (n=24), T1 (n=22), T2 (n=22)
Performance Deterioration	TC: T0 (n=24), T1 (n=22), T2 (n=20); AW: T0 (n=24), T1 (n=18), T2 (n=18); SR: T0 (n=24), T1 (n=19), T2 (n=18)

T0 Baseline
T1 12-week follow-up
T2 24-week follow-up

* T0 adjusted
** T0, age, and MVPA adjusted

Table 5 **Daily physical activity outcomes. Group comparisons are reported as mean difference (95% CI) based on ANCOVA analyses.**

	Mean (95% CI)			Mean Difference (95% CI)	
	Timing & Coordination (TC)	Aerobic Walking (AW)	Stretching & Relaxation (SR)	TC-SR	AW-SR
Physical Activity Scale for the Elderly (Score: 0-400)					
T0	102.8 (80.0, 125.7)	96.9 (75.1, 118.7)	99.5 (75.8, 123.2)	---	---
T1	110.7 (85.9, 135.4)	98.7 (71.0, 126.5)	85.1 (60.4, 109.7)	---	---
T1*	109.4 (86.1, 132.7)	99.9 (76.6, 123.2)	85.2 (61.9, 108.4)	24.2 (-15.3, 63.8) p=0.313	14.8 (-24.8, 54.3) p=0.646
T1**	108.5 (85.4, 131.6)	100.1 (77.0, 123.2)	85.9 (62.8, 109.0)	22.6 (-16.7, 61.9) p=0.358	14.2 (-25.1, 53.4) p=0.664
T2	103.7 (78.4, 129.0)	83.6 (60.5, 106.8)	85.9 (64.0, 107.7)	---	---
T2*	102.5 (81.2, 123.8)	84.7 (63.4, 106.0)	86.0 (64.7, 107.3)	16.5 (-19.6, 52.7) p=0.520	-1.3 (-37.5, 34.8) p=0.996
T2**	102.6 (81.1, 124.1)	84.7 (63.2, 106.1)	86.0 (64.5, 107.4)	16.6 (-19.9, 53.1) p=0.523	-1.3 (-37.7, 35.1) p=0.996
Daily Energy Expenditure (kcal/day)					
T0	2260 (2050, 2469)	2145 (1917, 2374)	2169 (1917, 2421)	---	---
T1	2327 (2055, 2600)	1981 (1791, 2172)	2090 (1829, 2353)	---	---
T1*	2194 (2087, 2300)	2116 (2007, 2224)	2158 (2043, 2273)	36 (-155, 228) p=0.890	-42 (-231, 147) p=0.851
T1**	2198 (2090, 2306)	2113 (2004, 2222)	2155 (2040, 2271)	43 (-150, 236) p=0.850	-41 (-231, 147) p=0.852
T2	2183 (1940, 2425)	1798 (1657, 1938)	2060 (1872, 2248)	---	---
T2*	2073 (1989, 2157)	1968 (1873, 2064)	2101 (2009, 2193)	-29 (-179, 122) p=0.889	-133 (-292, 26) p=0.116
T2**	2074 (1989, 2159)	1968 (1871, 2065)	2100 (2006, 2193)	-26 (-180, 129) p=0.914	-132 (-293, 29) p=0.128

