Pilot study for efficacy of Yuishinkai karate training community “dose” to improve balance and neuromuscular function in older adults

By

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Bachelor of Biology (conc. Neurobiology), University of Victoria, 2016

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We acknowledge with respect the Lekwungen peoples on whose traditional territory the university stands and the Songhees, Esquimalt and W̱SÁNEĆ peoples whose historical relationships with the land continue to this day.

Supervisory Committee

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Abstract

Purpose: To pilot test the efficacy of a documented 5-week karate training intervention for rehabilitation and neuroprotection in older adults. **Methods:** eleven older adults (4 male, 7 female, age 59-90y; 168.4±5.8cm; 67.2±10.7kg), five older adults (4 male, 1 female, age 67-76y;176.8±6.4 cm; 69.9±17.6kg) with chronic conditions, and two young adults (2 female, age 23; 165.1±4.9cm; 60.1±6.7 kg) participated. A commercial balance board was used to assess balance through dynamic posture. Arm and leg strength, Timed Up and Go (TUG), and spinal cord excitability (via the soleus H- reflex) were assessed. **Results:** Over the intervention participants completed approximately 2437 steps, 1762 turns, 3585 stance changes, 2047 punches, 2757 blocks, and 1253 strikes. Dynamic postural performance improved after the intervention (tTarget (18%, p=0.128), tCenter (9%, p<0.01), and tTotal (14%, p=0.073)), with 9 participants showing improvements in balance. No significant changes were found in TUG group data (p=0.539) but 5 neurologically intact participants (4-9%; p<0.05) and 1 Parkinson's Disease participant (3%, p<0.05) improved. There was significant improvement to strength in the left hand (2%, p=0.037) and right leg (40%, p=0.050). Spinal cord excitability remained unchanged across the group a but 5 (3 neurologically intact (195%, 215%, 48% (avg= 153%); p<0.05); 2 Parkinson's Disease participants (19%, 23%; p<0.05)) had significantly modulated H-reflex amplitudes following the intervention. **Conclusion:** Five weeks of training caused improvements in balance reactions and strength suggesting that neuromechanical integrity improved. Whole-body training in martial arts enhanced neuromuscular function and postural integration. The observations of this pilot investigation provide quantitative groundwork for explorations of dose and development of martial arts interventions as functional fitness intervention for older adults.

Keywords:

Balance; Hoffmann reflex; Spinal cord excitability; Martial arts; Rehabilitation; Aging

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List of Abbreviations

AD- Alzheimer’s Disease

ADL- Activities of Daily Living

BDNF- Brain-derived Neurotrophic Factor

COP- Center of Pressure

CPG- Central Pattern Generator

EMG- Electromyography

Hmax- Maximal H-reflex response

H-Reflex- Hoffmann Reflex

IaPSI- primary afferent fibre (Ia fibre) presynaptic inhibition

IaPSiIN- Ia presynaptic inhibitory interneuron

LA- Less affected

Mmax- Maximum compound action potential

PD- Parkinson’s Disease

QOL- Quality of Life

RM-ANOVA- Repeated Measures Analysis of Variance

SF-36 – Short Form 36 Health Survey Questionnaire

SOL- Soleus

TA- Tibialis Anterior

tCenter- Time to Center (WBB dynamic)

tTarget – Time to Target (WBB dynamic)

tTotal- Total Time (WBB dynamic)

TUG- Timed Up and Go Test

VL- Vastus Lateralis

WBB- Wii Balance Board

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Dedication

I dedicate this work to all those who helped me along the way ~ family.

Friends that were close to my heart.

Acquaintances that challenged me to learn & love a little deeper.

and to my strength & resilience throughout the process.

"Imagination is more important than knowledge.

For knowledge is limited to all we now know and understand,

while imagination embraces the entire world,

and all there ever will be to know and understand."

~ A. Einstein

Thank you.

♥

Chapter One: Review of Literature

1.1 Aging and integrated exercise

With aging comes a certain degradation of neuromuscular function and reduced capacity (Faude & Donath, 2019). Due to the decrease of abilities with aging, there is a greater risk of falls amongst the population. Falls are the second leading cause of accidental deaths worldwide and are the largest comorbidity in people ages 65 years or older (World Health Organization, 2015). In Canada, falls are the leading cause of injury-related hospitalizations in older adults and are associated with a financial cost of approximately $2 billion annually (Cost of Injury in Canada – Parachute, 2019). As a consequence, most rehabilitation programs focus on balance, functional learning for activities of daily living (ADL), and strength training to improve postural control as well as reduce the risk of falls (Pliske et al., 2016).

Dynamic posture regulation is critical for quality of life (QOL) and protective function in aging. As the risk of falls and chronic disease increases worldwide (Faude & Donath, 2019), holistic approaches to health may help as preventative or treatment techniques. Community-based interventions to maintain or enhance integrated function across the lifespan and after neurological impairment are needed (World Health Organization, 2015). Mind-body exercises that combine physical and cognitive components may improve overall QOL beyond traditional exercise programs (Dahmen-Zimmer & Jansen, 2017; Jansen et al., 2017).

Focus on balance and stance to mitigate the risk of falls in the elderly community is necessary. Integrated whole-body activities that emphasize postural cues such as martial arts like Tai Chi Chuan and the Alexander technique assist healthy older adults with improvements of static and dynamic balance (Cohen et al., 2020). These practices are evidence of how integrated mindful movement practices can alter physiology and improve QOL.

Physical activities that integrate cognitive challenges create new neural pathways in the hippocampus through a process called neurogenesis, which regulates learning and memory in the adult brain (Gheysen et al., 2018; Rothman & Mattson, 2013). Exercise optimizes brain function through a cascade of neurotrophic and angiogenic factors such as brain-derived neurotrophic factor (BDNF), vascular endothelial growth factor (VEGF), and insulin-like growth factor-1 (IGF-1) (Cho & Roh, 2019; Maass et al., 2016). Enriched environments that encourage physical activity, mental stimulation through learning, and social interactions cause a cascade of physiological events that give rise to neuroplasticity and neuroprotection through increased expression of BDNF (Maass et al., 2016; Rothman & Mattson, 2013). Neuroplasticity is the growth, reorganization, and creation of new neural networks and cortical remapping in the brain (Gheysen et al., 2018). Neuroprotection is a mechanism where neuronal structure and function are preserved over time, which maintains the integrity of the nervous system while reducing the rate of decline in individuals with chronic conditions such as Parkinson’s Disease (Sofroniew et al., 2001). BDNF is an essential protein that creates positive changes in the nervous system through signaling cascades and pathways such as the high-affinity connection with the tropomyosin receptor kinase B that stimulates the creation of neuroprotective proteins including trophic factors, protein chaperones, anti-apoptotic proteins, antioxidant enzymes, and DNA repair enzymes (Rothman & Mattson, 2013). The trophic factors are helper molecules that allow for connections between neurons and help with the management of neurological conditions such as Parkinson's Disease (Rothman & Mattson, 2013). BDNF is important for structural Long-Term Potentiation (LTP) and neuroplasticity throughout the lifespan by forming new connections in the nervous system, which is of utmost importance in neurologically compromised individuals (Yau et al., 2016). Impaired BDNF production because of insufficient exercise, cognitive stimulation, or genetic factors could result in the development of neurological conditions including Alzheimer's, Parkinson’s, and Huntington’s disease (Rothman & Mattson, 2013). Therefore, health promotion throughout the lifespan is imperative.

Exercise stimulates the creation of modulatory elements that are key to neurogenesis and cardiovascular function, allowing for increased blood flow, movement of toxins, and regulation of breath (Hong, 2000). Overall, regaining mobility and strength through physical activities that focus on balance is key. Preventative and rehabilitation programs for older adults with or without chronic conditions have been shown to improve physiology or reduce the rate of decline (Kaupp et al., 2018; Klarner et al., 2016a, 2016b; Nguyen et al., 2016). These are essential for managing aging and promotion of longer health spans.

The widespread use of holistic exercises to gain physical and mental wellbeing is growing globally. Movements such as yoga, Tai Chi Chuan, qi gong, meditation, and pilates show a reduction in stress while improving mindfulness and focus, amongst other cognitive benefits that could serve as a protective factor for dementia (Chan et al., 2005). The mind-body exercises are comparable to aerobic, recreation, and leisure activities executed by older adults such as walking, jogging, running, or hobby sports. The less vigorous movements involved in mind-body exercises are speculated to require more cognitive processing, leading to improvements in memory and function (Chan et al., 2005).

Mind-body exercises have been practiced traditionally in eastern cultures but the demand for the activities has increased in the western world throughout the years. Modernization of the practices has allowed for the use in the context of rehabilitation and alleviation of conditions for many. The application of the movements in the elderly is promising because of the integration that they create through the connection of the body and brain.

In Asia, the use of practices such as Japanese karate, Chinese martial arts like Tai Chi Chuan, Hsing I, Bagua Zhang, and general practices like Qi Gong are done by many across the lifespan. Rapidly aging populations require appropriate maintenance of activities to promote health and governments such as the city of Hong Kong encourage elderly citizens to attend classes regularly (GovHK (www.gov.hk), 2020). Since the origins of many of the most popular and accessible martial arts are from the orient, it is presumed that these physical activities would be commonly used there compared to other alternative leisure sports. Yet, over 100 million people practice various forms of martial arts worldwide, which reveals how alluring the exercises are to a diversity of individuals in disparate cultures (Bu et al., 2010).

Yoga is another functional movement practice whose roots began in India and have grown throughout the globe. Incorporating body movements, breathing, and meditation it has benefitted the mental and physical health of people. Research has shown that the practice can balance activity and tone in the sympathetic nervous system through coordinated movements and breathwork, leading to calming sensations overall and regulation of the hypothalamic-pituitary-adrenal axis (Ross & Thomas, 2010). Yoga has gained traction in comparison to typical exercises found at the gym because it amalgamates body awareness and cognitive function in a less strenuous way (Ross & Thomas, 2010). Additionally, there are several benefits to the fluid motions such as improved joint mobility, cardiovascular health, metabolism, muscle strength, and protection from injury (Kwok et al., 2016). Yoga and mindful movements are desirable across the lifespan since they can be done in various environments and are accessible to various body types and age groups.

As our population ages, there has been a global shift towards preventative medicines such as mindfulness movement practices throughout the lifespan so that the rate of illnesses and disease can decrease. Although there are many efforts in health promotion that encourage daily physical activities, sedentary lifestyles are apparent in several communities, especially in North America (Prince et al., 2020). Moreover, elderly individuals have less mobility and reduced capacities, which leads to less motivation in conducting exercise regiments regularly. The implementation of fitness through mind-body exercises is intriguing because they create a plethora of changes in the body and do not require arduous efforts. The execution of the physical activities in elderly communities is important for the maintenance of function and prevention of disease (Kwok et al., 2016). Although the administration of mind-body exercises is growing worldwide, their utilization in rehabilitation contexts is still relatively new. Justifications from the benefits that come with regular application of these practices are apparent in the literature but there is a need to advance their uses in clinical settings.

1.2 Current Neurological Rehabilitation Techniques

Neurotrauma and neurodegeneration following Stroke, Parkinson's, and Alzheimer's cause cognitive decline as well as deficits in motor coordination and balance (Kwok et al., 2016). As previously mentioned, regaining locomotion is essential for these individuals not only improving ADL but also enhancing cognitive and physical functioning through neurorehabilitation. The Canadian Society for Exercise Physiology released the Canadian Physical Activity Guidelines in 2011 with the recommendations for adults 65 years or older to partake in 150 minutes of moderate to vigorous-intensity aerobic physical activity per week in sessions of 10 minutes or more (Tremblay et al., 2011). The guidelines present that strength training twice per week and balance exercises for fall prevention are also beneficial (Tremblay et al., 2011). It is widely known that engaging in activities for at least 150 minutes per week lowers the risk of morbidity, mortality, and functional dependence by 30% (McPhee et al., 2016). The promotion of fitness throughout the lifespan is one of the best ways to support wellbeing in society (McPhee et al., 2016).

The guidelines above are for healthy individuals, but research examining neurodegenerative disorders administer similar exercise doses (Billinger et al., 2014; “Living with Parkinson’s Disease | American Parkinson Disease Assoc.,” 2017). The World Health Organization (WHO) states that falls are the second leading cause of accidental deaths worldwide and are the largest comorbidity in people ages 65 years or older (World Health Organization, 2015). Consequently, most rehabilitation programs focus on balance training, functional learning for ADL, and strength exercises to aid in postural control and reduce the risk of falling (Pliske et al., 2016).

Focus on balance training has been highlighted in many studies where the primary focus is to regain function in the sensory, cognitive, and musculoskeletal systems (e.g. Dunsky, 2019; Lichtenstein et al., 2019). Older adults have poor posture, increased muscle coactivation, and increased postural sway that contributes to impairments in balance (Cohen et al., 2020). Previous research validated the Wii Balance board as a tool to evaluate balance during interventions (Clark et al., 2018; Cullen et al., 2017; Sun et al., 2019). Degradation of complex functions in the vestibular, visual, somatosensory, motor, and central nervous system causes cascading deficits that need to be addressed and studies should focus on postural orientation (Horak, 2006). Aerobic exercises and resistance training can be used to reverse frailty in older adults through improving cardiorespiratory health, balance, and the musculoskeletal system (Hong, 2000). Additionally, community-based interventions are admirable ways of creating social interaction while exercising, leading to improved physical, social, and mental wellbeing (Jansen et al., 2017). A community “dose” involved practicing in a group setting with the same approach and content that could commonly be found in recreation programs.

Exercise interventions with the use of arm, arm and leg cycling, and supported treadmill training in older adults and individuals with chronic conditions like stroke can significantly improve function (Kaupp et al., 2018; Klarner et al., 2016a, 2016b). These interventions were done with chronic stroke participants and show how repeated movements over a 5-week training period can give benefits to locomotion while improving interlimb connections (Kaupp et al., 2018; Klarner et al., 2016a, 2016b). Although these therapies are effective, the equipment is usually only available in rehabilitation centers (Duncan et al., 2011; Klarner et al., 2016a, 2016b). Therefore, new therapies for individuals with chronic conditions must be investigated.

While the interventions to date use relatively accessible equipment, there are significant limitations to these therapies as they are only available in restricted environments, require specialized machinery, expensive administration, and substantial labour. Additionally, these training programs would target a subgroup of people rather than being accessible for all individuals, regardless of socioeconomic status or health condition. We aim to evaluate the combinatory effects of neurophysiology, balance, and psychosocial health through the implementation of an intervention that focuses on accessible, community-based activities while simply using the body as a tool.

1.3 Mind-Body Exercises in Health Promotion

Martial arts are ancient traditional practices that date back in history to combat and warring applications. Paradoxically, although they are glorified in popular media for violence, the roots are based on self-defense, confidence, exercise, and self-discipline (Lorge & Lorge, 2012). Such movements have been popular amongst children for physical activity and regulation of well-being for mental health conditions such as attention deficit hyperactivity disorder (ADHD) as well as showing higher levels of self-efficacy, healthy behaviour, and QOL (Kotarska et al., 2019;

Woodward, 2009). There has been growing popularity worldwide for mind-body exercises as community-based exercises for older adults. A preventative "pre-habilitation" approach to health is being promoted rather than using the medical system once there is an illness or disease. Modernization and integration of these ancient practices have been occurring for years. Presently, useful applications are found using these traditions to help individuals balance life stressors through mindful movement especially in the West (Brudnak et al., 2002).

Mind-Body exercises link physical fitness, mental focus, and controlled breathing to improve strength, balance flexibility, and overall health (Kwok et al., 2016). Karate athletes have improved physical health through increased muscle power, dynamic strength, flexibility, balance, and reaction time (Chaabene et al., 2019). Researchers have found significant differences in primary motor cortex excitability in karate athletes compared to controls (Monda et al., 2017), and the same changes in cortical excitability may arise in older adults and individuals with chronic conditions. Observations of elite karate athletes exhibit increases in grey matter volume in the temporal, occipital and premotor cortices, as well as an augmentation in white matter in the caudate nucleus, hypothalamus, and mammillary region, inferring functional and structural plasticity (Duru & Balcioglu, 2018). The white matter density changes in frontal and parietal lobes have been associated with changes in motor learning and the grey matter is the region of the brain for muscle control and sensory perception (Duru & Balcioglu, 2018). The mammillary bodies are associated with memory and maintaining a sense of direction, the caudate nucleus is associated with motor processing and procedural learning, while the hypothalamus links the nervous and endocrine system. The structures and regions mentioned above are essential for the maintenance of the healthy function of the brain and body throughout the lifespan, allowing for optimal activity and reduction in the risk of disease. Combat sports and martial arts lead to improved QOL in healthy, young participants (Kotarska et al., 2019), suggesting that regular training is beneficial.

Another study with neurologically intact participants at an average age of 30 found that karate training was associated with higher postural control, meaning that it functions as a pre-habilitation tool and potentially help with cognitive decline from aging (Hadad et al., 2020). The intervention matched karate practitioners to elite swimmers and found that there were significantly larger changes in the karate group. Observations that intralimb coordination through non-impact training allows for proper alignment of hip and knee, suggesting that interventions should focus on form rather than impact to receive maximal benefits (Quinzi et al., 2014).

Mind-body exercises in a meta-analysis evaluated five Tai Chi Chuan, two yoga, and two dance interventions in individuals with Parkinson's and concluded that all practices produced benefits to physiological health through motor coordination, postural stability, mobility, and balance training (Kwok et al., 2016). Holistic exercises such as mental practice use cognitively rehearsed physical movements for stroke rehabilitation (Page & Harnish, 2012). The mental practices are associated with reduced stroke-induced impairments, increased skill acquisition, function, neuroplasticity, and muscular and neural activation (Page & Harnish, 2012). Overall, mind-body exercises are intriguing because they provide cognitive benefits that extend into the body and allow for a comprehensive healing approach. Practicing karate results in long-term changes in postural control through observations of improved static balance by increasing body sway (Juras et al., 2013). The authors speculate that the results came from the redundancy of the sensorimotor system, where the physiological patterns and regions are maintained.

1.4 Clinical Assessment of Martial Arts & Rehabilitation

“Soft” vs. “Hard” Martial Arts

Martial arts, “the arts of war”, or as written in Chinese (wushu) and Japanese (budo) characters, the practices for stopping fighting, are widely recognized for their quick motions, punches, kicks, locks, throws that create an overall image of superhuman skill and ability. While the practices are often glorified in popular media for the powerful movements, prowess, and skill, there are immense tangible health benefits that come from training (Woodward, 2009). In Japanese martial arts, there are three different categories: martial arts/methods (bugei), martial techniques (bujutsu), and martial ways (budo) (Garcia, 2018). There are a variety of forms and practices but “martial arts” refers to these various sports and skills that originated in Japan and China. In Japanese martial arts, the hard and soft methods are compared to the “yin and yang” principles, and most Japanese styles combine the use of hard and soft to achieve greater balance (Lowry, 1995). The application of the different styles can benefit various populations depending on the desired results. An explanation of the “soft” versus “hard” martial arts follow, with the associated clinical applications.

Kung fu (more properly known as wushu) is the dedication to attaining extreme skill through committed effort. There are two related but different streams of martial arts, Shaolin and Wudang fist (quan, chuan), which originated from 2 centers in China. Shaolin is a Buddhist temple that hosts the more “external” or “hard” style martial arts. It is considered “external” because of the predominantly strong, quick and forceful movements and a common emphasis on using physical strength (Brudnak et al., 2002). External martial arts focus on strengthening the muscles, skin, and bone while building speed and strength. Examples of “hard” Shaolin-originating martial arts include Long Fist, and Praying Mantis in China, which significantly influenced the development of Okinawan and then Japanese karate, and Tae Kwon Do in Korea (Brudnak et al., 2002).

Wudang martial arts originated from Taoist practices with more of an emphasis on “internal” or “soft” style with a focus on meditative traditions which are in some ways subtly more complex. Wudang martial arts are centered around developing from the core to the outside. Internal martial arts prioritize skills such as focus, timing, awareness, precision, and the use of energy “Qi” (Lorge & Lorge, 2012). Examples of “soft” Wudang martial arts include Tai Chi, Aikido, Judo and Bagua.

“Soft” Martial Arts in the literature

Rehabilitation using whole body activation through martial arts training could have promising therapeutic applications. “Softer” martial arts (e.g. Tai Chi Chuan) are appealing practices for older adults due to their slow and concentrated movements. Tai Chi Chuan is the Chinese origin of martial arts used for meditation, mindfulness, and balance (Wayne et al., 2014). There have been several studies that examine the benefits of Tai Chi on balance control in older adults and those with Parkinson’s disease (Li et al., 2002, 2012). Tai Chi was found to improve postural stability and other functional outcomes in patients with Parkinson’s in comparison to participants undergoing resistance training or stretching (Li et al., 2012). Balance, gait, and mobility were enhanced in individuals with Parkinson’s following 20, 1-hr sessions of Tai Chi, using the Berg balance scale and Timed-Up-and-Go tests (Hackney & Earhart, 2008). Another study observed that Tai Chi practitioners with an average of 13 years of experience had improved heart rate, sit to stand, and total body rotation in comparison to the matched sedentary individuals (Hong, 2000). The slow movements provide aerobic benefits, cardiovascular fitness, improved balance control, flexibility, and emotional well-being (Gatts & Woollacott, 2007; Hong, 2000; Wayne et al., 2014).

Judo is a modern martial art, where opponents use balance and body weight to throw each other or hold each other in a lock (Bu et al., 2010). Judo is the second most studied martial art, after Tai Chi (Bu et al., 2010). Research highlights how practice can lower the risk of fall severity and hip impact (van der Zijden et al., 2012). The femoral fracture risk can be decreased through regular training and implementation of mindful fall techniques, which are of interest to older adults. Judo is also reverenced for the sensorimotor adaptations in balance control with eyes opened or closed in comparison to dancers (Perrin et al., 2002). The movements require enhanced proprioception and sensorimotor integration.

Karate originated in Okinawa, made its way to Japan and is commonly practiced for sport and self-defense worldwide, described as having “hard” movements while Tai Chi forms are softer and slower, making them more inviting for individuals with chronic disease. Although this was the main paradigm, there have been preliminary studies done using karate in rehabilitation and it is growing as a promising therapy. A 30-week karate training intervention with Parkinson’s participants improved balance and showed no decline of emotional well-being compared to controls (Dahmen-Zimmer & Jansen, 2017).