	Mean (95% CI)			Mean Difference (95% CI)	
	Timing & Coordination (TC)	Aerobic Walking (AW)	Stretching & Relaxation (SR)	TC-SR	AW-SR
Daily Step Count (steps/day)					
T0	4525 (2828, 6222)	3276 (2228, 4325)	3119 (2245, 3993)	---	---
T1	4713 (2832, 6594)	3067 (1657, 4477)	3028 (2069, 3988)	---	---
T1*	3831 (3280, 4382)	3704 (3147, 4261)	3679 (3082, 4276)	152 (-843, 1147) p=0.927	25 (-949, 999) p=0.998
T1**	3844 (3287, 4402)	3700 (3138, 4261)	3667 (3063, 4271)	177 (-832, 1186) p=0.905	32 (-951, 1016) p=0.997
T2	4958 (3058, 6858)	2651 (1477, 3826)	3253 (2354, 4151)	---	---
T2*	4116 (3381, 4851)	3395 (2571, 4218)	3622 (2803, 4440)	495 (-853, 1842) p=0.647	-227 (-1609, 1155) p=0.916
T2**	4106 (3355, 4857)	3393 (2559, 4228)	3636 (2796, 4476)	470 (-924, 1863) p=0.692	-243 (-1654, 1169) p=0.908
Daily Moderate-to-Vigorous Physical Activity (minutes/day)					
T0	81.3 (44.9, 117.7)	66.6 (30.0, 103.2)	48.2 (28.0, 68.3)	---	---
T1	93.8 (41.3, 146.3)	53.0 (22.1, 83.9)	39.2 (28.0, 50.5)	---	---
T1*	78.8 (61.5, 96.1)	60.7 (43.2, 78.2)	59.1 (40.1, 78.1)	19.7 (-11.8, 51.2) p=0.291	1.5 (-29.4, 32.5) p=0.992
T1**	78.8 (61.7, 95.9)	60.4 (43.1, 77.7)	59.5 (40.7, 78.3)	19.3 (-11.9, 50.5) p=0.298	0.9 (-29.7, 31.6) p=0.997
T2	95.5 (53.4, 137.6)	32.5 (16.4, 48.4)	37.6 (27.6, 47.5)	---	---
T2*	75.2 (60.2, 90.2)	51.3 (34.7, 68.0)	52.8 (36.3, 69.3)	22.4 (-5.1, 50.0) p=0.129	-1.5 (-29.2, 26.2) p=0.991
T2**	75.3 (60.1, 90.4)	51.0 (34.1, 67.9)	53.1 (36.4, 69.8)	22.2 (-5.7, 50.0) p=0.142	-2.1 (-30.3, 26.1) p=0.982

Physical Activity Scale for the Elderly Score: TC: T0 (n=24), T1 (n=23), T2 (n=23); AW: T0 (n=24), T1 (n=20), T2 (n=20); SR: T0 (n=24), T1 (n=22), T2 (n=22)
Daily Energy Expenditure, Step Count, and MVPA: TC: T0 (n=23), T1 (n=20), T2 (n=19); AW: T0 (n=24), T1 (n=16), T2 (n=16); SR: T0 (n=22), T1 (n=15), T2 (n=16)
T0 Baseline
T1 12-week follow-up
T2 24-week follow-up
* T0 adjusted
** T0 and age adjusted

Table 6 **Endurance outcome. Group comparisons are reported as mean difference (95% CI) based on ANCOVA analysis.**

	Mean (95% CI)			Mean Difference (95% CI)	
	Timing & Coordination (TC)	Aerobic Walking (AW)	Stretching & Relaxation (SR)	TC-SR	AW-SR
Time to Walk 400 meter (minutes)					
T0	6.2 (5.4, 7.1)	6.3 (5.6, 7.0)	6.00 (5.1, 6.9)	---	---
T1	5.7 (5.0, 6.4)	5.8 (5.18, 6.5)	5.7 (5.0, 6.4)	---	---
T1*	5.6 (5.2, 5.9)	5.8 (5.5, 6.2)	5.9 (5.5, 6.3)	-0.3 (-1.0, 0.3) p=0.428	-0.1 (-0.7, 0.6) p=0.964
T1**	5.7 (5.4, 6.0)	5.8 (5.5, 6.1)	5.6 (5.2, 6.1)	0.0 (-0.6, 0.7) p=0.997	0.1 (-0.5, 0.8) p=0.872
T2	5.9 (4.9, 6.8)	5.8 (5.0, 6.6)	6.0 (5.3, 6.8)	---	---
T2*	5.7 (5.1, 6.3)	6.0 (5.4, 6.6)	6.2 (5.5, 6.9)	-0.5 (-1.6, 0.6) p=0.465	-0.3 (-1.3, 0.8) p=0.837
T2**	5.7 (5.1, 6.3)	5.9 (5.3, 6.5)	6.2 (5.4, 6.9)	-0.5 (-1.7, 0.7) p=0.584	-0.3 (-1.4, 0.9) p=0.852

Time to Walk 400 meter — TC: T0 (n=18), T1 (n=20), T2 (n=15); AW: T0 (n=21), T1 (n=15), T2 (n=14); SR: T0 (n=14), T1 (n=12), T2 (n=13)

T0 Baseline
T1 12-week follow-up
T2 24-week follow-up

* T0 adjusted
** T0, age, and MVPA adjusted

Table 7 **Physical function outcomes. Group comparisons are reported as mean difference (95% CI) based on ANCOVA analyses.**

	Mean (95% CI)			Mean Difference (95% CI)	
	Timing & Coordination (TC)	Aerobic Walking (AW)	Stretching & Relaxation (SR)	TC-SR	AW-SR
Short Physical Performance Battery (Score: 0-12)					
T0	10.0 (9.2, 10.8)	10.0 (9.3, 10.6)	9.5 (8.8, 10.3)	---	---
T1	10.6 (10.9, 11.3)	10.2 (9.2, 11.2)	10.4 (9.5, 11.3)	---	---
T1*	10.5 (9.8, 11.1)	10.2 (9.6, 10.9)	10.6 (9.9, 11.3)	-0.2 (-1.2, 0.9) p=0.935	-0.4 (-1.5, 0.8) p=0.726
T1**	10.4 (9.8, 11.0)	10.2 (9.6, 10.9)	10.8 (10.1, 11.5)	-0.4 (-1.6, 0.7) p=0.613	-0.6 (-1.7, 0.5) p=0.417
T2	10.5 (9.7, 11.2)	10.1 (9.2, 11.0)	10.5 (9.8, 11.2)	---	---
T2*	10.3 (9.7, 10.9)	10.1 (9.5, 10.7)	10.7 (10.1, 11.4)	-0.5 (-1.5, 0.6) p=0.541	-0.6 (-1.7, 0.5) p=0.362
T2**	10.3 (9.7, 10.9)	10.1 (9.5, 10.7)	10.9 (10.3, 11.6)	-0.7 (-1.8, 0.4) p=0.292	-0.8 (-1.9, 0.3) p=0.169
3-minute Gait Speed (m/s)					
T0	0.966 (0.889, 1.043)	0.990 (0.899, 1.081)	0.875 (0.752, 0.997)	---	---
T1	1.110 (0.1.029, 1.190)	1.042 (0.910, 1.174)	0.944 (0.815, 1.073)	---	---
T1*	1.088 (1.029, 1.147)	1.024 (0.958, 1.089)	0.989 (0.923, 1.055)	0.099 (-0.008, 0.206) p=0.074	0.035 (-0.077, 0.147) p=0.731
T1**	1.082 (1.020, 1.145)	1.025 (0.958, 1.091)	0.999 (0.930, 1.068)	0.084 (-0.030, 0.197) p=0.186	0.026 (-0.090, 0.142) p-0.851
T2	1.057 (0.959, 1.154)	1.085 (0.945, 1.225)	0.965 (0.813, 1.117)	---	---
T2*	1.039 (0.968, 1.111)	1.045 (0.967, 1.124)	1.021 (0.944, 1.098)	0.018 (-0.109, 0.146) p=0.936	0.024 (-0.109, 0.158) p=0.899
T2**	1.047 (0.971, 1.123)	1.051 (0.971, 1.132)	1.035 (0.953, 1.116)	0.012 (-0.123, 0.147) p=0.974	0.017 (-0.122, 0.155) p=0.955

Short Physical Performance Battery — TC: T0 (n=24), T1 (n=22), T2 (n=21); AW: T0 (n=24), T1 (n=19), T2 (n=19); SR: T0 (n=24), T1 (n=19), T2 (n=18)
3-minute Gait Speed — TC: T0 (n=24), T1 (n=22), T2 (n=19); AW: T0 (n=24), T1 (n=18), T2 (n=16); SR: T0 (n=24), T1 (n=18), T2 (n=17)
T0 Baseline
T1 12-week follow-up
T2 24-week follow-up
* T0 adjusted
** T0, age, and MVPA adjusted

Table 8 **Life-space mobility outcomes. Group comparisons are reported as mean difference (95% CI) based on ANCOVA analyses unless otherwise stated.**