Martial arts training uses coordinated arm and leg movement patterns that could induce physiological changes to corticospinal excitability, increase locomotor activity and mobility (Moscatelli et al., 2016; Zehr et al., 2016). Tai Chi has been thoroughly researched as an effective complementary activity in rehabilitation for chronic diseases (Nguyen et al., 2016). Only a few studies have evaluated “harder” forms of martial arts that could provide similar effects as Tai Chi, with the potential of producing stronger connections and benefits than those seen in the “softer” arts. A major consideration is that there are typically more communities of the “hard” arts such as karate, tae kwon do, kickboxing, which make the practices more accessible in comparison to Tai Chi. Granted, there is a requirement for implementation of more research of these practices since there is more opportunity for people to participate.

Physiological changes in “softer” martial arts interventions such as Tai Chi have also been effective in older adults and individuals with neurological conditions, such as Parkinson’s Disease (Jahnke et al., 2010; Kwok et al., 2016; Li et al., 2012; Nguyen et al., 2016; Paillard et al., 2015). However, combined effects on neurophysiology, balance reactions, and clinical aspects of health are not well documented. More information is also required on the generalizability of various martial arts training approaches for application in older adults.

“Hard” Martial Arts in the literature

Several “hard” martial arts have been evaluated in the literature for improving physical activity such as Tae Kwon Do, Kickboxing, Ving Tsun “Wing Chun”, and Karate (Brudnak et al., 2002; Cho & Roh, 2019; Chung et al., 2020, 2020; Cromwell et al., 2007; Moscatelli et al., 2016; Perrin et al., 2002; Witte et al., 2016). All these practices involve more vigorous movements in comparison to tai chi and are thought to improve reaction time, physical strength, and balance in greater amounts (Chung et al., 2020; Cromwell et al., 2007; Fong et al., 2016; Ouergui et al., 2014).

Tae Kwon Do is a Korean martial art that involves high-kicks and powerful movements (Cho & Roh, 2019; Cromwell et al., 2007). Assessment of walking ability and balance in older adults found improvements in the multidirectional reach test, TUG, walking velocity, gait stability ratio, and sit-and-reach (Cromwell et al., 2007). The authors suggest that this may restore function and preserve mobility in older adults, which is the aim of most rehabilitation interventions. Another study found that older adults training in Tae Kwon Do increase one-leg balance but also indicated that one, 1-hour session a week was not sufficient for teaching the practice to the population (Brudnak et al., 2002).

Kickboxing is another combat sport based on kicking and punching that is a mix of karate and boxing (Ouergui et al., 2014). A training program done 3 times a week for 5 weeks had improvements in upper-body muscle power, aerobic power, anaerobic fitness, flexibility, and speed. The authors conclude that this practice was effective to change physical fitness in young, healthy participants. This training protocol has similar methodologies to our project, such as the training length, balance measures, and TUG assessment to test if the exercises improved function (Ouergui et al., 2014). There has also been growing popularity for kickboxing in individuals with Parkinson's Disease since the movements improve coordination and stability (Domingos et al., 2019).

Ving Tsun (VT) is a commonly found hard-style Chinese martial art that incorporates a balance of quick arm movements and softness techniques in a relaxed fashion. The activity targets muscular performance, functional balance, postural control, and cardiovascular endurance. Investigation of the practice in older adults (60 years and older) for 3 months examined the benefits of bone and muscular strength, hand-grip, balance, and confidence (Fong et al., 2013, 2016). Upper-limb sensorimotor function in this practice has also been tested and showed improved shoulder flexor muscles time to reach peak force (Chung et al., 2020).

Martial arts are known for their multifaceted benefits to physical, mental, and social health. A yearlong karate intervention with adults at the average age of 50 found that physical performance improved by practicing "hard" martial arts. Results from the SF36 and Beck Depression Inventory assessments show that there were physical and mental health benefits of the practice (Chateau-

Degat et al., 2010). The holistic approach of the study infers that these exercises help with multifaceted recovery and strengthening of the body and brain.

Another karate training intervention with older adults helped to enhance attention, resilience, and motor reaction time in 5 months but 10 months was more efficient (Witte et al., 2016). This study evaluated the deterioration of cognition as a function of aging, with emphasis on aerobic training and how white and grey matter increases significantly in comparison to stretching. With this ideology in mind, "hard" martial arts are more effective in fostering cognitive boosts in individuals in comparison to the slower movement practices such as tai chi chuan.

Martial arts such as karate use whole-body movement patterns that challenge balance and postural regulation using integrated training sequences called kata. Shotokan karate training over 8-weeks with older adults and individuals with Parkinson's Disease showed improvements to strength, cognitive wellness, and balance in older adults (Dahmen-Zimmer & Jansen, 2017; Jansen et al., 2017). Psychological measures were assessed through demographic data, cognitive and emotional variables, and balance motor function through a one-leg stand test (Dahmen-Zimmer & Jansen, 2017). Following the intervention, there were improvements in static balance for the participants (Dahmen-Zimmer & Jansen, 2017) and some small changes to emotional and cognitive aspects (Jansen et al., 2017). There are only a few studies in the literature that evaluate the psychological and physiological impacts of karate, but it is apparent that a multifaceted approach to interventions is beneficial.

1.5 Human Postural Balance

Postural balance requires maintaining the body's center of mass within the base of support. As previously mentioned, balance is a complex function of the body that requires the activity of sensorimotor systems through musculoskeletal action (Faude & Donath, 2019). Maintenance of balance equilibrium in static and dynamic contexts requires that somatosensory, visual, and vestibular information be gathered first by the peripheral nervous system then integrated by the central nervous system. Motor outputs and compensatory mechanisms coordinate skeletal muscle contractions to maintain postural stability (Figure 1) (Guskiewicz, 2001). The central nervous system takes the information from the different centers in the brain to inform suitable timing, direction, and amplitudes of muscle contractions to maintain postural control (Guskiewicz, 2001). The integration of information from these centers informs motor outputs to produce commands leading to movement and postural control. The somatosensory system uses receptors in the skin, muscles, joints, and fascia to gather information about proprioception (e.g. temperature, touch, and position). The visual system uses sight to integrate information from the outside environment to aid with position and coordination. The vestibular system is composed of the semicircular canals and otolith organs of the inner ear, which detect motion and provide information about movement, equilibrium, and orientation (Guskiewicz, 2001). The information from these three centers is received by the cerebellum, which is integral in the coordination of postural control and balance reactions (Guskiewicz, 2001). Compensatory mechanisms are initiated when the balance is disturbed to re-establish equilibrium and avoid falling.

Figure 1. Maintenance of postural control

With aging populations, there is a degradation of balance, which relates to a decline in individual functioning (Faude & Donath, 2019). Since fall risk is heightened, improving balance is a key element to many rehabilitation programs. Martial arts train the body and brain in coordination with the use of intricate movements. Variations in the environment test our ability to maintain postural control and requires reweighing of sensory information (Guskiewicz, 2001). Postural control relies on sensory integration where 70% comes from the somatosensory system, 20% vestibular, and 10% visual (Horak, 2006). Healthy individuals can integrate sensory information and initiate appropriate motor outputs in response to this information. The compensatory strategies in older adults are different since there can be impaired balance depending on the individual's health status or chronic conditions. Therefore, interventions must focus on regaining mobility and coordination through postural control.

1.6 Interlimb Coordination observed through arm and leg strength

Rehabilitation following neurotrauma requires reconnection and remapping of the intrinsic physiological aspects of the body. Humans evolved from quadrupedal ancestors that used their arms and legs for locomotion, which later transitioned to bipedal coordination (Zehr et al., 2016). Although humans have bipedal locomotion, the evolution from quadrupedal animals keeps our inherent properties such as coordinated limb movements and the neural networks that activate these motions alive (Zehr et al., 2009; Zehr et al., 2016). Coordinated movements between the arms and legs allow for synchronous motions of the limbs that create the graceful motions attributed to walking. The interlimb connections are modulated through spinal networks that control the rhythmic movement of the arms and legs in locomotion (Frigon, 2017).

Maintaining the interlimb connections between the arms and legs is something that has been studied extensively in chronic stroke participants by using recreationally available devices such as a supported treadmill, arm, and arm and leg cycle ergometer (Duncan et al., 2011; Kaupp et al., 2018; Klarner et al., 2016a, 2016b). The interlimb pathways that exist improve when the upper and lower limbs work in conjunction with one another, such as during walking, swimming, or running (Zehr et al., 2009; Zehr & Duysens, 2004). A 5-week training intervention with chronic stroke participants showed that 30-minute arm cycling, 3 times per week resulted in significant improvements to both arm and leg strength (Kaupp et al., 2018). An intervention with Parkinson's participants showed that the contralateral and ipsilateral coordination was reduced in comparison to older adults, emphasizing that interlimb pathways have a degradation for individuals with chronic conditions (Roemmich et al., 2013).

1.7 Spinal cord Excitability

Measuring spinal cord excitability in vivo has been studied through the evaluation of Hoffmann (H-) reflexes in humans and other animals. Clinical neurophysiology commonly utilizes the H-reflex in the soleus muscle to assess spinal cord excitability and adaptive plasticity (Alizadehsaravi et al., 2020; Barzi & Zehr, 2008; Mezzarane & Kohn, 2002; Noble et al., 2019; Zehr, 2002; Zehr et al., 2016). The muscle afferent reflex can be evoked by applying transcutaneous stimulation to a mixed peripheral nerve (i.e. containing both sensory and motor axons), which will elicit the tendon and Hoffmann (H-) reflex, respectively (Knikou, 2008; Misiaszek, 2003; Pierrot-Deseilligny & Mazevet, 2000; Voerman et al., 2005; Zehr, 2002). Measurements from the H-reflex allow for an understanding of the intrinsic properties that exist within the nervous system, such as assessing modulation of monosynaptic reflex activity in the spinal cord, and musculoskeletal systems.

The figure below shows the neural network that exists between the muscle spindles and the nervous system. The Ia afferent neuron is known to give presynaptic inhibition onto the muscle spindle, which evokes a variety of responses depending on the position (sitting, standing, lying) (Zehr, 2002), and the age or condition of the individual (Baudry & Duchateau, 2012). Presynaptic inhibition is amplified while in a standing position, resulting in a decline of the H-reflex signal (Zehr, 2002). Additionally, studies have shown that older adults have higher levels of co-

contraction which coincides with reduced soleus H-reflex gain (Alizadehsaravi et al., 2020). The larger co-contractions observed in older adults could contribute to the greater Ia presynaptic inhibition to ensure better control of agonist-antagonist muscles for balance (Baudry & Duchateau, 2012).

The mechanisms that contribute to the complex pathways can vary depending on neurotransmitter levels from the Ia afferents, such as GABA-ergic synapses from inhibitory interneurons, leading to post-activation depression or homosynaptic depression (Crone & Nielsen, 1989). Modification of the chemical release causes changes in neural activity and the response in the corresponding musculoskeletal system. Although no martial arts studies have tested H-reflexes to date, they have been used frequently in clinical research to assess the responsiveness in the nervous system.

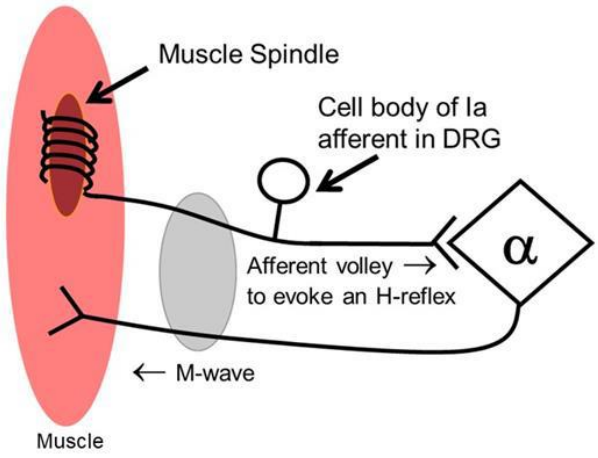


Figure 2. The H-reflex pathway (Figure adapted from (Zehr, 2002))

1.8 Epidemiology

Cerebrovascular accidents occur in Canada each year and the damage to the brain can lead to subsequent impairments in mobility, which may decrease the quality of life significantly. Stroke is the leading cause of death worldwide and the leading cause of disability in North America, with approximately 400,000 Canadians living with chronic stroke (Cheng et al., 2014; Lang et al., 2018; Thrift et al., 2017). As our population ages, it is predicted that for those who have had a stroke, 75% of them will require rehabilitation, and regaining locomotion is a primary goal that requires balance capacity (Pinter & Brainin, 2012; Zehr, 2011).

Parkinson's Disease is the second most common neurodegenerative disease caused by a decline in dopamine levels and highly characterized by motor (bradykinesia, rigidity, tremor, gait dysfunction, and postural instability) and cognitive (frontal lobe and executive dysfunction) system deficits (Lotharius & Brundin, 2002; Petzinger et al., 2015). Most research focuses on the basal ganglia and interconnected networks since it is the focal point for motor function, executive function, and emotional behaviours (Petzinger et al., 2015). Intensity, specificity, difficulty, and complexity of exercise influence neuroplasticity in this population, and goal-based exercises are important for improved performance (Petzinger et al., 2015). Like recovery following stroke, individuals with Parkinson's Disease must change behaviour and function through neuroplasticity to adapt to their condition and enhance QOL. There is no cure for Parkinson's, so management through exercise is critical to reducing the rate of neurological decline (Corcos et al., 2013; Paillard et al., 2015).

Vascular dementia represents 15% of cases following the development of Alzheimer's Disease, which is characterized by issues in reasoning, judgment, memory, and processing (O'Brien & Thomas, 2015). It is the second most common cause of dementia after Alzheimer's and can develop following a stroke but can also occur through less detectable means, such as late-life depression (O'Brien & Thomas, 2015). Blood flow to the brain is inhibited leading to impairments and rapid degradation. Effective studies involve vascular risk reduction, cognitive training, and exercise programs to reduce the risk of decline (Ngandu et al., 2015; O'Brien & Thomas, 2015).

1.9 Limitations of Existing Literature

The effects of karate on interlimb connectivity, balance control, and psychosocial health have not been tested in the current literature for older adults and the management of chronic conditions. It is known that participants with neurodegenerative diseases benefit from mind-body exercises that stimulate neuroplasticity. Martial arts training promotes health, wellness, and empowerment in women but the literature on physiological and psychological effects on females is scarce (Chaabene et al., 2019).

Furthermore, adapted karate training that targets movements at an individual basis for older adults are captivating programs (Chateau-Degat et al., 2010). The intensity and specificity of exercises should be modified for each individual to ensure that participation is maintained and there should be a focus on health and mobility rather than weight loss (McPhee et al., 2016). Depending on the condition and previous exercise experience of the individual, using various training doses would provide personalized benefits that would result in greater retention and improvements of function.

Additionally, the psychosocial effects of mind-body exercises in the Parkinson's Disease population are limited (Jansen et al., 2017; Kwok et al., 2016) and more interventions incorporating psychosocial wellbeing need to occur (Cheng et al., 2014). Since there are limited karate interventions in the literature that focus on quantitative measures from a holistic lens, our goal is to identify the possible benefits that the whole-body activation creates on physiological, psychological, and social health as a rehabilitation tool for aging individuals and those with chronic conditions.

It is critical that more research tests the efficacy of community-based martial arts like karate training as interventions to improve function and multiple dimensions of health in elderly individuals, with or without chronic conditions. Requirements of balance and postural control in karate training could strengthen interlimb connections and have beneficial effects on physiological function in older adults. Such outcomes could support the groundwork for future explorations of dose, applications to neuropathology, and development of community-based martial arts interventions as “pre-habilitation” for older adults.

1.10 References

Alizadehsaravi, L., Bruijn, S. M., Maas, H., & van Dieën, J. H. (2020). Modulation of soleus muscle H-reflexes and ankle muscle co-contraction with surface compliance during unipedal balancing in young and older adults. *Experimental Brain Research*. https://doi.org/10.1007/s00221-020-05784-0

Barss, T. S., Klarner, T., Pearcey, G. E. P., Sun, Y., & Zehr, E. P. (2018). Time course of interlimb strength transfer after unilateral handgrip training. *Journal of Applied Physiology*, *125*(5), 1594–1608. https://doi.org/10.1152/japplphysiol.00390.2017

Barzi, Y., & Zehr, E. P. (2008). Rhythmic arm cycling suppresses hyperactive soleus H-reflex amplitude after stroke. *Clinical Neurophysiology*, *119*(6), 1443–1452. https://doi.org/10.1016/j.clinph.2008.02.016

Baudry, S., & Duchateau, J. (2012). Age-related influence of vision and proprioception on Ia presynaptic inhibition in soleus muscle during upright stance: Ageing and Ia presynaptic inhibition during balance. *The Journal of Physiology*, *590*(21), 5541–5554. https://doi.org/10.1113/jphysiol.2012.228932

Billinger, S. A., Arena, R., Bernhardt, J., Eng, J. J., Franklin, B. A., Johnson, C. M., MacKay-Lyons, M., Macko, R. F., Mead, G. E., Roth, E. J., Shaughnessy, M., & Tang, A. (2014). Physical Activity and Exercise Recommendations for Stroke Survivors: A Statement for Healthcare Professionals From the American Heart Association/American Stroke Association. *Stroke*, *45*(8), 2532–2553. https://doi.org/10.1161/STR.0000000000000022

Brudnak, M. A., Dundero, D., & Van Hecke, F. M. (2002). Are the `hard’ martial arts, such as the Korean martial art, TaeKwon-Do, of benefit to senior citizens? *Medical Hypotheses*, *59*(4), 485–491. https://doi.org/10.1016/S0306-9877(02)00203-7

Bu, B., Haijun, H., Yong, L., Chaohui, Z., Xiaoyuan, Y., & Singh, M. F. (2010). Effects of martial arts on health status: A systematic review. *Journal of Evidence-Based Medicine*, *3*(4), 205–219. https://doi.org/10.1111/j.1756-5391.2010.01107.x

Burke, R. E. (2007). Sir Charles Sherrington's The integrative action of the nervous system: A centenary appreciation. *Brain*, *130*(4), 887–894. https://doi.org/10.1093/brain/awm022

Bütefisch, C., Hummelsheim, H., Denzler, P., & Mauritz, K.-H. (1995). Repetitive training of isolated movements improves the outcome of motor rehabilitation of the centrally paretic hand. *Journal of the Neurological Sciences*, *130*(1), 59–68. https://doi.org/10.1016/0022-510X(95)00003-K

Chaabene, H., Negra, Y., Capranica, L., Prieske, O., & Granacher, U. (2019). A Needs Analysis of Karate Kumite With Recommendations for Performance Testing and Training: *Strength and Conditioning Journal*, *41*(3), 35–46. https://doi.org/10.1519/SSC.0000000000000445

Chan, A. S., Ho, Y., Cheung, M., Albert, M. S., Chiu, H. F. K., & Lam, L. C. W. (2005). Association Between Mind-Body and Cardiovascular Exercises and Memory in Older Adults: EXERCISE AND MEMORY. *Journal of the American Geriatrics Society*, *53*(10), 1754–1760. https://doi.org/10.1111/j.1532-5415.2005.53513.x

Chateau-Degat, M.-L., G&amp, eacute, Papouin, R., Saint-Val, P., & Al, E. (2010). Effect of adapted karate training on quality of life and body balance in 50-year-old men. *Open Access Journal of Sports Medicine*, *2010*(default), 143–150.

Cheng, H. Y., Chair, S. Y., & Chau, J. P.-C. (2014). The effectiveness of psychosocial interventions for stroke family caregivers and stroke survivors: A systematic review and meta-analysis. *Patient Education and Counseling*, *95*(1), 30–44. https://doi.org/10.1016/j.pec.2014.01.005

Cho, S.-Y., & Roh, H.-T. (2019). Taekwondo Enhances Cognitive Function as a Result of Increased Neurotrophic Growth Factors in Elderly Women. *International Journal of Environmental Research and Public Health*, *16*(6). https://doi.org/10.3390/ijerph16060962

Chung, J. W. Y., Fong, S. S. M., Gao, Y., Yam, T. T. T., Chak, Y. T. C., Leung, J. C. Y., & Wong, T. K. S. (2020). Effects of Ving Tsun sticking-hand training on upper-limb sensorimotor performance in community-dwelling middle-aged and older adults: A randomized controlled trial. *International Journal of Nursing Sciences*, *7*(1), 29–34. https://doi.org/10.1016/j.ijnss.2019.11.001

Clark, R. A., Mentiplay, B. F., Pua, Y.-H., & Bower, K. J. (2018). Reliability and validity of the Wii Balance Board for assessment of standing balance: A systematic review. *Gait & Posture*, *61*, 40–54. https://doi.org/10.1016/j.gaitpost.2017.12.022

Cohen, R. G., Baer, J. L., Ravichandra, R., Kral, D., McGowan, C., & Cacciatore, T. W. (2020). Lighten Up! Postural Instructions Affect Static and Dynamic Balance in Healthy Older Adults. *Innovation in Aging*, *4*(2), igz056. https://doi.org/10.1093/geroni/igz056

Corcos, D. M., Robichaud, J. A., David, F. J., Leurgans, S. E., Vaillancourt, D. E., Poon, C., Rafferty, M. R., Kohrt, W. M., & Comella, C. L. (2013). A two-year randomized controlled trial of progressive resistance exercise for Parkinson’s disease: Progressive Resistance Exercise in PD. *Movement Disorders*, *28*(9), 1230–1240. https://doi.org/10.1002/mds.25380

Cost of Injury in Canada – Parachute. (n.d.). Retrieved October 5, 2020, from https://parachute.ca/en/professional-resource/cost-of-injury-report/

Cromwell, R. L., Meyers, P. M., Meyers, P. E., & Newton, R. A. (2007). Tae Kwon Do: An Effective Exercise for Improving Balance and Walking Ability in Older Adults. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *62*(6), 641–646. https://doi.org/10.1093/gerona/62.6.641

Crone, C., & Nielsen, J. (1989). Methodological implications of the post activation depression of the soleus H-reflex in man. *Experimental Brain Research*, *78*(1). https://doi.org/10.1007/BF00230683

Cullen, H. M., Sun, Y., Christie, B. R., & Zehr, E. P. (2017). Use of the wii balance board to assess changes in postural balance across athletic season. *British Journal of Sports Medicine*, *51*(11), A1–A1. https://doi.org/10.1136/bjsports-2016-097270.2

Dahmen-Zimmer, K., & Jansen, P. (2017). Karate and Dance Training to Improve Balance and Stabilize Mood in Patients with Parkinson’s Disease: A Feasibility Study. *Frontiers in Medicine*, *4*, 237. https://doi.org/10.3389/fmed.2017.00237

Domingos, J., Radder, D., Riggare, S., Godinho, C., Dean, J., Graziano, M., de Vries, N. M., Ferreira, J., & Bloem, B. R. (n.d.). *Implementation of a Community-Based Exercise Program for Parkinson Patients: Using Boxing as an Example*. 9.