	Mean (95% CI)			Mean Difference (95% CI)	
	Timing & Coordination (TC)	Aerobic Walking (AW)	Stretching & Relaxation (SR)	TC-SR	AW-SR
Life-Space Assessment (Score: 0-120)					
T0	65.6 (57.2, 74.0)	63.1 (53.3, 72.9)	53.1 (44.2, 61.9)	---	---
T1	79.5 (72.0, 86.8)	63.6 (54.3, 72.8)	64.3 (55.0, 73.6)	---	---
T1*	76.6 (69.8, 83.3)	63.2 (56.0, 70.3)	68.1 (61.2, 75.0)	8.5 (-3.3, 20.3) p=0.204	-4.9 (-16.9, 7.0) p=0.585
T1**	74.9 (68.0, 81.9)	63.7 (56.6, 70.8)	69.8 (62.5, 77.1)	5.1 (-7.2, 17.5) p=0.578	-6.1 (-18.3, 6.1) p-0.456
T2	71.4 (63.5, 79.2)	67.6 (60.5, 74.7)	64.9 (56.0, 73.7)	---	---
T2*	68.7 (62.3, 75.1)	67.2 (60.5, 74.0)	68.0 (61.4, 74.6)	0.7 (-10.5, 11.9) p=0.989	-0.8 (-12.1, 10.6) p=0.986
T2**	69.5 (62.8, 76.2)	67.5 (60.6, 74.4)	69.6 (62.6, 76.6)	-0.1 (-12.0, 11.8) p=1.000	-2.1 (-13.9, 9.7) p=0.900
Restricted Life-Space, N(%) - comparisons reported as odds ratios					
T0	9 (37.5)	6 (25.0)	12 (50.0)	---	---
T1	2 (8.7)	6 (30.0)	10 (45.5)	0.267 (0.046, 1.530) p=0.249	1.200 (0.293, 4.909) p=1.000
T2	6 (26.1)	5 (25.0)	11 (50.0)	0.727 (0.195, 2.716) p=0.744	0.909 (0.215, 3.843) p=1.000

Life-Space Assessment TC: T0 (n=24), T1 (n=23), T2 (n=23); AW: T0 (n=24), T1 (n=20), T2 (n=20); SR: T0 (n=24), T1 (n=21), T2 (n=22)
Restricted Life-Space TC: T0 (n=24), T1 (n=23), T2 (n=23); AW: T0 (n=24), T1 (n=20), T2 (n=20); SR: T0 (n=24), T1 (n=21), T2 (n=22)
T0 Baseline * T0 adjusted
T1 12-week follow-up ** T0, age, and MVPA adjusted
T2 24-week follow-up

Treadmill Energy Cost of Walking at 0.8 m/s

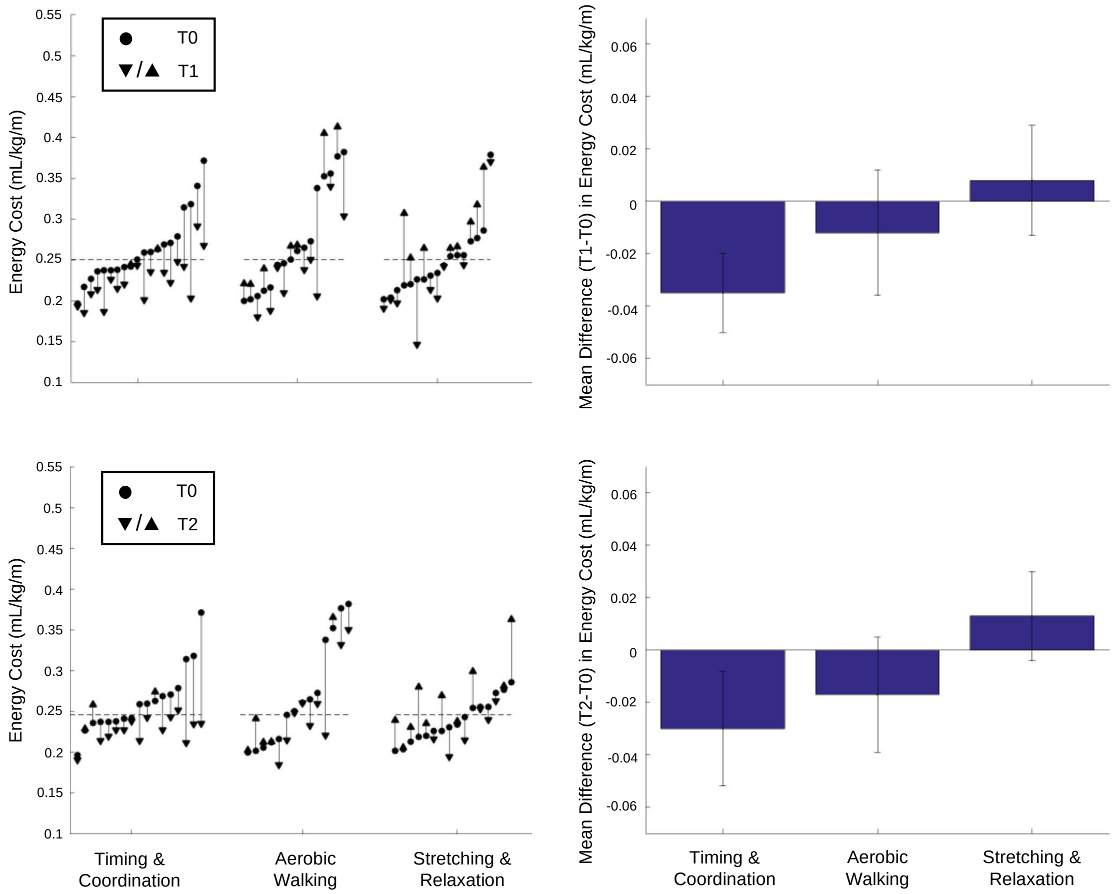

Figure 5 **Treadmill energy cost of walking at 0.8 m/s. Intervention effects (n=58): (Top-Left) Individual participant change from T0 to T1. (Top-Right) Mean difference from T0 to T1. Maintenance effects (n=50): (Bottom-Left) Individual participant change from T0 to T2. (Bottom-Right) Mean difference from T0 to T2 for each group. Dashed line represents the median baseline energy cost across all participants. Error bars represent 95% CI. T0: baseline; T1: 12-week follow-up; T2: 24-week follow-up.**