Dragert, K., & Zehr, E. P. (2013). High-intensity unilateral dorsiflexor resistance training results in bilateral neuromuscular plasticity after stroke. *Experimental Brain Research*, *225*(1), 93–104. https://doi.org/10.1007/s00221-012-3351-x

Duncan, P. W., Sullivan, K. J., Behrman, A. L., Azen, S. P., Wu, S. S., Nadeau, S. E., Dobkin, B. H., Rose, D. K., Tilson, J. K., Cen, S., & Hayden, S. K. (2011). Body-Weight–Supported

Treadmill Rehabilitation after Stroke. *New England Journal of Medicine*, *364*(21), 2026–2036. https://doi.org/10.1056/NEJMoa1010790

Dunsky, A. (2019). The Effect of Balance and Coordination Exercises on Quality of Life in Older Adults: A Mini-Review. *Frontiers in Aging Neuroscience*, *11*, 318. https://doi.org/10.3389/fnagi.2019.00318

Duru, A. D., & Balcioglu, T. H. (2018). Functional and Structural Plasticity of Brain in Elite Karate Athletes. *Journal of Healthcare Engineering*, *2018*, 1–8. https://doi.org/10.1155/2018/8310975

Faude, O., & Donath, L. (2019). Editorial: Neuromuscular Performance During Lifespan: Assessment Methods and Exercise Interventions. *Frontiers in Physiology*, *10*, 1348. https://doi.org/10.3389/fphys.2019.01348

Fong, S. S. M., Guo, X., Cheung, A. P. M., Jo, A. T. L., Lui, G. K. W., Mo, D. K. C., Ng, S. S. M., & Tsang, W. W. N. (2013). Elder Chinese Martial Art Practitioners Have Higher Radial Bone Strength, Hand-Grip Strength, and Better Standing Balance Control. *ISRN Rehabilitation*, *2013*, 1–6. https://doi.org/10.1155/2013/185090

Fong, S. S. M., Ng, S. S. M., Cheng, Y. T. Y., Wong, J. Y. H., Yu, E. Y. T., Chow, G. C. C., Chak, Y. T. C., Chan, I. K. Y., Zhang, J., Macfarlane, D., & Chung, L. M. Y. (2016). Effects of Ving Tsun Chinese Martial Art Training on Upper Extremity Muscle Strength and Eye-Hand Coordination in Community-Dwelling Middle-Aged and Older Adults: A Pilot Study. *Evidence-Based Complementary and Alternative Medicine : ECAM*, *2016*. https://doi.org/10.1155/2016/4013989

Frigon, A. (2017). The neural control of interlimb coordination during mammalian locomotion. *Journal of Neurophysiology*, *117*(6), 2224–2241. https://doi.org/10.1152/jn.00978.2016

Garcia, R. S. (2018). *The Historical Sociology of Japanese Martial Arts*. Routledge.

Gatts, S. K., & Woollacott, M. H. (2007). How Tai Chi improves balance: Biomechanics of recovery to a walking slip in impaired seniors. *Gait & Posture*, *25*(2), 205–214. https://doi.org/10.1016/j.gaitpost.2006.03.011

Gheysen, F., Poppe, L., DeSmet, A., Swinnen, S., Cardon, G., De Bourdeaudhuij, I., Chastin, S., & Fias, W. (2018). Physical activity to improve cognition in older adults: Can physical activity programs enriched with cognitive challenges enhance the effects? A systematic review and meta-analysis. *International Journal of Behavioral Nutrition and Physical Activity*, *15*(1), 63. https://doi.org/10.1186/s12966-018-0697-x

GovHK (www.gov.hk). (n.d.). *GovHK: Leisure and Cultural Activities for the Elderly*. Retrieved August 15, 2020, from https://www.gov.hk/en/residents/culture/recreation/activities/elderlyact.htm

Guertin, P. A. (2009). The mammalian central pattern generator for locomotion. *Brain Research Reviews*, *62*(1), 45–56. https://doi.org/10.1016/j.brainresrev.2009.08.002

Guskiewicz, K. M. (2001). Postural Stability Assessment Following Concussion: One Piece of the Puzzle: *Clinical Journal of Sport Medicine*, *11*(3), 182–189. https://doi.org/10.1097/00042752-200107000-00009

Hackney, M. E., & Earhart, G. M. (2008). Tai Chi improves balance and mobility in people with Parkinson disease. *Gait & Posture*, *28*(3), 456–460. https://doi.org/10.1016/j.gaitpost.2008.02.005

Hadad, A., Ganz, N., Intrator, N., Maimon, N., Molcho, L., & Hausdorff, J. M. (2020). Postural control in karate practitioners: Does practice make perfect? *Gait & Posture*, *77*, 218–224. https://doi.org/10.1016/j.gaitpost.2020.01.030

Hong, Y. (2000). Balance control, flexibility, and cardiorespiratory fitness among older Tai Chi practitioners. *British Journal of Sports Medicine*, *34*(1), 29–34. https://doi.org/10.1136/bjsm.34.1.29

Horak, F. B. (2006). Postural orientation and equilibrium: What do we need to know about neural control of balance to prevent falls? *Age and Ageing*, *35*(suppl_2), ii7–ii11. https://doi.org/10.1093/ageing/afl077

Ibrahim, A., Singh, D. K. A., & Shahar, S. (2017). 'Timed Up and Go' test: Age, gender and cognitive impairment stratified normative values of older adults. *PLOS ONE*, *12*(10), e0185641. https://doi.org/10.1371/journal.pone.0185641

Jahnke, R. A., Larkey, L. K., & Rogers, C. (2010). Dissemination and Benefits of a Replicable Tai Chi and Qigong Program for Older Adults. *Geriatric Nursing*, *31*(4), 272–280. https://doi.org/10.1016/j.gerinurse.2010.04.012

Jansen, P., Dahmen-Zimmer, K., Kudielka, B. M., & Schulz, A. (2017). Effects of Karate Training Versus Mindfulness Training on Emotional Well-Being and Cognitive Performance in Later Life. *Research on Aging*, *39*(10), 1118–1144. https://doi.org/10.1177/0164027516669987

Juras, G., Rzepko, M., Król, P., Czarny, W., Bajorek, W., Słomka, K., & Sobota, G. (n.d.). The effect of expertise in karate on postural control in quiet standing. *ARCHIVES OF BUDO*, 6.

Kaupp, C., Pearcey, G. E. P., Klarner, T., Sun, Y., Cullen, H., Barss, T. S., & Zehr, E. P. (2018). Rhythmic arm cycling training improves walking and neurophysiological integrity in chronic stroke: The arms can give legs a helping hand in rehabilitation. *Journal of Neurophysiology*, *119*(3), 1095–1112. https://doi.org/10.1152/jn.00570.2017

Klarner, T., Barss, T. S., Sun, Y., Kaupp, C., Loadman, P. M., & Zehr, E. P. (2016a). Exploiting Interlimb Arm and Leg Connections for Walking Rehabilitation: A Training Intervention in Stroke. *Neural Plasticity*, *2016*, 1–19. https://doi.org/10.1155/2016/1517968

Klarner, T., Barss, T., Sun, Y., Kaupp, C., Loadman, P., & Zehr, E. (2016b). Long-Term Plasticity in Reflex Excitability Induced by Five Weeks of Arm and Leg Cycling Training after Stroke. *Brain Sciences*, *6*(4), 54. https://doi.org/10.3390/brainsci6040054

Knikou, M. (2008). The H-reflex as a probe: Pathways and pitfalls. *Journal of Neuroscience Methods*, *171*(1), 1–12. https://doi.org/10.1016/j.jneumeth.2008.02.012

Kotarska, K., Nowak, L., Szark-Eckardt, M., & Nowak, M. (2019). Selected Healthy Behaviors and Quality of Life in People Who Practice Combat Sports and Martial Arts. *International Journal of Environmental Research and Public Health*, *16*(5), 875. https://doi.org/10.3390/ijerph16050875

Kwok, J. Y. Y., Choi, K. C., & Chan, H. Y. L. (2016). Effects of mind–body exercises on the physiological and psychosocial well-being of individuals with Parkinson's disease: A systematic review and meta-analysis. *Complementary Therapies in Medicine*, *29*, 121–131. https://doi.org/10.1016/j.ctim.2016.09.016

Lang, J. J., Alam, S., Cahill, L. E., Drucker, A. M., Gotay, C., Kayibanda, J. F., Kozloff, N., Mate, K. K. V., Patten, S. B., & Orpana, H. M. (2018). Global Burden of Disease Study trends for Canada from 1990 to 2016. *Canadian Medical Association Journal*, *190*(44), E1296–E1304. https://doi.org/10.1503/cmaj.180698

Li, F., Harmer, P., Fitzgerald, K., Eckstrom, E., Stock, R., Galver, J., Maddalozzo, G., & Batya, S. S. (2012). Tai Chi and Postural Stability in Patients with Parkinson's Disease. *New England Journal of Medicine*, *366*(6), 511–519. https://doi.org/10.1056/NEJMoa1107911

Li, F., Harmer, P., McAuley, E., Fisher, K. J., Duncan, T. E., & Duncan, S. C. (2002). Tai Chi, Self-Efficacy, and Physical Function in the Elderly. *Prevention Science*, 11.

Lichtenstein, E., Faude, O., Zubler, A., Roth, R., Zahner, L., Rössler, R., Hinrichs, T., van Dieën, J. H., & Donath, L. (2019). Validity and Reliability of a Novel Integrative Motor Performance Testing Course for Seniors: The “Agility Challenge for the Elderly (ACE).” *Frontiers in Physiology*, *10*, 44. https://doi.org/10.3389/fphys.2019.00044

Living with Parkinson’s Disease | American Parkinson Disease Assoc. (n.d.). *APDA*. Retrieved August 1, 2020, from https://www.apdaparkinson.org/resources-support/living-with-parkinsons-disease/

Lorge, P. A., & Lorge, P. A. (2012). *Chinese Martial Arts: From Antiquity to the Twenty-First Century*. Cambridge University Press.

Lotharius, J., & Brundin, P. (2002). Pathogenesis of Parkinson’s disease: Dopamine, vesicles and alpha-synuclein. *Nature Reviews. Neuroscience*, *3*(12), 932–942.

Lowry, D. (1995). *Sword and Brush: The Spirit of the Martial Arts*. Shambhala Publications.

Maass, A., Düzel, S., Brigadski, T., Goerke, M., Becke, A., Sobieray, U., Neumann, K., Lövdén, M., Lindenberger, U., Bäckman, L., Braun-Dullaeus, R., Ahrens, D., Heinze, H.-J., Müller, N. G., Lessmann, V., Sendtner, M., & Düzel, E. (2016). Relationships of peripheral IGF-1, VEGF and BDNF levels to exercise-related changes in memory, hippocampal perfusion and volumes in older adults. *NeuroImage*, *131*, 142–154. https://doi.org/10.1016/j.neuroimage.2015.10.084

McPhee, J. S., French, D. P., Jackson, D., Nazroo, J., Pendleton, N., & Degens, H. (2016). Physical activity in older age: Perspectives for healthy ageing and frailty. *Biogerontology*, *17*(3), 567–580. https://doi.org/10.1007/s10522-016-9641-0

Mezzarane, R. A., & Kohn, A. F. (2002). Bilateral Soleus H-Reflexes in Humans Elicited by Simultaneous Trains of Stimuli: Symmetry, Variability, and Covariance. *Journal of Neurophysiology*, *87*(4), 2074–2083. https://doi.org/10.1152/jn.00129.2001

Misiaszek, J. E. (2003). The H-reflex as a tool in neurophysiology: Its limitations and uses in understanding nervous system function. *Muscle & Nerve*, *28*(2), 144–160. https://doi.org/10.1002/mus.10372

Monda, V., Valenzano, A., Moscatelli, F., Salerno, M., Sessa, F., Triggiani, A. I., Viggiano, A., Capranica, L., Marsala, G., De Luca, V., Cipolloni, L., Ruberto, M., Precenzano, F., Carotenuto, M., Zammit, C., Gelzo, M., Monda, M., Cibelli, G., Messina, G., & Messina, A. (2017). Primary Motor Cortex Excitability in Karate Athletes: A Transcranial Magnetic Stimulation Study. *Frontiers in Physiology*, *8*, 695. https://doi.org/10.3389/fphys.2017.00695

Moscatelli, F., Messina, G., Valenzano, A., Petito, A., Triggiani, A. I., Messina, A., Monda, V., Viggiano, A., De Luca, V., Capranica, L., Monda, M., & Cibelli, G. (2016). Differences in corticospinal system activity and reaction response between karate athletes and non-athletes. *Neurological Sciences*, *37*(12), 1947–1953. https://doi.org/10.1007/s10072-016-2693-8

Ngandu, T., Lehtisalo, J., Solomon, A., Levälahti, E., Ahtiluoto, S., Antikainen, R., Bäckman, L., Hänninen, T., Jula, A., Laatikainen, T., Lindström, J., Mangialasche, F., Paajanen, T., Pajala, S., Peltonen, M., Rauramaa, R., Stigsdotter-Neely, A., Strandberg, T., Tuomilehto, J., … Kivipelto, M. (2015). A 2 year multidomain intervention of diet, exercise, cognitive training, and vascular risk monitoring versus control to prevent cognitive decline in at-risk elderly people (FINGER): A randomised controlled trial. *The Lancet*, *385*(9984), 2255–2263. https://doi.org/10.1016/S0140-6736(15)60461-5

Nguyen, D.-M., Laffont, I., & Dupeyron, A. (2016). Martials arts use in physical and rehabilitation medicine: Literature review and perspectives. *Annals of Physical and Rehabilitation Medicine*, *59*, e55–e56. https://doi.org/10.1016/j.rehab.2016.07.128

Noble, S., Pearcey, G. E. P., Quartly, C., & Zehr, E. P. (2019). Robot controlled, continuous passive movement of the ankle reduces spinal cord excitability in participants with spasticity: A pilot study. *Experimental Brain Research*, *237*(12), 3207–3220. https://doi.org/10.1007/s00221-019-05662-4

O'Brien, J. T., & Thomas, A. (2015). Vascular dementia. *The Lancet*, *386*(10004), 1698–1706. https://doi.org/10.1016/S0140-6736(15)00463-8

Ouergui, I., Hssin, N., Haddad, M., Padulo, J., Franchini, E., Gmada, N., & Bouhlel, E. (2014). The effects of five weeks of kickboxing training on physical fitness. *Muscles, Ligaments and Tendons Journal*, *4*(2), 106–113.

Page, S. J., & Harnish, S. (2012). Thinking about better speech: Mental practice for stroke-induced motor speech impairments. *Aphasiology*, *26*(2), 127–142. https://doi.org/10.1080/02687038.2011.636027

Paillard, T., Rolland, Y., & de Souto Barreto, P. (2015). Protective Effects of Physical Exercise in Alzheimer's Disease and Parkinson's Disease: A Narrative Review. *Journal of Clinical Neurology*, *11*(3), 212. https://doi.org/10.3988/jcn.2015.11.3.212

Pearcey, G. E. P., & Zehr, E. P. (2019). Exploiting cervicolumbar connections enhances short-term spinal cord plasticity induced by rhythmic movement. *Experimental Brain Research*, *237*(9), 2319–2329. https://doi.org/10.1007/s00221-019-05598-9

Perrin, P., Deviterne, D., Hugel, F., & Perrot, C. (2002). Judo, better than dance, develops sensorimotor adaptabilities involved in balance control. *Gait & Posture*, *15*(2), 187–194. https://doi.org/10.1016/S0966-6362(01)00149-7

Petzinger, G. M., Holschneider, D. P., Fisher, B. E., McEwen, S., Kintz, N., Halliday, M., Toy, W., Walsh, J. W., Beeler, J., & Jakowec, M. W. (2015). The Effects of Exercise on Dopamine Neurotransmission in Parkinson's Disease: Targeting Neuroplasticity to Modulate Basal Ganglia Circuitry. *Brain Plasticity*, *1*(1), 29–39. https://doi.org/10.3233/BPL-150021

Pierrot-Deseilligny, E., & Mazevet, D. (2000). The monosynaptic reflex: A tool to investigate motor control in humans. Interest and limits. *Neurophysiologie Clinique = Clinical Neurophysiology*, *30*, 67–80. https://doi.org/10.1016/S0987-7053(00)00062-9

Pinter, M. M., & Brainin, M. (2012). Rehabilitation after stroke in older people. *Maturitas*, *71*(2), 104–108. https://doi.org/10.1016/j.maturitas.2011.11.011

Pliske, G., Emmermacher, P., Weinbeer, V., & Witte, K. (2016). Changes in dual-task performance after 5 months of karate and fitness training for older adults to enhance fall prevention. *Aging Clinical and Experimental Research*, *28*(6), 1179–1186. https://doi.org/10.1007/s40520-015-0508-z

Public Health and Aging: Trends in Aging—United States and Worldwide. (2003). *JAMA*, *289*(11), 1371. https://doi.org/10.1001/jama.289.11.1371

Quinzi, F., Sbriccoli, P., Alderson, J., Di Mario, A., & Camomilla, V. (2014). Intra-limb coordination in karate kicking: Effect of impacting or not impacting a target. *Human Movement Science*, *33*, 108–119. https://doi.org/10.1016/j.humov.2013.07.021

Roemmich, R. T., Field, A. M., Elrod, J. M., Stegemöller, E. L., Okun, M. S., & Hass, C. J. (2013). Interlimb coordination is impaired during walking in persons with Parkinson’s disease. *Clinical Biomechanics*, *28*(1), 93–97. https://doi.org/10.1016/j.clinbiomech.2012.09.005

Rogers, C. E., Larkey, L. K., & Keller, C. (2009). A Review of Clinical Trials of Tai Chi and Qigong in Older Adults. *Western Journal of Nursing Research*, *31*(2), 245–279. https://doi.org/10.1177/0193945908327529

Ross, A., & Thomas, S. (2010). The Health Benefits of Yoga and Exercise: A Review of Comparison Studies. *The Journal of Alternative and Complementary Medicine*, *16*(1), 3–12. https://doi.org/10.1089/acm.2009.0044

Rothman, S. M., & Mattson, M. P. (2013). Activity-dependent, stress-responsive BDNF signaling and the quest for optimal brain health and resilience throughout the lifespan. *Neuroscience*, *239*, 228–240. https://doi.org/10.1016/j.neuroscience.2012.10.014

Sofroniew, M. V., Howe, C. L., & Mobley, W. C. (2001). Nerve Growth Factor Signaling, Neuroprotection, and Neural Repair. *Annual Review of Neuroscience*, *24*(1), 1217–1281. https://doi.org/10.1146/annurev.neuro.24.1.1217

Sullivan, G. M., & Feinn, R. (2012). Using Effect Size—Or Why the *P* Value Is Not Enough. *Journal of Graduate Medical Education*, *4*(3), 279–282. https://doi.org/10.4300/JGME-D-12-00156.1

Sun, Y., Cullen, H. M., & Zehr, E. P. (2019). Harnessing the Power of a Novel Program for Dynamic Balance Perturbation with Supported Body Weight. *Journal of Motor Behavior*, 1–13. https://doi.org/10.1080/00222895.2019.1670129

Sun, Y., Ledwell, N. M. H., Boyd, L. A., & Zehr, E. P. (2018). *Unilateral wrist extension training after stroke improves strength and neural plasticity in both arms | SpringerLink*. https://link-springer-com.ezproxy.library.uvic.ca/article/10.1007/s00221-018-5275-6

Sun, Y., & Zehr, E. P. (2019). Training-Induced Neural Plasticity and Strength Are Amplified After Stroke: *Exercise and Sport Sciences Reviews*, *47*(4), 223–229. https://doi.org/10.1249/JES.0000000000000199

Thrift, A. G., Howard, G., Cadilhac, D. A., Howard, V. J., Rothwell, P. M., Thayabaranathan, T., Feigin, V. L., Norrving, B., & Donnan, G. A. (2017). Global stroke statistics: An update of mortality data from countries using a broad code of “cerebrovascular diseases.” *International Journal of Stroke*, *12*(8), 796–801. https://doi.org/10.1177/1747493017730782

Tremblay, M. S., Warburton, D. E. R., Janssen, I., Paterson, D. H., Latimer, A. E., Rhodes, R. E., Kho, M. E., Hicks, A., LeBlanc, A. G., Zehr, L., Murumets, K., & Duggan, M. (2011). New Canadian Physical Activity Guidelines. *Applied Physiology, Nutrition, and Metabolism*, *36*(1), 36–46. https://doi.org/10.1139/H11-009

van der Zijden, A. M., Groen, B. E., Tanck, E., Nienhuis, B., Verdonschot, N., & Weerdesteyn, V. (2012). Can martial arts techniques reduce fall severity? An in vivo study of femoral loading configurations in sideways falls. *Journal of Biomechanics*, *45*(9), 1650–1655. https://doi.org/10.1016/j.jbiomech.2012.03.024

van Dijk, G. P., Lenssen, A. F., Leffers, P., Kingma, H., & Lodder, J. (2013). Taekwondo Training Improves Balance in Volunteers Over 40. *Frontiers in Aging Neuroscience*, *5*. https://doi.org/10.3389/fnagi.2013.00010

Voerman, G. E., Gregorič, M., & Hermens, H. J. (2005). Neurophysiological methods for the assessment of spasticity: The Hoffmann reflex, the tendon reflex, and the stretch reflex. *Disability and Rehabilitation*, *27*(1–2), 33–68. https://doi.org/10.1080/09638280400014600

Wayne, P. M., Walsh, J. N., Taylor-Piliae, R. E., Wells, R. E., Papp, K. V., Donovan, N. J., & Yeh, G. Y. (2014). Effect of Tai Chi on Cognitive Performance in Older Adults: Systematic Review and Meta-Analysis. *Journal of the American Geriatrics Society*, *62*(1), 25–39. https://doi.org/10.1111/jgs.12611

Witte, K., Kropf, S., Darius, S., Emmermacher, P., & Böckelmann, I. (2016). Comparing the effectiveness of karate and fitness training on cognitive functioning in older adults—A randomized controlled trial. *Journal of Sport and Health Science*, *5*(4), 484–490. https://doi.org/10.1016/j.jshs.2015.09.006

Woodward, T. W. (2009). A review of the effects of martial arts practice on health. *WMJ : Official Publication of the State Medical Society of Wisconsin*, *108*(1), 40–43.

World Health Organization (Ed.). (2015). *World report on ageing and health*. World Health Organization.

Yau, S. Y., Li, A., Sun, X., Fontaine, C. J., Christie, B. R., & So, K.-F. (2016). Potential Biomarkers for Physical Exercise-Induced Brain Health. *Role of Biomarkers in Medicine*. https://doi.org/10.5772/62458

Zehr, E. Paul. (2002). Considerations for use of the Hoffmann reflex in exercise studies. *European Journal of Applied Physiology*, *86*(6), 455–468. https://doi.org/10.1007/s00421-002-0577-5

Zehr, E. Paul. (2011). Evidence-based risk assessment and recommendations for physical activity clearance: Stroke and spinal cord injury [1] This paper is one of a selection of papers published in this Special Issue, entitled Evidence-based risk assessment and recommendations for physical activity clearance, and has undergone the Journal's usual peer review process. *Applied Physiology, Nutrition, and Metabolism*, *36*(S1), S214–S231. https://doi.org/10.1139/h11-055

Zehr, E. Paul, & Duysens, J. (2004). Regulation of Arm and Leg Movement during Human Locomotion. *The Neuroscientist*, *10*(4), 347–361. https://doi.org/10.1177/1073858404264680

Zehr, E. Paul, Hundza, S. R., & Vasudevan, E. V. (2009). The Quadrupedal Nature of Human Bipedal Locomotion. *Exercise and Sport Sciences Reviews*, *37*(2), 102–108. https://doi.org/10.1097/JES.0b013e31819c2ed6

Zehr, E.P., Barss, T. S., Dragert, K., Frigon, A., Vasudevan, E. V., Haridas, C., Hundza, S., Kaupp, C., Klarner, T., Klimstra, M., Komiyama, T., Loadman, P. M., Mezzarane, R. A., Nakajima, T., Pearcey, G. E. P., & Sun, Y. (2016). Neuromechanical interactions between the limbs during human locomotion: An evolutionary perspective with translation to rehabilitation. *Experimental Brain Research*, *234*(11), 3059–3081. https://doi.org/10.1007/s00221-016-4715-4

Zhang, S., Xu, W., Zhu, Y., Tian, E., & Kong, W. (2020). Impaired Multisensory Integration Predisposes the Elderly People to Fall: A Systematic Review. *Frontiers in Neuroscience*, *14*, 411. https://doi.org/10.3389/fnins.2020.00411

Chapter Two: Manuscript

2.1 Introduction

Advances in medicine and technology have led to increased longevity in humans worldwide but unfortunately, the growing number aging individuals is causing a greater demand on health care systems and need for treatment of chronic disease ("Public Health and Aging," 2003). A degradation of neuromuscular function occurs with aging and result in lowered postural control (Faude & Donath, 2019). Falls are the second leading cause of accidental death worldwide and the leading cause of injury-related hospitalization in older adults. Subsequently, rehabilitation programs focus on balance, ADL, and strength training to enhance dynamic movements and QOL (Faude & Donath, 2019; Lichtenstein et al., 2019; Pliske et al., 2016).

The rate of individuals with chronic conditions such as stroke, PD, and AD is rising in Canada and these populations will require rehabilitation, where regaining locomotion is a primary goal (Pinter & Brainin, 2012; Zehr, 2011). Though there are therapies available for individuals with chronic conditions they are usually expensive, only available in centers and require substantial labour. Rehabilitation using whole body activation through martial arts training is a promising therapy.

Martial arts are ancient practices that have been growing in popularity in the western world, and recently in scientific studies. There is a large body of evidence that show the benefits slower movement practices such as Tai Chi on balance control in older adults and those with Parkinson's disease (Gatts & Woollacott, 2007; Hackney & Earhart, 2008; Hong, 2000; Jahnke et al., 2010; Li et al., 2002, 2012; Rogers et al., 2009; Wayne et al., 2014).

Karate is a type of martial arts training using coordinated movement patterns that could induce physiological changes to corticospinal excitability, which correlates to increase locomotor activity (Moscatelli et al., 2016; Zehr et al., 2016). Additionally, karate training reduces depression and improves confidence & self-efficacy in older adults (Jansen et al., 2017). However, the effects of karate on interlimb connectivity, balance and psychosocial implications have not been tested in the current literature.

The purpose of this study is to develop and test **accessible (low cost and widely available) and beneficial** therapies for older adults with or without chronic conditions that can be used in community-based settings. Considering the prevalence of impairments, aging of the global population and lack of treatment accessibility, the development of a holistic approach to health through martial arts training can one day be used in clinical interventions for various chronic diseases. The observations lay the groundwork for future explorations of dose, applications to neuropathology, and development of community based martial arts interventions as "pre-habilitation" for older adults.

The objectives of this study were: 1) to assess efficacy of karate training for elderly individuals, with or without chronic conditions that can be used for rehabilitation/neuroprotection. 2) to provide evidence for the mechanisms behind any change to reflex excitability or interlimb connections (arm & leg strength) 3) to evaluate the postural and balance coordination changes that could occur after a 5-week intervention.

We hypothesize that the requirements of balance and postural control in karate training will strengthen interlimb connections and have beneficial effects on physiological function in older adults.

2.2 Methods

2.2.1 Experimental Design

The study employed a prospective time series design with repeated measures.

2.2.2 Participants

Eleven older adults (4 male, 7 female, age 59-90y; 168.4±5.8cm; 67.2±10.7kg), five older adults (4 male, 1 female, age 67-76y;176.8±6.4 cm; 69.9±17.6kg) with chronic conditions (Parkinson's disease, dementia, stroke), and two young adults (2 female, age 23; 165.1±4.9cm; 60.1±6.7 kg) participated in the study with informed written consent under a protocol approved by the University of Victoria Human Research Ethics Board (Protocol #18-213). Inclusion criteria were that participants did not use a pacemaker and could stand independently without assistance. Exclusion criteria were if participants had previous mind-body exercise experience (i.e. any form of martial arts, qigong, or yoga). Participants completed assessments of static and dynamic balance, arm and leg strength, Timed Up and Go for walking function, and spinal cord excitability before (pre) and after (post) the intervention.

2.2.3 Study Procedure

Control Procedures

A multiple baseline approach using 3 pre-intervention visits for assessment, within-participant control design was performed as in our recent intervention studies (Kaupp et al., 2018; Klarner et al., 2016b; Noble et al., 2019; Pearcey & Zehr, 2019). The approach allows participants to create a baseline of their variability that enables them to act as their own control. This reduces the impact of between-subject variability and allowing additionally for single participant statistical analysis using 95% confidence intervals from the pre-intervention data. The triple baseline procedure provides higher internal consistency of measures and decreased variability (Bütefisch et al., 1995; Dragert & Zehr, 2013; Kaupp et al., 2018; Klarner et al., 2016b). The order of test administration, time of the day, and other environmental conditions were consistent for each participant and testing sessions. In addition, participants were asked not to start any new forms of exercise throughout the duration of the training intervention but also maintain their pre-existing routines.

Contents of karate intervention

This pilot began with feasibility assessment in two healthy, university-aged individuals with the subsequent broader intervention with two cohort intakes of older adults. The intervention spanned over ten weeks total: baseline control procedure tests (see below) were in the first three weeks (one test per week), karate training occurred for 5 weeks after that (3 sessions/week, 15 sessions total), and finally the post-intervention tests was done. For the feasibility assessment in the young participants, a follow-up data collection was conducted three months after the first post-intervention test to assess maintenance in balance and spinal cord excitability.

Figure 3. Illustration of the data collection and training protocol. A multiple baseline within-subject control design was used for this study. Three baseline tests were conducted in the pre-intervention period, followed by 5 weeks of training (3 times a week), and finally there was 1 post-intervention data collection test.

The participants underwent a 5-week training intervention consisting of 1-hour sessions 3 times a week (Monday/Wednesday/Friday). These sessions were delivered by black-belt instructors (YS and EPZ) experienced in teaching martial arts in community-based settings. This “dosing” schedule is similar to previous strength and locomotor interventions conducted in our laboratory (Kaupp et al., 2018; Klarner et al., 2016b; Noble et al., 2019). The sessions consisted of a warmup involving general arm and leg movement followed by practicing individual techniques of punches, step punching, open hand striking and blocking. Instruction and explanation of the fighting applications of all techniques were also provided to create additional context for the movements practiced. The bulk of the practice was repetition (~45-60 s per cycle) of the training pattern kata “Pinan Nidan”. This kata consists of 13 stepping, 11 turning, 7 punching, 2 striking and 13 blocking movements in 9 directions and with 21 stance changes. The version used here was from the traditional Yushinkai system, but many karate styles include this and related patterns in their training curriculum. This kata was selected because it includes an emphasis on whole body integration, bodyweight shifting and balance changes, but does not include any static single leg standing or kicking. At each session an average of 10 repetitions of Pinan Nidan were completed with a minimum of 150 kata cycles across the 5-week training period. Movements were modified and done at slow speed to be refined according to the range of motion, functional ability and neurological status of each participant. Tracking of the movements was done by direct observation and written documentation for every participant at each session to quantify the number and types (e.g. step, block, punch, etc) of techniques performed.

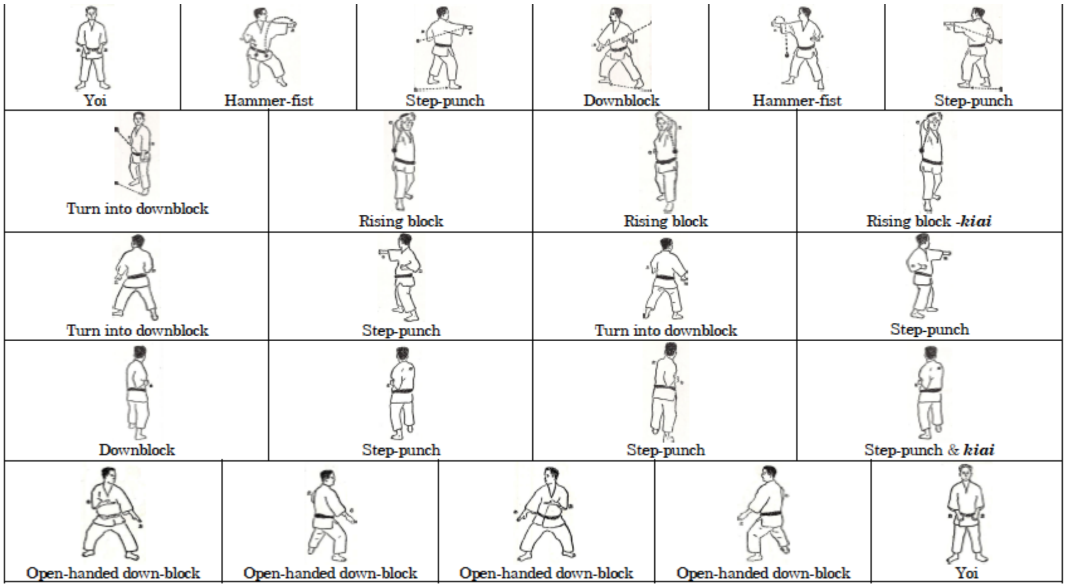


Figure 4. Pinan Nidan Kata Sequence used in the research intervention. The kata consists of 13 stepping, 11 turning, 7 punching, 2 striking and 13 blocking movements in 9 directions and with 21 stance changes. Retrieved from: www.seikenryu.com/Pinan%20Nidan.pdf

2.2.4 Outcome Measures

Research assistants involved in data collection were trained in instrument administration by the Principal Investigator and PhD students in the lab. All the questionnaires were scored by a single researcher. Participants completed the demographic questionnaire (Appendix B), SF-36 General Health Questionnaire (Appendix C), and the Physical Activity Readiness Questionnaire (Appendix D) as a part of study intake. Participants completed the H-reflex spinal cord excitability, static WBB, dynamic WBB, handgrip, leg force, and Timed-Up-and-Go assessments at *baseline* and *post-intervention*. Electromyography was collected during all tests except for the Timed-Up-and-Go. The order was consistent for all participants and all testing sessions.

2.2.4.1 Demographic Questionnaire

Participants completed a demographic questionnaire during the *baseline* data collection session. The questionnaire gathered information about participants' general characteristics (e.g. age, ethnicity, gender, etc.) and more detailed information such as income.

2.2.4.2 Physical Activity Readiness Questionnaire (PARQ)

Participants self-administered the Physical Activity Readiness Questionnaire (PAR-Q) according to guidelines published by the Canadian Society for Exercise Physiology (Canadian Society for Exercise Physiology, 2002). The PAR-Q was used to determine participant eligibility where participants who selected "yes" for any of the screening questions were excluded from study participation or required medical clearance before participation.

2.2.4.3 Short Form 36 Health Survey Questionnaire (SF-36)

Participants completed the SF-36, a general health questionnaire, at the baseline and post-intervention data collection sessions. The assessment is used to indicate the health status of a population and is especially useful as a screening tool for clinical research. The SF-36 was used to determine an individual’s eligibility to participate in the intervention, while also providing some background information on health status and measures the impact of clinical and social interventions.

2.2.4.4 Balance Assessment

During the dynamic balance assessment, each participant stood barefoot on the BB, feet at shoulder width, eyes open, hands on the hips, and in front of a laptop screen which displayed the centre of pressure (CoP) as a white dot as described previously (Cullen et al., 2017; Sun et al., 2019). The trial began with a target dot (red) that appeared on the screen and moved in a random sequence amongst eight cardinal and ordinal directions. Participants were instructed to shift their weight distribution so that the CoP met the target on the screen as quickly and accurately as possible. Following the initial set, participants completed five trials with 1-5 minutes of rest time between the intervals. The averaged time to reach target (tTarget), time to return to center from target (tCenter), and the computed sum (tTOTAL) were obtained and used for analysis (Sun et al., 2019).

A commercially available balance board (BB; Nintendo, Kyoto, Japan) was used with a computer using customized software (LabVIEW 2011 National Instruments, Austin, TX, USA), and data were sampled at 100 Hz. The BB is a validated (r=0.99) and reliable (ICC=0.88) force detecting instrument that is widely available and relatively inexpensive (Clark et al., 2018; Cullen et al., 2017; Sun et al., 2019).

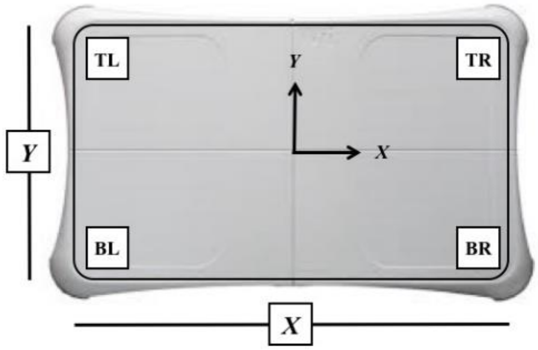


Figure 5. Top view of the Nintendo Wii Fit balance board with the four force sensor locations. Adapted from Cullen (2017).

2.2.4.5 Clinical Assessments

The Timed Up and Go test was used as a clinical measure of functional capacity. TUG is a simple test that investigates the mobility of an individual through the evaluation of both static and dynamic balance (Ibrahim et al., 2017; Sullivan & Feinn, 2012). The test is known to assess the fall risk and measure the progress of balance, sit to stand, and walking in elderly individuals, primarily those with neurological or chronic conditions (Ibrahim et al., 2017).

2.2.4.6 Strength Measures

Strength in the arms were assessed using commercial handgrip dynamometers (Right: Takei Scientific Instruments Company Ltd., Niigata, Japan; Left: Lafayette Instrument Co.). Participants were in a seated posture with one arm relaxed on the lap during single arm measurements and extended their arm and palm facing downward at a 45° angle for 5-s maximal contractions. The trials alternated between single hand measurements of right then left arm strength three times per trial, followed by assessments of both arms at the same time for the bilateral strength measures. Load cells were used to measure the strength in the lower limbs and muscle activation was recorded with a customized Matlab program (Nantick, MA, USA).

2.2.4.7 Muscle Activity and Spinal Cord Excitability

Hoffmann (H-) reflexes were evoked as proxy measures of spinal cord excitability while participants stood with both feet flat on the floor. An overhead harness system was utilized to ensure that there was no risk of falling (Sun et al., 2019). Electromyography (EMG) was collected using bipolar surface electrodes placed bilaterally on the tibialis anterior (TA), vastus lateralis (VL), and soleus (SOL) muscles while a grounding electrode was placed over the right or left patella. Recordings were amplified (500-1000 times for Soleus and 5000 times for other muscles), and filtered (10-1000 Hz for Soleus and 100-300 Hz for others) (P511 Grass Instruments, AstroMedInc, West Warwick, RI, USA) and sampled at 2.5 kHz on a computer running customized software (LabVIEW, National Instruments, Austin, TX, USA).

The tibial nerve on the dominant leg was stimulated at the popliteal fossae using 1 ms square wave pulses to evoke H-reflexes in the SOL. Bipolar surface electrodes were used for stimulation delivered pseudo randomly 3-5s apart for all trials using a Digitimer (Mendtel, NSW, Australia) constant current stimulator (model DS7A). A non-contact milliammeter (mA-2000, Bell Technologies, Orlando, FL, USA) was used to measure current delivered for each stimulus. A recruitment curve was recorded by continuously increasing stimulation intensity until at least three maximal M-waves were recorded. Participants monitored the EMG level on a computer at 10% of the Maximal Voluntary Contraction (MVC) in their legs, which was determined prior to the experiment. M-wave and H-Reflex (M-H) recruitment curves of 40 stimulations were collected for each trial. These curves were used to determine the maximum action potential of the soleus muscle (M_{max}) amplitudes to normalize data (Noble et al., 2019).

2.2.4.8 Data Analysis & Statistical Methods

All statistical analyses were performed using SPSS (v.24, Armonk, NY: IBM Corp). The difference between post and baseline values were expressed as percent change from the pre-intervention results (%Δ). For group comparisons, the three pre-intervention sessions were first compared via Repeated Measures Analysis of Variance (rmANOVA). Sphericity was assumed via Mauchly's Test ($p>0.05$) and if not, degrees of freedom and p-value were corrected using the Greenhouse-Geisser method. When there were no differences between the 3 pre results, an averaged pre-intervention value was formed and then compared to the post-intervention results using a paired t-test, as done in previous training studies (Kaupp et al., 2018; Klarner et al., 2016b; Noble et al., 2019). For individual comparisons, a 95% confidence interval (CI) was established from the triple baseline. Post-intervention values were then compared to the respective 95% CI and considered statistically significant if they fell outside this range. Effect size (Cohen's *d*) was calculated to provide the magnitude of changes (6). The level of significance was set at $p<0.05$.

2.3 Results

2.3.1 Participant Characteristics

Table 1: Participant data

N	Condition	Sex/Age/LA Side
1	Older adult (N/A)	M-71-R
2	Older adult (N/A)	M-66-R
3	Older adult (N/A)	F-73-L
4	Older adult (N/A)	M-63-R
5	Older adult (N/A)	F-70-R
6	Older adult (N/A)	F-66-R
7	Older adult (N/A)	F-70-L
8	Older adult (N/A)	M-90-R
9	Older adult (N/A)	F-59-L
10	Older adult (N/A)	F-79-R
11	Older adult (N/A)	F-66-R
12	Parkinson's Disease	M-67-R

13	Parkinson's Disease	M-76-R
14	Parkinson's Disease	F-74-R
15	Alzheimer's Disease	M-76-R
16	Chronic Stroke	M-72-L
17	Young adult (N/A)	F-23-R
18	Young adult (N/A)	F-23-R

Abbreviations: LA, less affected/dominant; M, male; F, female; L, left; R, right; BL, bilateral left; BR, bilateral right; PD, Parkinsons Disease; AD, Alzheimers Disease; PS, Post Stroke.