Treadmill Energy Cost of Walking at Preferred Speed

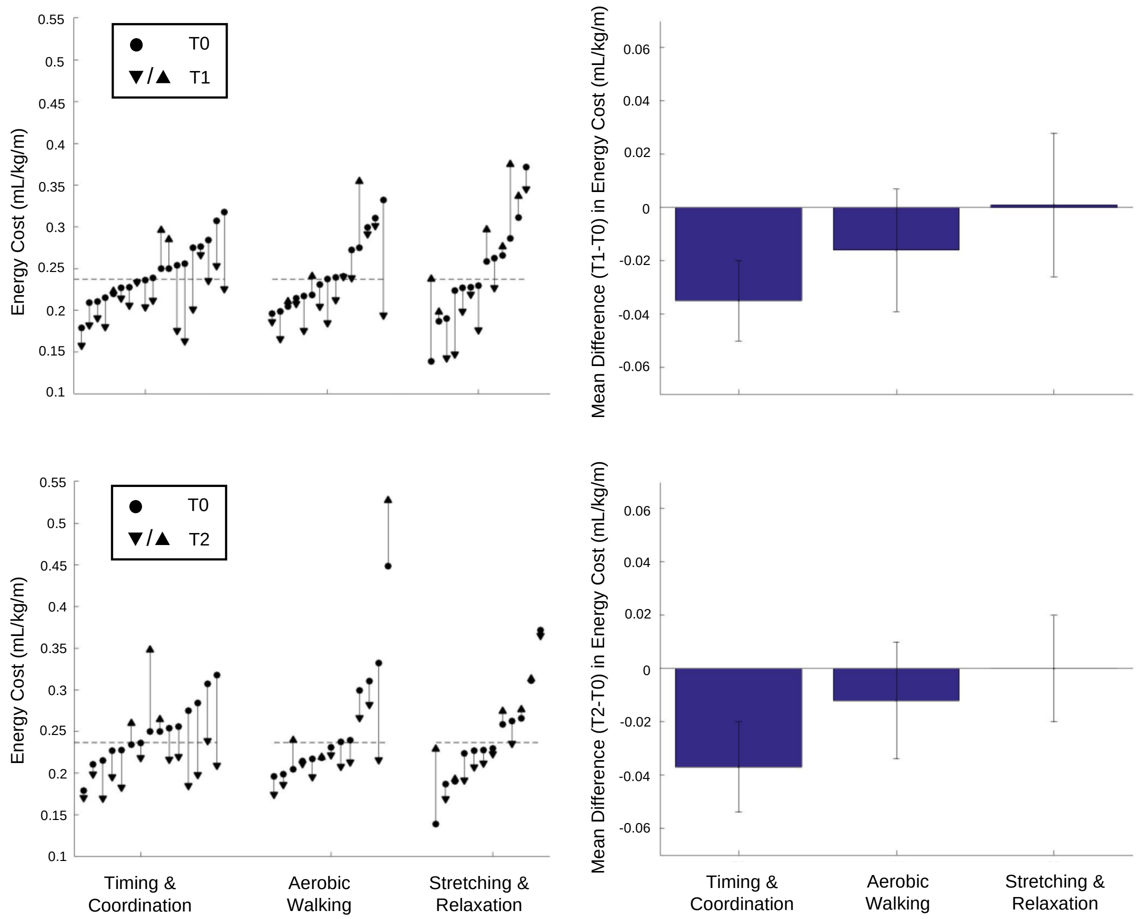

Figure 6 **Treadmill energy cost of walking at preffered speed. Intervention effects (n=55): (Top-Left) Individual participant change from T0 to T1. (Top-Right) Mean difference from T0 to T1. Maintenance effects (n=48): (Bottom-Left) Individual participant change from T0 to T2. (Bottom-Right) Mean difference from T0 to T2. Dashed line represents the median baseline energy cost across all participants. Error bars represent 95% CI. T0: baseline; T1: 12-week follow-up; T2: 24-week follow-up.**

Table 9 **Energy cost of walking outcomes separated into higher or lower than median baseline energy cost for each walk test. Group comparisons are reported as mean difference (95% CI) based on ANCOVA analyses.**

	Baseline Energy Cost	Mean Difference (95% CI) TC-SR	AW-SR
Treadmill at 0.8 m/s (mL/kg/m)			
T1*	High	-0.062 (-0.125, 0.001) p=0.055	-0.0002 (-0.068, 0.070) p=1.000
	Low	-0.009 (-0.069, 0.050) p=0.997	-0.001 (-0.063, 0.061) p=1.000
T2*	High	-0.044 (-0.097, 0.009) p=0.160	0.002 (-0.053, 0.057) p=1.000
	Low	-0.008 (-0.056, 0.040) p=0.997	-0.022 (-0.075, 0.030) p=0.795
Treadmill at Preferred Speed (mL/kg/m)			
T1*	High	-0.065 (-0.128, -0.002) p=0.038	-0.017 (-0.084, 0.050) p=0.974
	Low	0.009 (-0.052, 0.070) p=0.998	0.009 (-0.055, 0.072) p=1.000
T2*	High	-0.046 (-0.132, 0.039) p=0.582	0.002 (-0.089, 0.094) p=1.000
	Low	-0.005 (-0.090, 0.080) p=1.000	0.002 (-0.083, 0.087) p=1.000
Overground at Preferred Speed (mL/kg/m)			
T1*	High	-0.046 (-0.137, 0.046) p=0.676	-0.011 (-0.100, 0.078) p=0.999
	Low	-0.001 (-0.088, 0.086) p=1.000	0.007 (-0.094, 0.107) p=1.000
T2*	High	-0.032 (-0.134, 0.071) p=0.939	-0.010 (-0.095, 0.114) p=1.000
	Low	-0.009 (-0.105, 0.087) p=1.000	0.001 (-0.104, 0.106) p=1.000

Treadmill at 0.8 m/s
High: TC: T0 (n=13), T1 (n=11), T2 (n=9); AW: T0 (n=11), T1 (n=8), T2 (n=7); SR: T0 (n=9), T1 (n=7), T2 (n=6)
Low: TC: T0 (n=9), T1 (n=9), T2 (n=8); AW: T0 (n=12), T1 (n=8), T2 (n=7); SR: T0 (n=12), T1 (n=10), T2 (n=10)
Treadmill at Preferred Speed
High: TC: T0 (n=13), T1 (n=11), T2 (n=10); AW: T0 (n=9), T1 (n=8), T2 (n=6); SR: T0 (n=11), T1 (n=7), T2 (n=6)
Low: TC: T0 (n=10), T1 (n=10), T2 (n=8); AW: T0 (n=14), T1 (n=9), T2 (n=9); SR: T0 (n=9), T1 (n=8), T2 (n=7)
Overground at Preferred Speed
High: TC: T0 (n=10), T1 (n=9), T2 (n=8); AW: T0 (n=11), T1 (n=9), T2 (n=7); SR: T0 (n=13), T1 (n=9), T2 (n=7)
Low: TC: T0 (n=13), T1 (n=13), T2 (n=11); AW: T0 (n=12), T1 (n=8), T2 (n=8); SR: T0 (n=9), T1 (n=8), T2 (n=8)

TC	Timing and Coordination	T0	Baseline
AW	Aerobic Walking	T1	12-week follow-up
SR	Stretching and Relaxation	T2	24-week follow-up
*	T0 adjusted		