Table 2: Baseline participant characteristics for the older adult group data (11 total: 4 male, 7 females without chronic conditions)

	M ± SD
Age (years)	59-90 y
Height (cm)	168.4 ± 5.8
Weight (kg)	67.2 ± 10.7

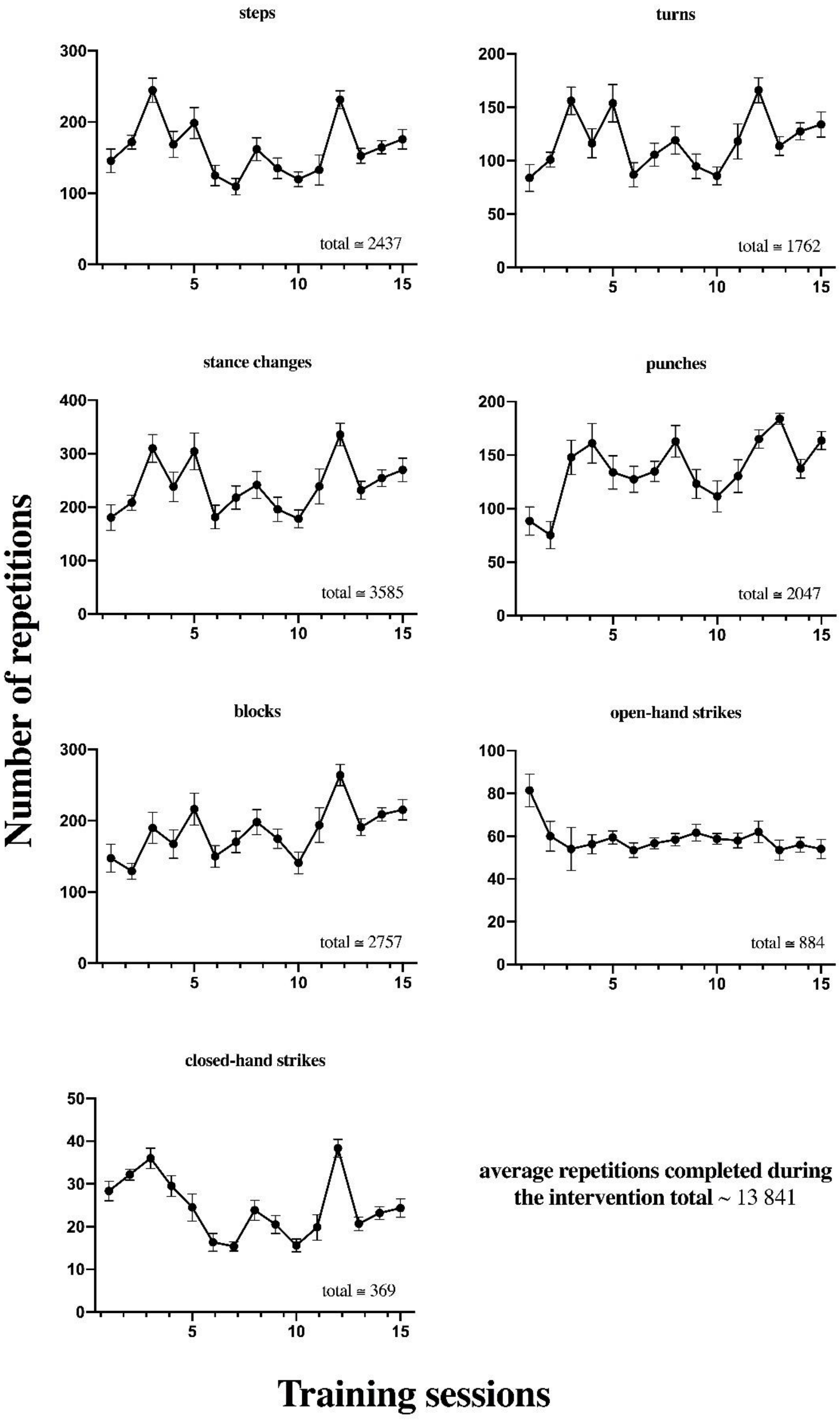
Note: M = Mean; SD = Standard Deviation; age range displayed

chronic conditions: five older adults: 4 male, 1 female, age 67-76y;176.8±6.4 cm; 69.9±17.6kg

young adults: 2 female, age 23; 165.1±4.9cm; 60.1±6.7 kg

2.3.2 Training Contents Completed

The participants were guided through a set of warm-ups, Kihon (basics training), Pinan nidan kata cycles, and some kumite applications in each intervention session. All movements were recorded by two researchers then extrapolated to show the different techniques and strategies acquired throughout the training period. The participants had an average of 2437 steps, 1762 turns, 3585 stance changes, 2047 punches, 2757 blocks, 884 open-hand strikes and 369 closed-hand strikes, with a total of 13,841 movements throughout the intervention. The training contents varied daily so it was our goal to record all motions for all the participants and quantify what was done over the 5 weeks.



average repetitions completed during the intervention total ~ 13 841

Figure 6. Daily movement repetitions during the karate training intervention categorized into different movement techniques. The data show the movements that were done during the

warmup as well as during the Pinan nidan kata repetitions. The group averages are displayed in the figures and the sum of each technique is summarized in the bottom right panel.

2.3.3 Dynamic Balance Assessment

The older group average balance reaction time improved by 18% for tTarget (t(10)=1.657; p=0.128; *d*=0.663), 9% for tCenter (t(10)=3.999; $p<0.01$; *d*=0.945), and 14% for tTotal (t(10)=2.001; p=0.073; *d*=0.651), respectively. ANOVA showed no difference between the three baseline tests for tTarget ($F_{2,20}$=2.879, p=0.080), tCenter ($F_{2,20}$=6.917, p=0.005), and tTotal ($F_{2,20}$=4.016, p=0.073). Individual data analysis suggests that performance was improved in 9 participants and reduced in 4. One neurologically intact participant showed significant changes tTarget (44%, $p<0.05$), three showed changes tCenter (16%, 21%, 14%; $p<0.05$) and two showed significant changes in tTotal (35%, 36%; $p<0.05$).

Two participants with PD showed significant (12% and 26%, $p<0.05$); improvements for tCenter and one for tTarget (34%, $p<0.05$). Neither showed individual changes in tTotal. The participant with vascular dementia had 5% (NS) increase for tCenter, decreased for tTarget by 11% (NS) and tTotal 5% (NS). The chronic stroke participant showed significant (12%, $p<0.05$) improvements for tCenter. No individual changes in tTarget or tTotal.

The two young adult participants had a decrease in tTarget by (3%, 15%; NS), tCenter (3.3%, 38%; NS) and tTotal (5%, 10.8%; NS) in the post-intervention tests. The reaction time improved in the follow-up examination for tTarget (18%, 20%; $p<0.05$) and tTotal (17%, 45%; p=0.10). No changes were observed in tCenter (10%, 40%; NS).

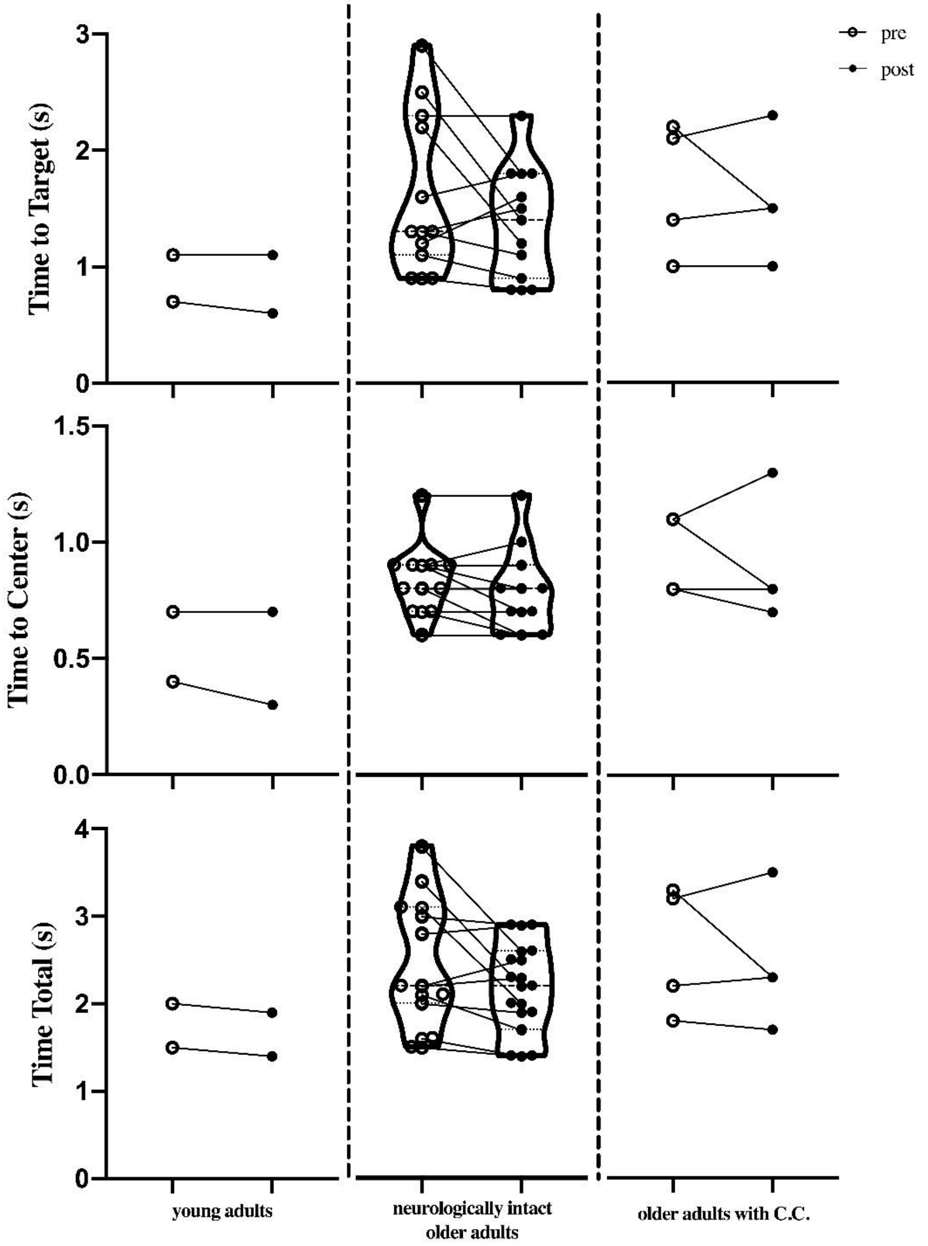


Figure 7. Time to reach the target (tTarget), to get back to center (tCenter) and the sum of them (tTotal) in the dynamic postural test; the left panel represents the young adults data, the middle panel is for the neurologically intact older adult group, and the final panel displays the data for the older adults with chronic conditions. * $p<0.05$.

2.3.4 Clinical Assessment

The Timed Up and Go group data were unchanged following the intervention ($t(10)=0.636$; $p=0.539$; $d=0.913$) and ANOVA showed no differences ($F_{2,20}=0.012$, $p=0.988$). Most participants were within the typical range (<12s). The TUG is typically used to assess individuals with chronic conditions (Cromwell et al., 2007) but since most participants (n=11) were neurologically intact, there were subtle differences in the pre- and post- values.

Four of the neurologically intact older adults showed significant improvements (6%, 8%, 4%, 9%; $p<0.05$) in TUG, while seven had no change (7%, 1%, 5%, 2%, 1%, 4%; NS). One of the PD participants showed significant change (3%, $p<0.05$) in the TUG analysis. The individual with vascular dementia had no change and the chronic stroke participant had a significant change (14%, $p<0.05$) in TUG.

Table 3: Timed-Up-and-Go individual results for the older adults, with or without chronic conditions

	Time (s)															
participant	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Pre$_{AVG}$	11.6	10.2	10.6	10.7	8.2	8.7	8.2	11.8	9.3	11.1	9.3	9.4	10.6	9.7	15.9	10.6
post	12.4	9.5	10.7	9.8	8.7	8.3	8.0	11.8	9.3	10.2	9.7	9.7	11	10	15.6	12.2
Δ change (%)	7	6	1	8	5	4	2	0	1	9	4	3	4	3	2	14

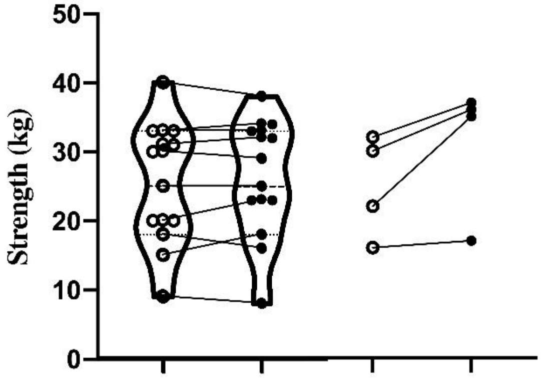
These results were taken after 5-weeks of training and the corresponding magnitudes of change for each participant. Scores ≥12 seconds represent a risk of falls in older adults, therefore nearly everyone in this study was not at a high risk for falls. One participant had results of approximately 15 s before and after training, but their chronic condition (vascular dementia) is t associated with challenges in locomotor function.

2.3.5 Strength Data

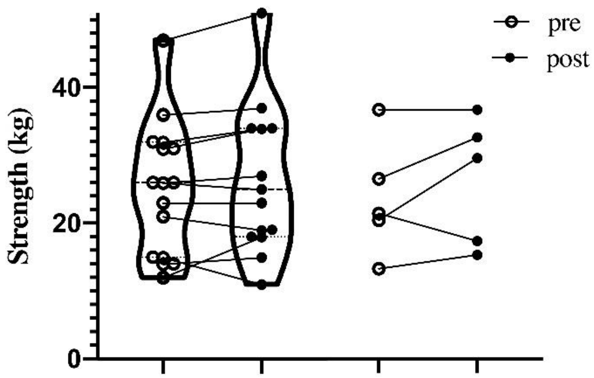
In the older adults strength improved in the legs by 40% ($t(6)=-2.453$; $p=0.050$; $d=0.769$) in the right leg but NS for the left (19% ($t(8)=-2.029$; $p=0.077$; $d=0.805$)). Smaller effects (2%) were found for the left hand ($t(10)=-2.412$; $p=0.037$; $d=0.969$). The neurologically intact older adults had five individuals with significant improvements (10%, 53%, 10%, 5%, 5%; $p<0.05$) in the right arm strength. Six participants had significant improvements for the left arm (60%, 13%, 11%, 12%, 16%, 9%; $p<0.05$). Three participants showed significant changes in bilateral right arm measures (20%, 17%, 4%; $p<0.05$) and four participants showed significant changes in the bilateral left arm (11%, 11%, 7%, 20%; $p<0.05$). Five participants had significant changes in the right leg (89%, 71%, 114%, 102%, 29%; $p<0.05$) and five participants had significant changes in the left leg strength (46%, 54%, 21%, 105%, 33%; $p<0.05$).

PD participants (n=3) had two individuals with significant (43%, 19%; $p<0.05$) improvements and one with a significant (18%, $p<0.05$) decrease in right arm strength. One participant had significant (19%, $p<0.05$) increased for left arm strength. The bilateral right assessment had two individuals with significant (48%, 13%; $p<0.05$) improvements and one with a significant (14%, $p<0.05$) decrease. Finally, one participant had improvements (21%, $p<0.05$) for bilateral left arm strength. Two participants showed significant (36%, 26%; $p<0.05$) improvements in right leg force and all three had significant (116%, 12%, 46%; $p<0.05$) improvements in left leg force.

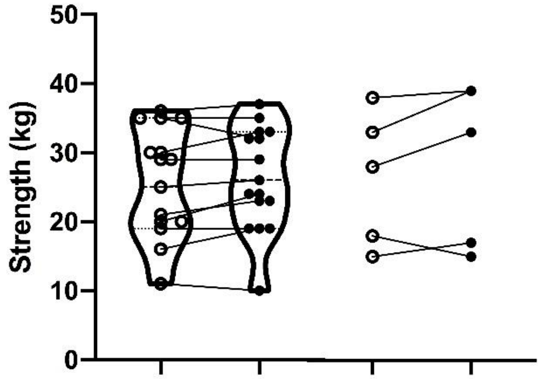
The individual with vascular dementia showed significant ($p<0.05$) improvements for right arm (39%), left (57%), and bilateral left (21%), respectively. No change was noted for left arm, nor right and left leg strength. The chronic stroke participant had significant ($p<0.05$) improvements for left (15%) and bilateral left (3%).



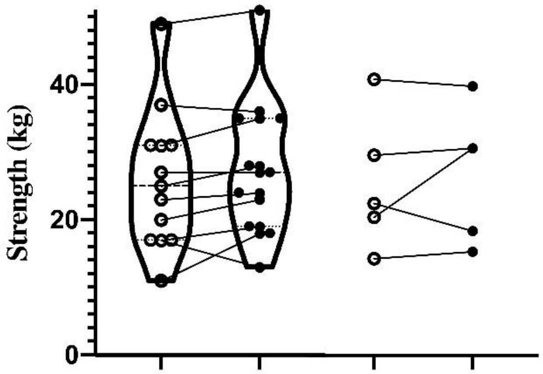
Left Arm



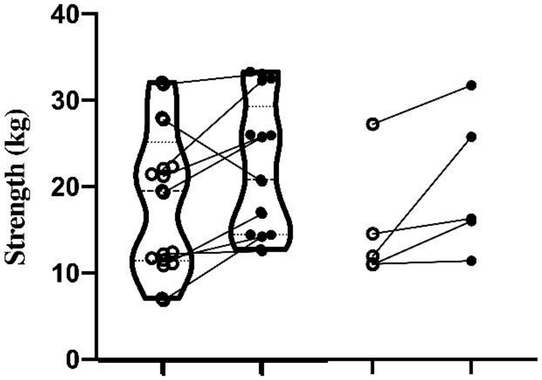
Right Arm



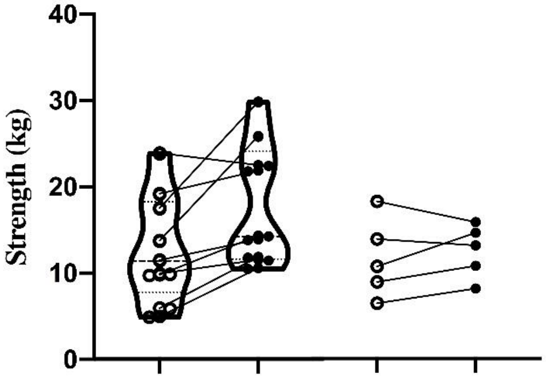
Bilateral Left Arm



Bilateral Right Arm



Left Leg



Right Leg

Figure 8. Pre-post comparison of strength, measures in force per kilogram (kg), in the arms and legs. Bilateral measurements were taken while both arms were contracted at the same time.

2.3.6 Spinal Cord Excitability

Across the karate intervention muscle activation level during sampling and gross assessment of spinal cord reflex excitability, as observed by the H_{max}/M_{max} ratios, were unchanged across the group of NI participants. The pre-intervention averages for H_{max}/M_{max} ratios were 16.2% while the post-intervention was 16.7%, respectively (Δ3%; $p=0.894$).

Three of the neurologically intact older adults showed significant (195%, 215%, 48% (avg= 153%); $p<0.05$) improvements in spinal cord excitability, while one showed a significant decrease (36%; $p<0.05$). The PD participants (n=2) had significant (19%, 23%; $p<0.05$) improvements in spinal cord excitability. No individual changes were observed in the vascular dementia and chronic stroke participants.

One younger adult showed significant changes in the right SOL (53%; $p<0.05$) while no significant changes were observed in the right SOL of the other individual (45%; NS) from the post-intervention test. The follow-up examinations had a similar trend, where one younger adult showed significant changes in the right SOL (27%; $p<0.05$) and no significant changes were seen in the right SOL of the other younger adult (40%; NS).

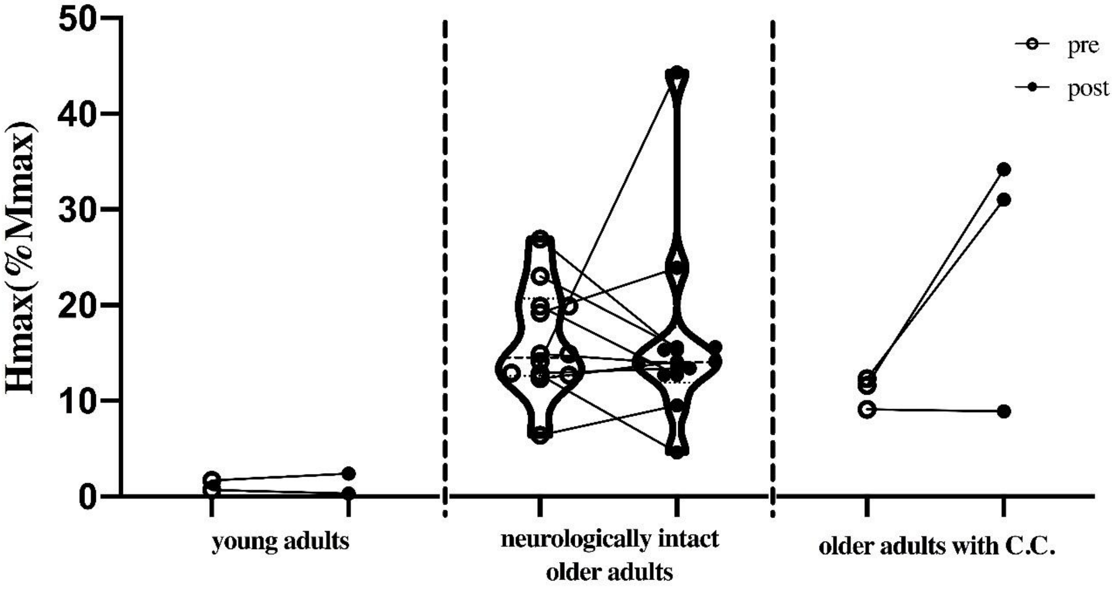


Figure 9. Pre-post comparison of spinal cord excitability ratios. Left panel represents the young adults data, the middle is the older adults without chronic conditions (group data), and the right panel is the older adults with chronic conditions.

2.4 Discussion

A realistic community-level dose of martial arts training appears promising as an intervention for improving balance and posture in older adults with and without neurological conditions. Our pilot observations suggest an approach worthy of further refinement and assessment.

2.4.1 Dynamic balance and postural corrections improved by karate training

Following the training intervention, all participants showed an improvement in reaction time during the postural balance test. This enhanced dynamic balance performance leads to better postural control and reduction of sway in older adults, which is congruent with similar studies that observed the stabilizing effects of ‘hard’ martial arts (Chung et al., 2020; Cromwell et al., 2007; Fong et al., 2013; Lang et al., 2018). Balance requires complex neuromechanical integration of muscular, somatosensory, visual, and vestibular coordination (Cromwell et al., 2007; Dunsky, 2019; Faude & Donath, 2019; Horak, 2006; Zhang et al., 2020). Our data suggest that this multisensory integration was improved by karate training.

The Pinan Nidan kata focuses on shifting of body weight distribution and does not have any kicking motions, so the maintenance and strengthening of balance control were anticipated. Studies of martial arts such as Tae Kwon Do and Wing Tsun improved hand grip strength, balance and gait in older adults of similar ages to those in our study (Chung et al., 2020; Cromwell et al., 2007; van Dijk et al., 2013). One study with Tae Kwon Do reviewed psychosocial aspects and found improvements to quality of life for the participants and their caregivers (van Dijk et al., 2013), while the other revealed changes to balance and walking ability through the TUG test (Cromwell et al., 2007). The results of the Ving Tsun intervention highlighted that the complex functionality through balance measures could be regained after a year of training, for 2-8 hours per week (Chung et al., 2020).

Postural regulation is key for the prevention of falls in elderly populations; therefore, the changes are correlated with improved skeletal and proprioceptive muscle strength that minimizes the risk of injuries (Faude & Donath, 2019; Horak, 2006; van der Zijden et al., 2012; van Dijk et al., 2013; Zhang et al., 2020). Coordination of different limbs is needed for the enhancement of gait control, which can be accelerated through exercises involving whole-body movements (Chung et al., 2020; Faude & Donath, 2019; Li et al., 2012; Lichtenstein et al., 2019; Quinzi et al., 2014; Zhang et al., 2020). As the data suggest, quicker reaction times infers that participants gained more stability in their legs allowing for minimization of fall risk. Additionally, the improvements in balance correlate to the musculoskeletal control in various muscles in the body meaning that overall strength was gained (Cromwell et al., 2007).

Karate is a type of martial arts training using coordinated movement patterns that could induce physiological changes to corticospinal excitability, which might relate to an increase in integrity of coordination of neuronal locomotor activity (van Dijk et al., 2013; Zhang et al., 2020). The coordination that exists is due to the coupling of neural oscillators (2 that control arm & 2 that control leg movements), which leads to the rhythmic movements that are seen during daily activities (Sun & Zehr, 2019). Since mobility is compromised with aging, the enhancement of these integral patterns is critical for maintaining function in the body. We speculate that interlimb circuits may be amplified due to the increases in coordinated use that produces both upper and lower limb strength enhancement, such as previous work with arm and leg interventions in chronic stroke participants (Barss et al., 2018; Klarner et al., 2016a, 2016b).

2.4.2 Timed-up-and-go data suggest that risk of falls minimized.

The functional mobility of participants was assessed using the timed-up-and-go test. All individuals became faster with their movements and showed improvements in their posture, stride, and steadiness. The clinical assessment tool is known to have good validity and if individuals take less than 12 seconds to complete the task, their risk of falling is reduced (Ibrahim et al., 2017). Our data suggest that on average the participants had a low risk of falling when this task is taking into consideration, meaning that the karate intervention helped improved posture and stability.

2.4.3 Effects on muscle strength.

Strength was improved in both the arms and the legs, which aligns with previous research that showed rehabilitation with arm and leg cycling improved walking function after training (Kaupp et al., 2018; Klarner et al., 2016b). Although measurements of both arms were taken to test bilateral deficit, there were no pronounced changes. Bilateral deficit is a phenomenon that can occur when maximal force is being produced, but there are inconsistencies in this measure as described in other studies (Kaupp et al., 2018). Bilateral facilitation is present in the averaged bilateral left data, where the maximal bilateral force is greater than the sum of unilateral forces.

Strength in the arms and legs augmented during the 5-week training protocol, suggesting that interlimb pathways may have been amplified due to exercise. Previous studies in our lab with chronic stroke participants evaluated how the linkages between central pattern generator (CPG) networks required for arm and leg movement during locomotion improved with arm and leg cycling training (Kaupp et al., 2018; Klarner et al., 2016b). It's conceivable that such CPG networks and related interlimb connections might be enhanced by the karate training (Kaupp et al., 2018; Klarner et al., 2016b).

The improvement of strength in both the arms and legs of the older adult participants highlights that whole-body movements without the use of machinery can allow for changes in neuromuscular performance. The locomotor circuits that exist evoke the supraspinal and spinal regulatory mechanisms that are needed for neurological interaction during activities such as walking (Dragert & Zehr, 2013; Kaupp et al., 2018; Sun & Zehr, 2019). The primary goal of rehabilitation following neurotrauma is to regain function in movements such as walking and it is also important to strengthen these connections with aging to avoid the risk of falls (World Health Organization, 2015). We predict that training through holistic approaches involving whole body movement could maintain or enhance the intrinsic systems that exist through coordinated movement in all limbs.

2.4.4 Spinal cord excitability after 5-weeks of training.

Spinal cord excitability as assessed by H-reflex amplitude, was measured from an upright position to be as task-specific to the training stimulus (Kaupp et al., 2018). We found no strong group effect, but 6/16 participants did show significant changes from baseline. While the upright position is ideal for matching training conditions, group Ia presynaptic inhibition is enhanced in this posture (Kaupp et al., 2018; Mezzarane & Kohn, 2002; Zehr, 2002). Since changes in reflex amplitude due to training in other work (Noble et al., 2019) shows Ia PSI as a mechanism of neuroplasticity, our choice of standing may have weakened our ability to detect change. Future work should include reflex measurement across a variety of tasks from sitting, standing, and walking (Zehr, 2002) to better assess any changes in reflex excitability.

Amongst this population, the largest magnitudes of change were observed in individuals with PD. Following neurotrauma, there is a greater capacity for restructuring of circuitries that can be attributed to the neural plasticity in the participants (Kwok et al., 2016). The single subject analysis revealed that six (38%) of the participants showed significant changes in this study. Other research with PD presents that neurological integrity of movement is lost, therefore regaining strength and function is of utmost importance. It was anticipated that those with neurological impairments would demonstrate noteworthy transformations due to the nature of the condition and the motor systems involved with complex movements such as martial arts (Dahmen-Zimmer & Jansen, 2017; Kwok et al., 2016; Lichtenstein et al., 2019; Paillard et al., 2015).

2.4.5 Therapeutic efficacy of martial arts training “dose”

While important and useful, past martial arts training interventions provide few details about the actual content of physical performance and lacks a record of techniques used and the number of movements. Here we aimed to provide insight into the quantity required. Other martial arts interventions mention the style of exercises used, such as Shotokan karate in (Dahmen-Zimmer & Jansen, 2017), with a mixture of kihon, kumite, and kata. To our knowledge, this is the first time that specific movements were recorded and analysed. Although the results were efficacious, we still do not know the “threshold” for the dosages of movements to produce significant benefits across all measures and this should be further explored. Studies on strength training with chronic stroke participants show training-induced neural plasticity following a 5-week intervention with similar protocols to our karate study (Dragert & Zehr, 2013; Sun & Zehr, 2019). Strength training as well as locomotor training studies in chronic stroke participants exemplify how dose can be evaluated in a controlled setting (Dragert & Zehr, 2013; Kaupp et al., 2018; Klarner et al., 2016b; Sun & Zehr, 2019). For example, previous work on arm cycling produced a final dosage of 25,890 revolutions after 5 weeks of training (Kaupp et al., 2018) and another study of arm and leg cycling had approximately 26,130 revolutions after 5 weeks (Klarner et al., 2016a). Training with chronic stroke participants showed desired results could occur in the intervention period, with dosages of 375 repetitions of maximal wrist extensions (Sun et al., 2018) for changes in the arm, 470 repetitions of maximal hand grip contractions (Barss et al., 2018) for changes in the arm, and 720 repetitions of ankle contractions (Dragert & Zehr, 2013) for changes in the legs. The calculation of dose is simpler in controlled environment and our understanding is that this is the first time a martial arts “dosage” has been quantified. Additionally, balance assessments in older adults typically focus on gait stability through training with specific motor tasks (Faude & Donath, 2019; Lichtenstein et al., 2019) but evaluation of specific martial arts techniques such as stance changes has not been done in the literature. Regardless, we hope that this preliminary report will create a foundation for doses of movement techniques required to produce changes in neurologically intact and impaired participants.

2.4.6 Recommendations and Future Considerations

This pilot project suggests that 5-weeks of training leads to better overall movement in older adults and those with chronic conditions. While useful data were obtained there are some important recommendations for the future:

1) Enhanced documentation and assessment of physical performance. For example, incorporating detailed enumeration of techniques as here combined with movement tracking using activity monitors during training. This would be especially useful in studies assessing threshold dose.

2) The study was underpowered for some measures due to small effects and we suggest that future research needs to be conducted with a greater sample size with multiple intakes, or an intervention with a longer duration (5 weeks of training might not be sufficient);

3) Clinical tests more specifically related to posture and balance (e.g. BERG balance test) would be better used in place of the insensitive Timed Up and Go;

4) Bilateral deficit assessment is time consuming, did not yield useful outcomes, and should be avoided in future work;

5) Assessment of dynamic balance is an important factor when the intervention trains this parameter. Future work should consider our and related approaches to capture this effectively;

6) Simple measures of spinal cord reflex excitability as assessed by the H-reflex were insensitive here. Suggestions are to assess multiple sizes of H-reflexes with recruitment curves, H-reflexes conditioned by somatosensory stimulation, and interlimb reflexes in future work;

Holistic, whole body integrated exercise programs are being implemented worldwide due to the benefits that are gained both mentally and physically. Future work should continue to explore the promise of mindful, enjoyable and engaging activities (Dahmen-Zimmer & Jansen, 2017; Jansen et al., 2017) that contain content available in the community. We suggest participants are more likely to continue with the practices beyond the intervention timeline. Indeed, anecdotally, over 2/3 of older participants wanted to continue training in this “prehabilitation” after the intervention completed.

2.4.7 Conclusions

The results are evidence of enhanced nervous system response to stimuli and increased postural integration. Significant changes in balance, strength & spinal cord excitability found after 5 weeks of training suggest that neuromechanical integrity can be improved in the aging populations. Our observations lay the groundwork for future explorations of dose, applications to neuropathology, and development of community-based martial arts interventions as “pre-habilitation” for older adults.

2.6 References

Alizadehsaravi, L., Bruijn, S. M., Maas, H., & van Dieën, J. H. (2020). Modulation of soleus muscle H-reflexes and ankle muscle co-contraction with surface compliance during unipedal balancing in young and older adults. *Experimental Brain Research*. https://doi.org/10.1007/s00221-020-05784-0

Barss, T. S., Klarner, T., Pearcey, G. E. P., Sun, Y., & Zehr, E. P. (2018). Time course of interlimb strength transfer after unilateral handgrip training. *Journal of Applied Physiology*, *125*(5), 1594–1608. https://doi.org/10.1152/japplphysiol.00390.2017

Barzi, Y., & Zehr, E. P. (2008). Rhythmic arm cycling suppresses hyperactive soleus H-reflex amplitude after stroke. *Clinical Neurophysiology*, *119*(6), 1443–1452. https://doi.org/10.1016/j.clinph.2008.02.016

Baudry, S., & Duchateau, J. (2012). Age-related influence of vision and proprioception on Ia presynaptic inhibition in soleus muscle during upright stance: Ageing and Ia presynaptic inhibition during balance. *The Journal of Physiology*, *590*(21), 5541–5554. https://doi.org/10.1113/jphysiol.2012.228932

Billinger, S. A., Arena, R., Bernhardt, J., Eng, J. J., Franklin, B. A., Johnson, C. M., MacKay-Lyons, M., Macko, R. F., Mead, G. E., Roth, E. J., Shaughnessy, M., & Tang, A. (2014). Physical Activity and Exercise Recommendations for Stroke Survivors: A Statement for Healthcare Professionals From the American Heart Association/American Stroke Association. *Stroke*, *45*(8), 2532–2553. https://doi.org/10.1161/STR.0000000000000022

Brudnak, M. A., Dundero, D., & Van Hecke, F. M. (2002). Are the `hard’ martial arts, such as the Korean martial art, TaeKwon-Do, of benefit to senior citizens? *Medical Hypotheses*, *59*(4), 485–491. https://doi.org/10.1016/S0306-9877(02)00203-7

Bu, B., Haijun, H., Yong, L., Chaohui, Z., Xiaoyuan, Y., & Singh, M. F. (2010). Effects of martial arts on health status: A systematic review. *Journal of Evidence-Based Medicine*, *3*(4), 205–219. https://doi.org/10.1111/j.1756-5391.2010.01107.x

Burke, R. E. (2007). Sir Charles Sherrington's The integrative action of the nervous system: A centenary appreciation. *Brain*, *130*(4), 887–894. https://doi.org/10.1093/brain/awm022

Bütefisch, C., Hummelsheim, H., Denzler, P., & Mauritz, K.-H. (1995). Repetitive training of isolated movements improves the outcome of motor rehabilitation of the centrally paretic hand. *Journal of the Neurological Sciences*, *130*(1), 59–68. https://doi.org/10.1016/0022-510X(95)00003-K

Canadian Society for Exercise Physiology. (2002). PAR-Q and You.

Chaabene, H., Negra, Y., Capranica, L., Prieske, O., & Granacher, U. (2019). A Needs Analysis of Karate Kumite With Recommendations for Performance Testing and Training: *Strength and Conditioning Journal*, *41*(3), 35–46. https://doi.org/10.1519/SSC.0000000000000445

Chan, A. S., Ho, Y., Cheung, M., Albert, M. S., Chiu, H. F. K., & Lam, L. C. W. (2005). Association Between Mind-Body and Cardiovascular Exercises and Memory in Older Adults: EXERCISE AND MEMORY. *Journal of the American Geriatrics Society*, *53*(10), 1754–1760. https://doi.org/10.1111/j.1532-5415.2005.53513.x

Chateau-Degat, M.-L., G&amp, eacute, Papouin, R., Saint-Val, P., & Al, E. (2010). Effect of adapted karate training on quality of life and body balance in 50-year-old men. *Open Access Journal of Sports Medicine*, *2010*(default), 143–150.

Cheng, H. Y., Chair, S. Y., & Chau, J. P.-C. (2014). The effectiveness of psychosocial interventions for stroke family caregivers and stroke survivors: A systematic review and meta-analysis. *Patient Education and Counseling*, *95*(1), 30–44. https://doi.org/10.1016/j.pec.2014.01.005

Cho, S.-Y., & Roh, H.-T. (2019). Taekwondo Enhances Cognitive Function as a Result of Increased Neurotrophic Growth Factors in Elderly Women. *International Journal of Environmental Research and Public Health*, *16*(6). https://doi.org/10.3390/ijerph16060962

Chung, J. W. Y., Fong, S. S. M., Gao, Y., Yam, T. T. T., Chak, Y. T. C., Leung, J. C. Y., & Wong, T. K. S. (2020). Effects of Ving Tsun sticking-hand training on upper-limb sensorimotor performance in community-dwelling middle-aged and older adults: A randomized controlled trial. *International Journal of Nursing Sciences*, *7*(1), 29–34. https://doi.org/10.1016/j.ijnss.2019.11.001

Clark, R. A., Mentiplay, B. F., Pua, Y.-H., & Bower, K. J. (2018). Reliability and validity of the Wii Balance Board for assessment of standing balance: A systematic review. *Gait & Posture*, *61*, 40–54. https://doi.org/10.1016/j.gaitpost.2017.12.022

Cohen, R. G., Baer, J. L., Ravichandra, R., Kral, D., McGowan, C., & Cacciatore, T. W. (2020). Lighten Up! Postural Instructions Affect Static and Dynamic Balance in Healthy Older Adults. *Innovation in Aging*, *4*(2), igz056. https://doi.org/10.1093/geroni/igz056

Corcos, D. M., Robichaud, J. A., David, F. J., Leurgans, S. E., Vaillancourt, D. E., Poon, C., Rafferty, M. R., Kohrt, W. M., & Comella, C. L. (2013). A two-year randomized controlled trial of progressive resistance exercise for Parkinson’s disease: Progressive Resistance Exercise in PD. *Movement Disorders*, *28*(9), 1230–1240. https://doi.org/10.1002/mds.25380

Cost of Injury in Canada – Parachute. (n.d.). Retrieved October 5, 2020, from https://parachute.ca/en/professional-resource/cost-of-injury-report/

Cromwell, R. L., Meyers, P. M., Meyers, P. E., & Newton, R. A. (2007). Tae Kwon Do: An Effective Exercise for Improving Balance and Walking Ability in Older Adults. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *62*(6), 641–646. https://doi.org/10.1093/gerona/62.6.641

Crone, C., & Nielsen, J. (1989). Methodological implications of the post activation depression of the soleus H-reflex in man. *Experimental Brain Research*, *78*(1). https://doi.org/10.1007/BF00230683

Cullen, H. M., Sun, Y., Christie, B. R., & Zehr, E. P. (2017). Use of the wii balance board to assess changes in postural balance across athletic season. *British Journal of Sports Medicine*, *51*(11), A1–A1. https://doi.org/10.1136/bjsports-2016-097270.2

Dahmen-Zimmer, K., & Jansen, P. (2017). Karate and Dance Training to Improve Balance and Stabilize Mood in Patients with Parkinson's Disease: A Feasibility Study. *Frontiers in Medicine*, *4*, 237. https://doi.org/10.3389/fmed.2017.00237

Domingos, J., Radder, D., Riggare, S., Godinho, C., Dean, J., Graziano, M., de Vries, N. M., Ferreira, J., & Bloem, B. R. (n.d.). *Implementation of a Community-Based Exercise Program for Parkinson Patients: Using Boxing as an Example*. 9.

Dragert, K., & Zehr, E. P. (2013). High-intensity unilateral dorsiflexor resistance training results in bilateral neuromuscular plasticity after stroke. *Experimental Brain Research*, *225*(1), 93–104. https://doi.org/10.1007/s00221-012-3351-x

Duncan, P. W., Sullivan, K. J., Behrman, A. L., Azen, S. P., Wu, S. S., Nadeau, S. E., Dobkin, B. H., Rose, D. K., Tilson, J. K., Cen, S., & Hayden, S. K. (2011). Body-Weight–Supported

Treadmill Rehabilitation after Stroke. *New England Journal of Medicine*, *364*(21), 2026–2036. https://doi.org/10.1056/NEJMoa1010790

Dunsky, A. (2019). The Effect of Balance and Coordination Exercises on Quality of Life in Older Adults: A Mini-Review. *Frontiers in Aging Neuroscience*, *11*, 318. https://doi.org/10.3389/fnagi.2019.00318

Duru, A. D., & Balcioglu, T. H. (2018). Functional and Structural Plasticity of Brain in Elite Karate Athletes. *Journal of Healthcare Engineering*, *2018*, 1–8. https://doi.org/10.1155/2018/8310975

Faude, O., & Donath, L. (2019). Editorial: Neuromuscular Performance During Lifespan: Assessment Methods and Exercise Interventions. *Frontiers in Physiology*, *10*, 1348. https://doi.org/10.3389/fphys.2019.01348

Fong, S. S. M., Guo, X., Cheung, A. P. M., Jo, A. T. L., Lui, G. K. W., Mo, D. K. C., Ng, S. S. M., & Tsang, W. W. N. (2013). Elder Chinese Martial Art Practitioners Have Higher Radial Bone Strength, Hand-Grip Strength, and Better Standing Balance Control. *ISRN Rehabilitation*, *2013*, 1–6. https://doi.org/10.1155/2013/185090

Fong, S. S. M., Ng, S. S. M., Cheng, Y. T. Y., Wong, J. Y. H., Yu, E. Y. T., Chow, G. C. C., Chak, Y. T. C., Chan, I. K. Y., Zhang, J., Macfarlane, D., & Chung, L. M. Y. (2016). Effects of Ving Tsun Chinese Martial Art Training on Upper Extremity Muscle Strength and Eye-Hand Coordination in Community-Dwelling Middle-Aged and Older Adults: A Pilot Study. *Evidence-Based Complementary and Alternative Medicine : ECAM*, *2016*. https://doi.org/10.1155/2016/4013989

Frigon, A. (2017). The neural control of interlimb coordination during mammalian locomotion. *Journal of Neurophysiology*, *117*(6), 2224–2241. https://doi.org/10.1152/jn.00978.2016

Garcia, R. S. (2018). *The Historical Sociology of Japanese Martial Arts*. Routledge.

Gatts, S. K., & Woollacott, M. H. (2007). How Tai Chi improves balance: Biomechanics of recovery to a walking slip in impaired seniors. *Gait & Posture*, *25*(2), 205–214. https://doi.org/10.1016/j.gaitpost.2006.03.011

Gheysen, F., Poppe, L., DeSmet, A., Swinnen, S., Cardon, G., De Bourdeaudhuij, I., Chastin, S., & Fias, W. (2018). Physical activity to improve cognition in older adults: Can physical activity programs enriched with cognitive challenges enhance the effects? A systematic review and meta-analysis. *International Journal of Behavioral Nutrition and Physical Activity*, *15*(1), 63. https://doi.org/10.1186/s12966-018-0697-x

GovHK (www.gov.hk). (n.d.). *GovHK: Leisure and Cultural Activities for the Elderly*. Retrieved August 15, 2020, from https://www.gov.hk/en/residents/culture/recreation/activities/elderlyact.htm

Guertin, P. A. (2009). The mammalian central pattern generator for locomotion. *Brain Research Reviews*, *62*(1), 45–56. https://doi.org/10.1016/j.brainresrev.2009.08.002

Guskiewicz, K. M. (2001). Postural Stability Assessment Following Concussion: One Piece of the Puzzle: *Clinical Journal of Sport Medicine*, *11*(3), 182–189. https://doi.org/10.1097/00042752-200107000-00009

Hackney, M. E., & Earhart, G. M. (2008). Tai Chi improves balance and mobility in people with Parkinson disease. *Gait & Posture*, *28*(3), 456–460. https://doi.org/10.1016/j.gaitpost.2008.02.005

Hadad, A., Ganz, N., Intrator, N., Maimon, N., Molcho, L., & Hausdorff, J. M. (2020). Postural control in karate practitioners: Does practice make perfect? *Gait & Posture*, *77*, 218–224. https://doi.org/10.1016/j.gaitpost.2020.01.030

Hong, Y. (2000). Balance control, flexibility, and cardiorespiratory fitness among older Tai Chi practitioners. *British Journal of Sports Medicine*, *34*(1), 29–34. https://doi.org/10.1136/bjsm.34.1.29

Horak, F. B. (2006). Postural orientation and equilibrium: What do we need to know about neural control of balance to prevent falls? *Age and Ageing*, *35*(suppl_2), ii7–ii11. https://doi.org/10.1093/ageing/afl077

Ibrahim, A., Singh, D. K. A., & Shahar, S. (2017). 'Timed Up and Go' test: Age, gender and cognitive impairment stratified normative values of older adults. *PLOS ONE*, *12*(10), e0185641. https://doi.org/10.1371/journal.pone.0185641

Jahnke, R. A., Larkey, L. K., & Rogers, C. (2010). Dissemination and Benefits of a Replicable Tai Chi and Qigong Program for Older Adults. *Geriatric Nursing*, *31*(4), 272–280. https://doi.org/10.1016/j.gerinurse.2010.04.012

Jansen, P., Dahmen-Zimmer, K., Kudielka, B. M., & Schulz, A. (2017). Effects of Karate Training Versus Mindfulness Training on Emotional Well-Being and Cognitive Performance in Later Life. *Research on Aging*, *39*(10), 1118–1144. https://doi.org/10.1177/0164027516669987

Juras, G., Rzepko, M., Król, P., Czarny, W., Bajorek, W., Słomka, K., & Sobota, G. (n.d.). The effect of expertise in karate on postural control in quiet standing. *ARCHIVES OF BUDO*, 6.