Chapter 4. Discussion

In community-dwelling older adults with self-reported mobility limitation enrolled in the HealthySteps Study, we found that 12 weeks of twice-weekly TC training reduced the energy cost of walking on a treadmill at 0.8 m/s by 15% and at preferred speed by 13%, relative to an active control; the reduction in energy cost was greater among those with high (> median) baseline energy cost. The reduction in energy cost was also maintained 12 weeks after the intervention end, particularly among those with high baseline energy cost and those without OA. TC training was designed to improve gait inefficiencies by improving the body's capacity for movement through recent and relevant training. Our findings indicate that this training program led to improved walking energetics, and to a trend in a clinically meaningful increase in preferred gait speed.

The HealthySteps Study replicates and extends the previous work of VanSwearingen et al. (VanSwearingen et al., 2009, 2011) and Brach et al.(Brach et al., 2015, 2013) who reported that 12 weeks of one-to-one physical therapist guided, twice-weekly TC training improved walking ability among older adults with a range of walking difficulties, such that walking became faster, more efficient, and more skilled, and walking confidence increased. Our results suggest that the effects of TC training are sustained following 12-weeks of training cessation, which has not been previously reported, and they appear to be robust to intervention setting, delivery mode, and participant group. Specifically, we demonstrated that TC training can be reliably and effectively delivered to small groups of older adults with self-reported mobility limitation in community settings by fitness instructors. Importantly, the effect size reduction in the energy cost of walking was consistent with those of one-to-one physical therapist guided interventions (Brach & VanSwearingen, 2013), and average intervention adherence was high at 86%.

Despite reductions in the energy cost of walking on a treadmill among those that completed TC training compared to SR, reductions were not observed on the overground walk. The most standardized test for the energy cost of walking measurement in the HealthySteps Study was the 0.8 m/s test, as it standardized the workload between and within all subjects at each time point. Neither the treadmill preferred speed nor the overground preferred speed tests were standardized between subjects; however, the treadmill preferred speed test was standardized within subjects. For this reason, the overground walk introduced the most variability into the energy cost of walking measurement, which may have contributed to the lack of intervention effect.

The observed reduction in the energy cost of walking was not accompanied by a corresponding reduction in measured fatigability, as would have been predicted by Schrack's energetic pathway to mobility loss (Schrack et al., 2010b). Others have recorded perceived exertion during walking tests and reported a similar lack of the expected relationship between perceived effort and energy cost of walking (Julius, Brach, Wert, & VanSwearingen, 2012); however, there are a few possible explanations for this finding. One explanation is that the moderate reduction in energetic cost of walking was not large enough to cause perceivable changes in fatigability, and participants may not have obtained enough experience at the lower energetic cost to perceive a change in their fatigability. A longer duration trial that elicits larger reductions in energy cost or provides more experience at a lower energetic cost may lead to changes in fatigability. A second explanation is that older adults with waking difficulty have a high baseline level of fatigability that has developed over years of experience that is insensitive to change. In support of this notion, HealthySteps participants reported mean baseline Pittsburgh Fatigability Scale Physical scores of 20 or above for each group, representing high baseline fatigability (Glynn et al., 2015).

Participants had a baseline gait speed of 0.9 m/s, which is consistent with older adults who report walking difficulty. We observed a trend toward a clinically meaningful increase in gait speed of 0.1 m/s at intervention end in TC compared to control, consistent with other trials of TC training (Brach et al., 2013; VanSwearingen et al., 2009). The TC intervention did not, however, lead to discernable changes in other outcomes theorized to be downstream of the energy cost of walking (Schrack et al., 2010b) including endurance, daily physical activity, or life-space mobility. TC training did not specifically target lower extremity strength or endurance; thus, it might require more than 12 weeks of training to realize improvements in these domains secondary to reduced energetic cost. In addition, TC training did not incorporate behavior change techniques, which may be necessary to achieve improvements in daily physical activity and life-space mobility.

AW did not improve the energy cost of walking or any of the downstream secondary outcomes. Walking difficulty in older adults is typically attributed to age-related changes that impose inefficiencies within the gait cycle; specifically, alterations to the biomechanics and movement control of walking that develop and produce slow, inefficient, and unskilled movement (Brach & VanSwearingen, 2013). The results of this study suggest that practicing outdoor walking regularly does not sufficiently address these age-related changes in gait that impact walking ability.