Kaupp, C., Pearcey, G. E. P., Klarner, T., Sun, Y., Cullen, H., Barss, T. S., & Zehr, E. P. (2018). Rhythmic arm cycling training improves walking and neurophysiological integrity in chronic stroke: The arms can give legs a helping hand in rehabilitation. *Journal of Neurophysiology*, *119*(3), 1095–1112. https://doi.org/10.1152/jn.00570.2017

Klarner, T., Barss, T. S., Sun, Y., Kaupp, C., Loadman, P. M., & Zehr, E. P. (2016a). Exploiting Interlimb Arm and Leg Connections for Walking Rehabilitation: A Training Intervention in Stroke. *Neural Plasticity*, *2016*, 1–19. https://doi.org/10.1155/2016/1517968

Klarner, T., Barss, T., Sun, Y., Kaupp, C., Loadman, P., & Zehr, E. (2016b). Long-Term Plasticity in Reflex Excitability Induced by Five Weeks of Arm and Leg Cycling Training after Stroke. *Brain Sciences*, *6*(4), 54. https://doi.org/10.3390/brainsci6040054

Knikou, M. (2008). The H-reflex as a probe: Pathways and pitfalls. *Journal of Neuroscience Methods*, *171*(1), 1–12. https://doi.org/10.1016/j.jneumeth.2008.02.012

Kotarska, K., Nowak, L., Szark-Eckardt, M., & Nowak, M. (2019). Selected Healthy Behaviors and Quality of Life in People Who Practice Combat Sports and Martial Arts. *International Journal of Environmental Research and Public Health*, *16*(5), 875. https://doi.org/10.3390/ijerph16050875

Kwok, J. Y. Y., Choi, K. C., & Chan, H. Y. L. (2016). Effects of mind–body exercises on the physiological and psychosocial well-being of individuals with Parkinson’s disease: A systematic review and meta-analysis. *Complementary Therapies in Medicine*, *29*, 121–131. https://doi.org/10.1016/j.ctim.2016.09.016

Lang, J. J., Alam, S., Cahill, L. E., Drucker, A. M., Gotay, C., Kayibanda, J. F., Kozloff, N., Mate, K. K. V., Patten, S. B., & Orpana, H. M. (2018). Global Burden of Disease Study trends for Canada from 1990 to 2016. *Canadian Medical Association Journal*, *190*(44), E1296–E1304. https://doi.org/10.1503/cmaj.180698

Li, F., Harmer, P., Fitzgerald, K., Eckstrom, E., Stock, R., Galver, J., Maddalozzo, G., & Batya, S. S. (2012). Tai Chi and Postural Stability in Patients with Parkinson’s Disease. *New England Journal of Medicine*, *366*(6), 511–519. https://doi.org/10.1056/NEJMoa1107911

Li, F., Harmer, P., McAuley, E., Fisher, K. J., Duncan, T. E., & Duncan, S. C. (2002). Tai Chi, Self-Efficacy, and Physical Function in the Elderly. *Prevention Science*, 11.

Lichtenstein, E., Faude, O., Zubler, A., Roth, R., Zahner, L., Rössler, R., Hinrichs, T., van Dieën, J. H., & Donath, L. (2019). Validity and Reliability of a Novel Integrative Motor Performance Testing Course for Seniors: The “Agility Challenge for the Elderly (ACE).” *Frontiers in Physiology*, *10*, 44. https://doi.org/10.3389/fphys.2019.00044

Living with Parkinson’s Disease | American Parkinson Disease Assoc. (n.d.). *APDA*. Retrieved August 1, 2020, from https://www.apdaparkinson.org/resources-support/living-with-parkinsons-disease/

Lorge, P. A., & Lorge, P. A. (2012). *Chinese Martial Arts: From Antiquity to the Twenty-First Century*. Cambridge University Press.

Lotharius, J., & Brundin, P. (2002). Pathogenesis of Parkinson’s disease: Dopamine, vesicles and alpha-synuclein. *Nature Reviews. Neuroscience*, *3*(12), 932–942.

Lowry, D. (1995). *Sword and Brush: The Spirit of the Martial Arts*. Shambhala Publications.

Maass, A., Düzel, S., Brigadski, T., Goerke, M., Becke, A., Sobieray, U., Neumann, K., Lövdén, M., Lindenberger, U., Bäckman, L., Braun-Dullaeus, R., Ahrens, D., Heinze, H.-J., Müller, N. G., Lessmann, V., Sendtner, M., & Düzel, E. (2016). Relationships of peripheral IGF-1, VEGF and BDNF levels to exercise-related changes in memory, hippocampal perfusion and volumes in older adults. *NeuroImage*, *131*, 142–154. https://doi.org/10.1016/j.neuroimage.2015.10.084

McPhee, J. S., French, D. P., Jackson, D., Nazroo, J., Pendleton, N., & Degens, H. (2016). Physical activity in older age: Perspectives for healthy ageing and frailty. *Biogerontology*, *17*(3), 567–580. https://doi.org/10.1007/s10522-016-9641-0

Mezzarane, R. A., & Kohn, A. F. (2002). Bilateral Soleus H-Reflexes in Humans Elicited by Simultaneous Trains of Stimuli: Symmetry, Variability, and Covariance. *Journal of Neurophysiology*, *87*(4), 2074–2083. https://doi.org/10.1152/jn.00129.2001

Misiaszek, J. E. (2003). The H-reflex as a tool in neurophysiology: Its limitations and uses in understanding nervous system function. *Muscle & Nerve*, *28*(2), 144–160. https://doi.org/10.1002/mus.10372

Monda, V., Valenzano, A., Moscatelli, F., Salerno, M., Sessa, F., Triggiani, A. I., Viggiano, A., Capranica, L., Marsala, G., De Luca, V., Cipolloni, L., Ruberto, M., Precenzano, F., Carotenuto, M., Zammit, C., Gelzo, M., Monda, M., Cibelli, G., Messina, G., & Messina, A. (2017). Primary Motor Cortex Excitability in Karate Athletes: A Transcranial Magnetic Stimulation Study. *Frontiers in Physiology*, *8*, 695. https://doi.org/10.3389/fphys.2017.00695

Moscatelli, F., Messina, G., Valenzano, A., Petito, A., Triggiani, A. I., Messina, A., Monda, V., Viggiano, A., De Luca, V., Capranica, L., Monda, M., & Cibelli, G. (2016). Differences in corticospinal system activity and reaction response between karate athletes and non-athletes. *Neurological Sciences*, *37*(12), 1947–1953. https://doi.org/10.1007/s10072-016-2693-8

Ngandu, T., Lehtisalo, J., Solomon, A., Levälahti, E., Ahtiluoto, S., Antikainen, R., Bäckman, L., Hänninen, T., Jula, A., Laatikainen, T., Lindström, J., Mangialasche, F., Paajanen, T., Pajala, S., Peltonen, M., Rauramaa, R., Stigsdotter-Neely, A., Strandberg, T., Tuomilehto, J., … Kivipelto, M. (2015). A 2 year multidomain intervention of diet, exercise, cognitive training, and vascular risk monitoring versus control to prevent cognitive decline in at-risk elderly people (FINGER): A randomised controlled trial. *The Lancet*, *385*(9984), 2255–2263. https://doi.org/10.1016/S0140-6736(15)60461-5

Nguyen, D.-M., Laffont, I., & Dupeyron, A. (2016). Martials arts use in physical and rehabilitation medicine: Literature review and perspectives. *Annals of Physical and Rehabilitation Medicine*, *59*, e55–e56. https://doi.org/10.1016/j.rehab.2016.07.128

Noble, S., Pearcey, G. E. P., Quartly, C., & Zehr, E. P. (2019). Robot controlled, continuous passive movement of the ankle reduces spinal cord excitability in participants with spasticity: A pilot study. *Experimental Brain Research*, *237*(12), 3207–3220. https://doi.org/10.1007/s00221-019-05662-4

O'Brien, J. T., & Thomas, A. (2015). Vascular dementia. *The Lancet*, *386*(10004), 1698–1706. https://doi.org/10.1016/S0140-6736(15)00463-8

Ouergui, I., Hssin, N., Haddad, M., Padulo, J., Franchini, E., Gmada, N., & Bouhlel, E. (2014). The effects of five weeks of kickboxing training on physical fitness. *Muscles, Ligaments and Tendons Journal*, *4*(2), 106–113.

Page, S. J., & Harnish, S. (2012). Thinking about better speech: Mental practice for stroke-induced motor speech impairments. *Aphasiology*, *26*(2), 127–142. https://doi.org/10.1080/02687038.2011.636027

Paillard, T., Rolland, Y., & de Souto Barreto, P. (2015). Protective Effects of Physical Exercise in Alzheimer's Disease and Parkinson's Disease: A Narrative Review. *Journal of Clinical Neurology*, *11*(3), 212. https://doi.org/10.3988/jcn.2015.11.3.212

Pearcey, G. E. P., & Zehr, E. P. (2019). Exploiting cervicolumbar connections enhances short-term spinal cord plasticity induced by rhythmic movement. *Experimental Brain Research*, *237*(9), 2319–2329. https://doi.org/10.1007/s00221-019-05598-9

Perrin, P., Deviterne, D., Hugel, F., & Perrot, C. (2002). Judo, better than dance, develops sensorimotor adaptabilities involved in balance control. *Gait & Posture*, *15*(2), 187–194. https://doi.org/10.1016/S0966-6362(01)00149-7

Petzinger, G. M., Holschneider, D. P., Fisher, B. E., McEwen, S., Kintz, N., Halliday, M., Toy, W., Walsh, J. W., Beeler, J., & Jakowec, M. W. (2015). The Effects of Exercise on Dopamine Neurotransmission in Parkinson's Disease: Targeting Neuroplasticity to Modulate Basal Ganglia Circuitry. *Brain Plasticity*, *1*(1), 29–39. https://doi.org/10.3233/BPL-150021

Pierrot-Deseilligny, E., & Mazevet, D. (2000). The monosynaptic reflex: A tool to investigate motor control in humans. Interest and limits. *Neurophysiologie Clinique = Clinical Neurophysiology*, *30*, 67–80. https://doi.org/10.1016/S0987-7053(00)00062-9

Pinter, M. M., & Brainin, M. (2012). Rehabilitation after stroke in older people. *Maturitas*, *71*(2), 104–108. https://doi.org/10.1016/j.maturitas.2011.11.011

Pliske, G., Emmermacher, P., Weinbeer, V., & Witte, K. (2016). Changes in dual-task performance after 5 months of karate and fitness training for older adults to enhance fall prevention. *Aging Clinical and Experimental Research*, *28*(6), 1179–1186. https://doi.org/10.1007/s40520-015-0508-z

Public Health and Aging: Trends in Aging—United States and Worldwide. (2003). *JAMA*, *289*(11), 1371. https://doi.org/10.1001/jama.289.11.1371

Quinzi, F., Sbriccoli, P., Alderson, J., Di Mario, A., & Camomilla, V. (2014). Intra-limb coordination in karate kicking: Effect of impacting or not impacting a target. *Human Movement Science*, *33*, 108–119. https://doi.org/10.1016/j.humov.2013.07.021

Roemmich, R. T., Field, A. M., Elrod, J. M., Stegemöller, E. L., Okun, M. S., & Hass, C. J. (2013). Interlimb coordination is impaired during walking in persons with Parkinson’s disease. *Clinical Biomechanics*, *28*(1), 93–97. https://doi.org/10.1016/j.clinbiomech.2012.09.005

Rogers, C. E., Larkey, L. K., & Keller, C. (2009). A Review of Clinical Trials of Tai Chi and Qigong in Older Adults. *Western Journal of Nursing Research*, *31*(2), 245–279. https://doi.org/10.1177/0193945908327529

Ross, A., & Thomas, S. (2010). The Health Benefits of Yoga and Exercise: A Review of Comparison Studies. *The Journal of Alternative and Complementary Medicine*, *16*(1), 3–12. https://doi.org/10.1089/acm.2009.0044

Rothman, S. M., & Mattson, M. P. (2013). Activity-dependent, stress-responsive BDNF signaling and the quest for optimal brain health and resilience throughout the lifespan. *Neuroscience*, *239*, 228–240. https://doi.org/10.1016/j.neuroscience.2012.10.014

Sofroniew, M. V., Howe, C. L., & Mobley, W. C. (2001). Nerve Growth Factor Signaling, Neuroprotection, and Neural Repair. *Annual Review of Neuroscience*, *24*(1), 1217–1281. https://doi.org/10.1146/annurev.neuro.24.1.1217

Sullivan, G. M., & Feinn, R. (2012). Using Effect Size—Or Why the *P* Value Is Not Enough. *Journal of Graduate Medical Education*, *4*(3), 279–282. https://doi.org/10.4300/JGME-D-12-00156.1

Sun, Y., Cullen, H. M., & Zehr, E. P. (2019). Harnessing the Power of a Novel Program for Dynamic Balance Perturbation with Supported Body Weight. *Journal of Motor Behavior*, 1–13. https://doi.org/10.1080/00222895.2019.1670129

Sun, Y., Ledwell, N. M. H., Boyd, L. A., & Zehr, E. P. (2018). *Unilateral wrist extension training after stroke improves strength and neural plasticity in both arms | SpringerLink*. https://link-springer-com.ezproxy.library.uvic.ca/article/10.1007/s00221-018-5275-6

Sun, Y., & Zehr, E. P. (2019). Training-Induced Neural Plasticity and Strength Are Amplified After Stroke: *Exercise and Sport Sciences Reviews*, *47*(4), 223–229. https://doi.org/10.1249/JES.0000000000000199

Thrift, A. G., Howard, G., Cadilhac, D. A., Howard, V. J., Rothwell, P. M., Thayabaranathan, T., Feigin, V. L., Norrving, B., & Donnan, G. A. (2017). Global stroke statistics: An update of mortality data from countries using a broad code of "cerebrovascular diseases." *International Journal of Stroke*, *12*(8), 796–801. https://doi.org/10.1177/1747493017730782

Tremblay, M. S., Warburton, D. E. R., Janssen, I., Paterson, D. H., Latimer, A. E., Rhodes, R. E., Kho, M. E., Hicks, A., LeBlanc, A. G., Zehr, L., Murumets, K., & Duggan, M. (2011). New Canadian Physical Activity Guidelines. *Applied Physiology, Nutrition, and Metabolism*, *36*(1), 36–46. https://doi.org/10.1139/H11-009

van der Zijden, A. M., Groen, B. E., Tanck, E., Nienhuis, B., Verdonschot, N., & Weerdesteyn, V. (2012). Can martial arts techniques reduce fall severity? An in vivo study of femoral loading configurations in sideways falls. *Journal of Biomechanics*, *45*(9), 1650–1655. https://doi.org/10.1016/j.jbiomech.2012.03.024

van Dijk, G. P., Lenssen, A. F., Leffers, P., Kingma, H., & Lodder, J. (2013). Taekwondo Training Improves Balance in Volunteers Over 40. *Frontiers in Aging Neuroscience*, *5*. https://doi.org/10.3389/fnagi.2013.00010

Voerman, G. E., Gregorič, M., & Hermens, H. J. (2005). Neurophysiological methods for the assessment of spasticity: The Hoffmann reflex, the tendon reflex, and the stretch reflex. *Disability and Rehabilitation*, *27*(1–2), 33–68. https://doi.org/10.1080/09638280400014600

Wayne, P. M., Walsh, J. N., Taylor-Piliae, R. E., Wells, R. E., Papp, K. V., Donovan, N. J., & Yeh, G. Y. (2014). Effect of Tai Chi on Cognitive Performance in Older Adults: Systematic Review and Meta-Analysis. *Journal of the American Geriatrics Society*, *62*(1), 25–39. https://doi.org/10.1111/jgs.12611

Witte, K., Kropf, S., Darius, S., Emmermacher, P., & Böckelmann, I. (2016). Comparing the effectiveness of karate and fitness training on cognitive functioning in older adults—A randomized controlled trial. *Journal of Sport and Health Science*, *5*(4), 484–490. https://doi.org/10.1016/j.jshs.2015.09.006

Woodward, T. W. (2009). A review of the effects of martial arts practice on health. *WMJ : Official Publication of the State Medical Society of Wisconsin*, *108*(1), 40–43.

World Health Organization (Ed.). (2015). *World report on ageing and health*. World Health Organization.

Yau, S. Y., Li, A., Sun, X., Fontaine, C. J., Christie, B. R., & So, K.-F. (2016). Potential Biomarkers for Physical Exercise-Induced Brain Health. *Role of Biomarkers in Medicine*. https://doi.org/10.5772/62458

Zehr, E. Paul. (2002). Considerations for use of the Hoffmann reflex in exercise studies. *European Journal of Applied Physiology*, *86*(6), 455–468. https://doi.org/10.1007/s00421-002-0577-5

Zehr, E. Paul. (2011). Evidence-based risk assessment and recommendations for physical activity clearance: Stroke and spinal cord injury [1] This paper is one of a selection of papers published in this Special Issue, entitled Evidence-based risk assessment and recommendations for physical activity clearance, and has undergone the Journal's usual peer review process. *Applied Physiology, Nutrition, and Metabolism*, *36*(S1), S214–S231. https://doi.org/10.1139/h11-055

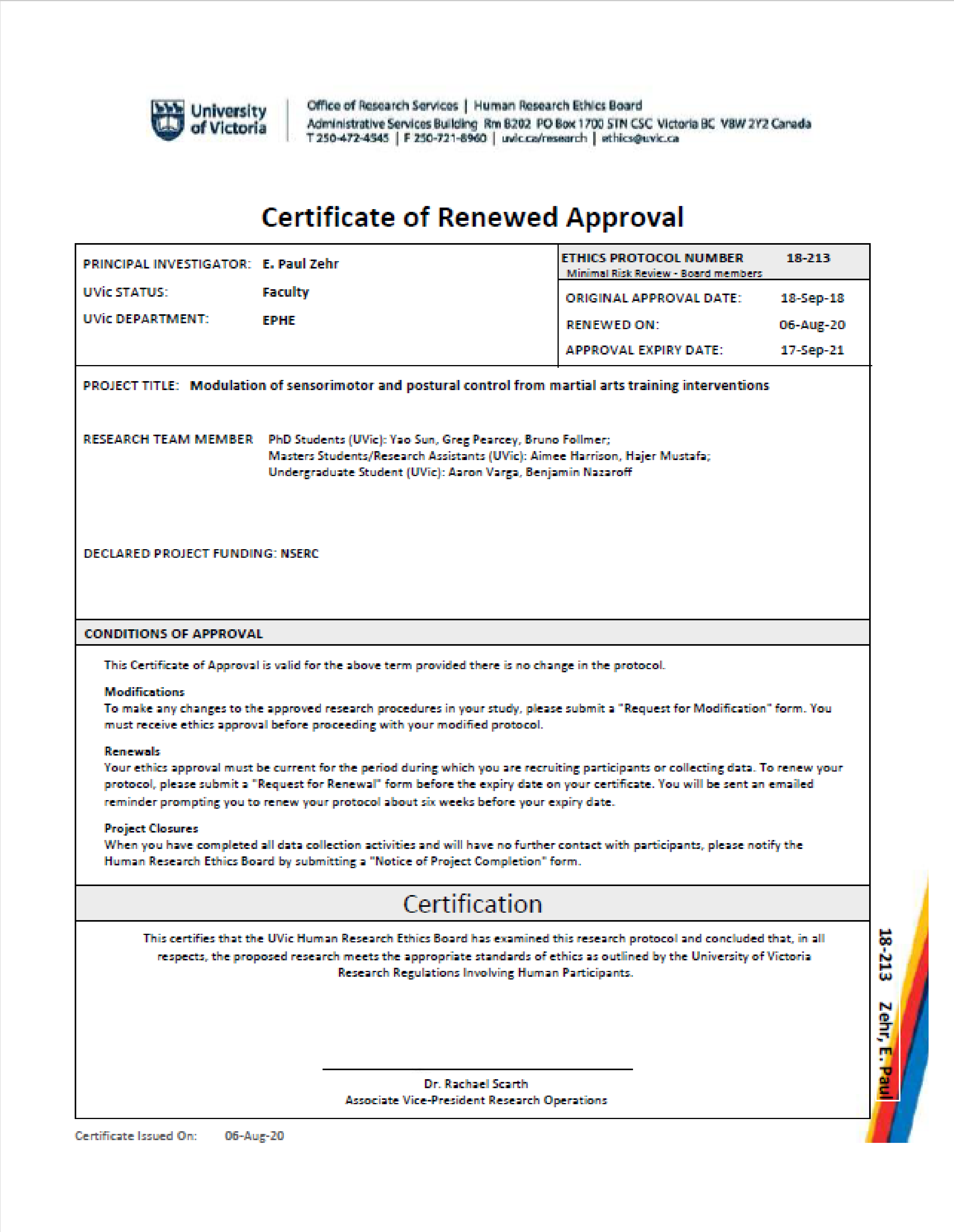
Zehr, E. Paul, & Duysens, J. (2004). Regulation of Arm and Leg Movement during Human Locomotion. *The Neuroscientist*, *10*(4), 347–361. https://doi.org/10.1177/1073858404264680

Zehr, E. Paul, Hundza, S. R., & Vasudevan, E. V. (2009). The Quadrupedal Nature of Human Bipedal Locomotion. *Exercise and Sport Sciences Reviews*, *37*(2), 102–108. https://doi.org/10.1097/JES.0b013e31819c2ed6

Zehr, E.P., Barss, T. S., Dragert, K., Frigon, A., Vasudevan, E. V., Haridas, C., Hundza, S., Kaupp, C., Klarner, T., Klimstra, M., Komiyama, T., Loadman, P. M., Mezzarane, R. A., Nakajima, T., Pearcey, G. E. P., & Sun, Y. (2016). Neuromechanical interactions between the limbs during human locomotion: An evolutionary perspective with translation to rehabilitation. *Experimental Brain Research*, *234*(11), 3059–3081. https://doi.org/10.1007/s00221-016-4715-4

Zhang, S., Xu, W., Zhu, Y., Tian, E., & Kong, W. (2020). Impaired Multisensory Integration Predisposes the Elderly People to Fall: A Systematic Review. *Frontiers in Neuroscience*, *14*, 411. https://doi.org/10.3389/fnins.2020.00411

Appendix A: Certification of Research Ethics Approval



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Certificate of Renewed Approval

PRINCIPAL INVESTIGATOR:	**E. Paul Zehr**	**ETHICS PROTOCOL NUMBER** Minimal Risk Review - Board members	**18-213**
UVic STATUS:	**Faculty**	ORIGINAL APPROVAL DATE:	18-Sep-18
UVic DEPARTMENT:	**EPHE**	RENEWED ON:	06-Aug-20
		APPROVAL EXPIRY DATE:	17-Sep-21

PROJECT TITLE: **Modulation of sensorimotor and postural control from martial arts training interventions**

RESEARCH TEAM MEMBER PhD Students (UVic): Yao Sun, Greg Pearcey, Bruno Follmer;
Masters Students/Research Assistants (UVic): Aimee Harrison, Hajer Mustafa;
Undergraduate Student (UVic): Aaron Varga, Benjamin Nazaroff

DECLARED PROJECT FUNDING: NSERC

CONDITIONS OF APPROVAL

This Certificate of Approval is valid for the above term provided there is no change in the protocol.