The HealthySteps Study provides evidence in support of recommendations from Brach and colleagues (Brach et al., 2016) to translate the novel TC program into group exercise classes within the community setting. Brach and colleagues (Brach et al., 2016) suggested that group class size be kept below 10 and include older adults who ambulate independently, and that physical therapists should lead the groups. HealthySteps classes involved groups of 5-6 participants with self-reported mobility limitation, and were led by 1 fitness instructor and 2 student volunteers per class. We found this ratio of instructor/volunteers to participants facilitated a positive class dynamic, as the instructor was able to demonstrate the various stepping and walking patterns in the front of the room, and the volunteers were able to work closely with the participants to ensure they were understanding and following instructions. Brach and colleagues also recommended using a large enough space to allow for performance of exercises without reducing the intimacy of the setting. To this end, HealthySteps provided an inclusive environment that was conducive to the implementation of the TC program HealthySteps focused on creating a social, fun, and positive environment that participants enjoyed coming to each week. Music was played during the TC classes, and participants were free to take rest breaks as needed throughout the classes. Participants also seemed to enjoy interacting with the younger generation volunteers, and this may have contributed to high adherence.

4.1. Study Limitations

The HealthySteps Study has certain limitations. First, as this was a pilot study, the sample size was small, and the study was not powered to detect changes in the secondary outcomes. Nevertheless, the effect size estimates observed in HealthySteps may help to plan appropriate sample sizes for future trials. Second, the 12-week intervention period was relatively short in duration; the intervention and maintenance effects may have been larger if the study was extended. Third, screening participants for inclusion based on self-reported mobility limitation was efficient and precluded the need for in-person screening, but it also resulted in a large degree of variability in baseline energy cost of walking. Since results of this study showed that those with higher baseline energy cost experienced larger intervention-induced reductions in the energy cost of walking, future studies or community programs may benefit by screening for inclusion based on energy cost. Fourth, TC participants completed treadmill walking during their exercise classes, so the reduction in energy cost of walking observed in the TC group may be due in part to a learning effect of repeated exposure to treadmill walking during the intervention period; nevertheless, all participants had time to become familiar with treadmill walking prior to each assessment.

4.2. Future Directions

As walking difficulty is a common characteristic of aging, addressing mobility limitations are a major public health concern. With the combined impacts of an increasingly aging and sedentary population, the burden of this condition will continue to grow unless action is taken. It would be worthwhile to design and evaluate a multicomponent exercise program that addresses a more comprehensive array of the determinants of mobility to improve and maintain older adult mobility. For older adults, strength and balance training have been successful in falls prevention (Karlsson, Vonschewelov, Karlsson, Coster, & Rosengen, 2013; Shubert, 2011), resistance and aerobic training have been shown to improve cognition (Bherer, Erickson, & Liu-Ambrose, 2013; Karlsson et al., 2013), TC training can reduce the energy cost of walking, and behaviour change strategies are effective at improving older adults' motivation toward physical activity and being mobile within the community (Stewart et al., 2006; Stewart, Sepsis, King, McLellan, & Ritter, 1997). By prescribing a comprehensive exercise training program that is beneficial to overall older adult mobility, rather than prescribing a single form of exercise, we could have greater benefits for preventing disability and reducing admissions into long-term institutional care, and maintaining functional autonomy in vulnerable older adults.

Beyond this direct application, a more fundamental question remains as to the relationship between the energy cost of walking and fatigability. An observational trial have shown an association between fatigability and the energy cost of walking

(Simonsick et al., 2016); however, changes in the energy cost of walking were not reflected in fatigability measurements in the HealthySteps Study or in previous studies (Julius et al., 2012). This lack of an associated change suggests there may be an alternative pathway in which fatigability impacts mobility. Future research is needed to investigate the determinants of fatigability among older adults.

4.3. Conclusion

In conclusion, we provide novel evidence from a randomized controlled trial that a 12-week targeted TC training program delivered by fitness instructors to small groups of community-dwelling older adults with mobility limitation led to a reduction in the energy cost of walking, particularly among those with high baseline energy cost. This effect was sustained following 12 weeks of training cessation. However, TC training did not have an effect on fatigability, daily physical activity, endurance, physical function, and life-space mobility. In addition, AW training had no effect on energy cost of walking fatigability, daily physical activity, endurance, physical function, or life-space mobility.

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