Modifications
To make any changes to the approved research procedures in your study, please submit a "Request for Modification" form. You must receive ethics approval before proceeding with your modified protocol.

Renewals
Your ethics approval must be current for the period during which you are recruiting participants or collecting data. To renew your protocol, please submit a "Request for Renewal" form before the expiry date on your certificate. You will be sent an emailed reminder prompting you to renew your protocol about six weeks before your expiry date.

Project Closures
When you have completed all data collection activities and will have no further contact with participants, please notify the Human Research Ethics Board by submitting a "Notice of Project Completion" form.

Certification

This certifies that the UVic Human Research Ethics Board has examined this research protocol and concluded that, in all respects, the proposed research meets the appropriate standards of ethics as outlined by the University of Victoria Research Regulations Involving Human Participants.

Dr. Rachael Scarth
Associate Vice-President Research Operations

18-213 Zehr, E. Paul

Certificate Issued On: 06-Aug-20

Appendix B: Demographics Questionnaire

Please check the correct boxes below.

What is your age?

- ○ Under 12 years old
- ○ 12-17 years old
- ○ 18-24 years old
- ○ 25-34 years old
- ○ 35-44 years old
- ○ 45-54 years old
- ○ 55-64 years old
- ○ 65-74 years old
- ○ 75 years or older
- ○ Prefer not to answer

What is your ethnicity?

- ○ Caucasian
- ○ African-American
- ○ American Indian or Alaskan Native
- ○ Asian
- ○ Native Hawaiian or other Pacific islander
- ○ Some other ethnicity (please specify)
- ○ Prefer not to answer

What is your gender?

- ○ Female
- ○ Male
- ○ Other (specify)
- ○ Prefer not to answer

What is your marital status?

- ○ Married
- ○ Widowed
- ○ Divorced

- ○ Separated
- ○ Never married
- ○ Prefer not to answer

What is the highest level of school you have completed or the highest degree you have received?

- ○ Less than high school degree
- ○ High school degree or equivalent (e.g., GED)
- ○ Some college but no degree
- ○ Associate degree
- ○ Bachelor degree
- ○ Graduate degree
- ○ Prefer not to answer

Which of the following categories best describes your employment status?

- ○ Employed, working 1-39 hours per week
- ○ Employed, working 40 or more hours per week
- ○ Not employed, looking for work
- ○ Not employed, NOT looking for work
- ○ Retired
- ○ Disabled, not able to work
- ○ Prefer not to answer

How much total combined money did all members of your household earn in 2017?

- ○ $0 – $9,999
- ○ $10,000 – $19,999
- ○ $20,000 – $29,999
- ○ $30,000 – $39,999
- ○ $40,000 – $49,999

○ $50,000 – $59,999

○ $60,000 – $69,999

○ $70,000 – $79,999

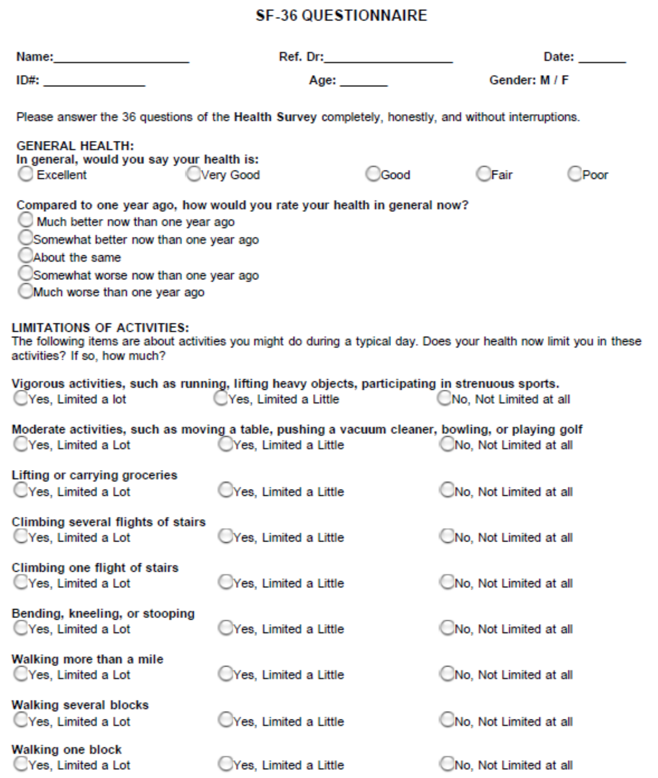
○ $80,000 – $89,999

○ $90,000 – $99,999

○ $100,000 or more

○ Prefer not to answer

Appendix C: SF-36 General Health Questionnaire



SF-36 QUESTIONNAIRE

Name:___________________ **Ref. Dr:**_________________ **Date:** _______

ID#: ______________ **Age:** _______ **Gender: M / F**

Please answer the 36 questions of the **Health Survey** completely, honestly, and without interruptions.

GENERAL HEALTH:
In general, would you say your health is:
○ Excellent ○Very Good ○Good ○Fair ○Poor

Compared to one year ago, how would you rate your health in general now?
○ Much better now than one year ago
○Somewhat better now than one year ago
○About the same
○Somewhat worse now than one year ago
○Much worse than one year ago

LIMITATIONS OF ACTIVITIES:
The following items are about activities you might do during a typical day. Does your health now limit you in these activities? If so, how much?

Vigorous activities, such as running, lifting heavy objects, participating in strenuous sports.
○Yes, Limited a lot ○Yes, Limited a Little ○No, Not Limited at all

Moderate activities, such as moving a table, pushing a vacuum cleaner, bowling, or playing golf
○Yes, Limited a Lot ○Yes, Limited a Little ○No, Not Limited at all

Lifting or carrying groceries
○Yes, Limited a Lot ○Yes, Limited a Little ○No, Not Limited at all

Climbing several flights of stairs
○Yes, Limited a Lot ○Yes, Limited a Little ○No, Not Limited at all

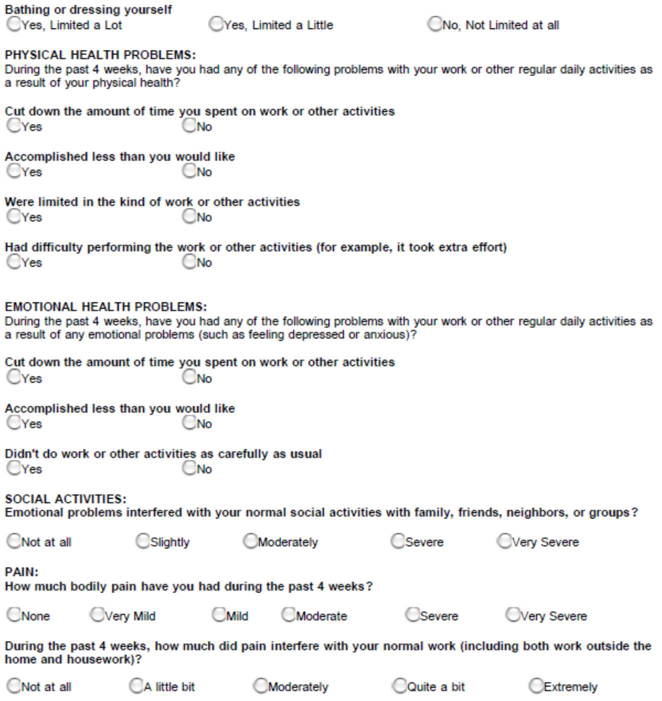
Climbing one flight of stairs
○Yes, Limited a Lot ○Yes, Limited a Little ○No, Not Limited at all

Bending, kneeling, or stooping
○Yes, Limited a Lot ○Yes, Limited a Little ○No, Not Limited at all

Walking more than a mile
○Yes, Limited a Lot ○Yes, Limited a Little ○No, Not Limited at all

Walking several blocks
○Yes, Limited a Lot ○Yes, Limited a Little ○No, Not Limited at all

Walking one block
○Yes, Limited a Lot ○Yes, Limited a Little ○No, Not Limited at all



Bathing or dressing yourself
○Yes, Limited a Lot ○Yes, Limited a Little ○No, Not Limited at all

PHYSICAL HEALTH PROBLEMS:
During the past 4 weeks, have you had any of the following problems with your work or other regular daily activities as a result of your physical health?

Cut down the amount of time you spent on work or other activities
○Yes ○No

Accomplished less than you would like
○Yes ○No

Were limited in the kind of work or other activities
○Yes ○No

Had difficulty performing the work or other activities (for example, it took extra effort)
○Yes ○No

EMOTIONAL HEALTH PROBLEMS:
During the past 4 weeks, have you had any of the following problems with your work or other regular daily activities as a result of any emotional problems (such as feeling depressed or anxious)?

Cut down the amount of time you spent on work or other activities
○Yes ○No

Accomplished less than you would like
○Yes ○No

Didn't do work or other activities as carefully as usual
○Yes ○No

SOCIAL ACTIVITIES:
Emotional problems interfered with your normal social activities with family, friends, neighbors, or groups?

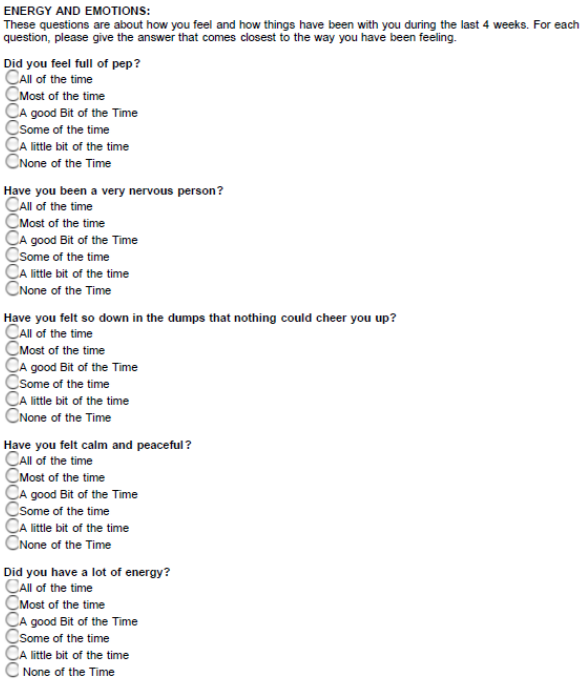
○Not at all ○Slightly ○Moderately ○Severe ○Very Severe

PAIN:
How much bodily pain have you had during the past 4 weeks?

○None ○Very Mild ○Mild ○Moderate ○Severe ○Very Severe

During the past 4 weeks, how much did pain interfere with your normal work (including both work outside the home and housework)?

○Not at all ○A little bit ○Moderately ○Quite a bit ○Extremely



ENERGY AND EMOTIONS:
These questions are about how you feel and how things have been with you during the last 4 weeks. For each question, please give the answer that comes closest to the way you have been feeling.

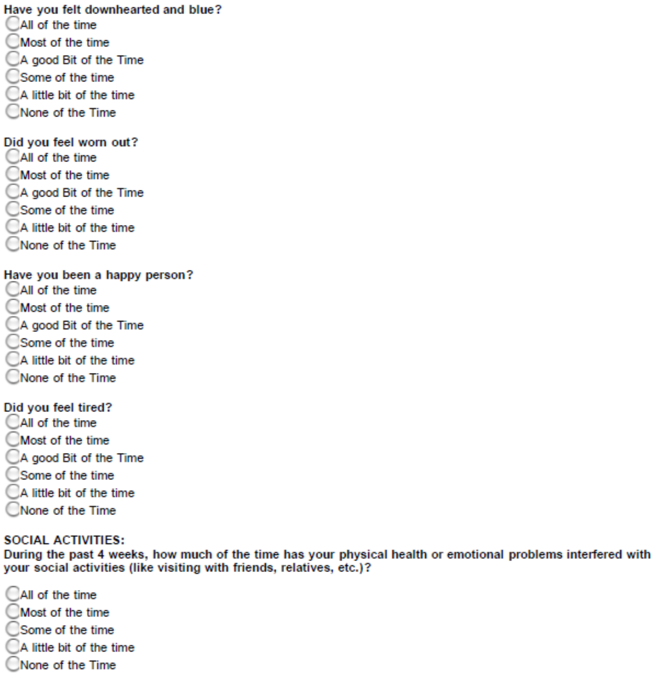
Did you feel full of pep?
○All of the time
○Most of the time
○A good Bit of the Time
○Some of the time
○A little bit of the time
○None of the Time

Have you been a very nervous person?
○All of the time
○Most of the time
○A good Bit of the Time
○Some of the time
○A little bit of the time
○None of the Time

Have you felt so down in the dumps that nothing could cheer you up?
○All of the time
○Most of the time
○A good Bit of the Time
○Some of the time
○A little bit of the time
○None of the Time

Have you felt calm and peaceful?
○All of the time
○Most of the time
○A good Bit of the Time
○Some of the time
○A little bit of the time
○None of the Time

Did you have a lot of energy?
○All of the time
○Most of the time
○A good Bit of the Time
○Some of the time
○A little bit of the time
○None of the Time



Have you felt downhearted and blue?
○All of the time
○Most of the time
○A good Bit of the Time
○Some of the time
○A little bit of the time
○None of the Time

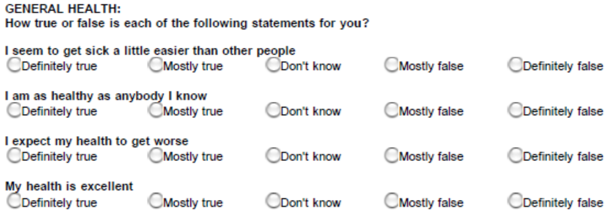
Did you feel worn out?
○All of the time
○Most of the time
○A good Bit of the Time
○Some of the time
○A little bit of the time
○None of the Time

Have you been a happy person?
○All of the time
○Most of the time
○A good Bit of the Time
○Some of the time
○A little bit of the time
○None of the Time

Did you feel tired?
○All of the time
○Most of the time
○A good Bit of the Time
○Some of the time
○A little bit of the time
○None of the Time

SOCIAL ACTIVITIES:
During the past 4 weeks, how much of the time has your physical health or emotional problems interfered with your social activities (like visiting with friends, relatives, etc.)?

○All of the time
○Most of the time
○Some of the time
○A little bit of the time
○None of the Time



GENERAL HEALTH:
How true or false is each of the following statements for you?

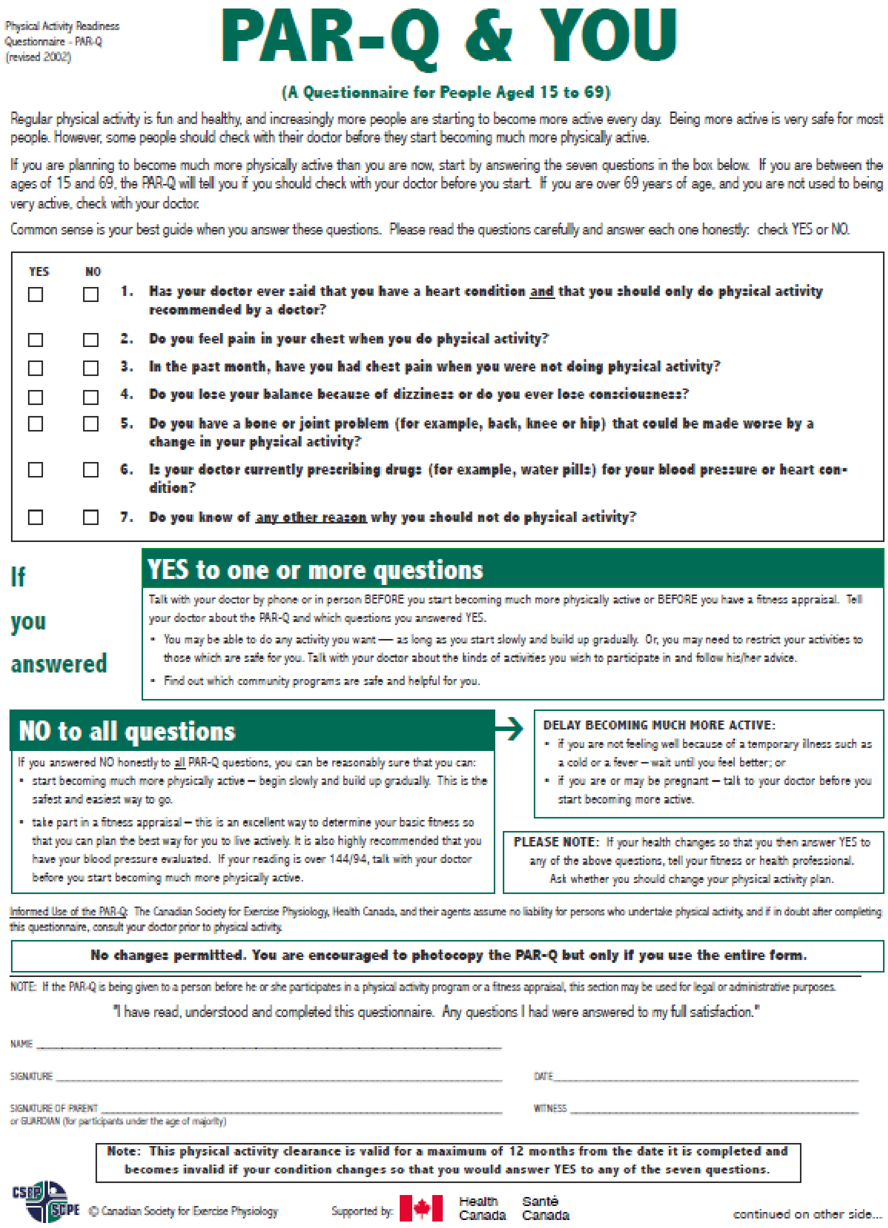
I seem to get sick a little easier than other people
○Definitely true ○Mostly true ○Don't know ○Mostly false ○Definitely false

I am as healthy as anybody I know
○Definitely true ○Mostly true ○Don't know ○Mostly false ○Definitely false

I expect my health to get worse
○Definitely true ○Mostly true ○Don't know ○Mostly false ○Definitely false

My health is excellent
○Definitely true ○Mostly true ○Don't know ○Mostly false ○Definitely false

Appendix D: Physical Activity Readiness Questionnaire



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

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

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

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

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

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

If you answered

YES to one or more questions

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

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

NO to all questions

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

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

→

DELAY BECOMING MUCH MORE ACTIVE:

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

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

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

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

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

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

NAME ______________________________

SIGNATURE ______________________________ DATE ______________________

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

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

Supported by: Health Canada Santé Canada

continued on other side...

Appendix E: Pilot Data Results

Table 4: Balance Reaction time for two, apparently healthy younger adults.

N	Sex/Age/LA Side /Condition	Balance Reaction Time (seconds)											
		to target				to center				total			
		pre	post	followup	Δ score	pre	post	followup	Δ score	pre	post	followup	Δ score
1	F-23-R-N/A	0.7	0.6	0.6	15.1	0.4	0.3	0.2	38.0	1.5	1.4	0.8	10.79
2	F-23-R-N/A	1.1	1.1	0.9	3.0	0.7	0.7	0.8	3.3	2.0	1.9	1.7	5.05

The table includes follow-up data that was collected after 3 months after the initial post-intervention test.

Table 5: Spinal cord excitability data (H-reflex ratios) for two, apparently healthy younger adults.

H/%Mmax															
RSOL				LSOL				RFCR				LFCR			
pre	post	followup	Δ score	pre	post	followup	Δ score	pre	post	followup	Δ score	pre	post	followup	Δ score
1.7	2.4	1.0	45.4	2.7	0.9	1.6	64.8	0.3	0.1	0.2	50.5	0.3	0.1	0.2	59.5
0.7	0.3	0.5	53.2	0.7	0.6	0.7	8.2	0.5	0.6	0.6	6.1	0.3	0.3	0.3	0.0

The table includes follow-up data collected 3 months after the initial post intervention. Additionally, the reflex measures were done in both arms (FCR) and legs (SOL) for these participants, rather than just the dominant leg.

Appendix F: Consent Form

UNIVERSITY OF VICTORIA
THE HUMAN RESEARCH ETHICS BOARD

Participant Consent Form

Modulation of sensorimotor and postural control from martial arts training interventions

You are invited to participate in a study entitled **Modulation of sensorimotor and postural control after martial arts training** that is being conducted by **Dr. E. Paul Zehr**. Dr. Zehr is a Faculty Member in the School of Exercise Science, Physical, & Health Education in the Faculty of Education at the University of Victoria and you may contact him if you have further questions by email, telephone (721-8379), or at his laboratory (RM 191 McKinnon Building).

The purpose of this research project is to understand how nervous system function can be improved after martial arts training. A specific focus is on karate forms (kata) practice, which emphasizes integrated arm and leg movements, whole-body stepping motions and postural transitions. There are two primary objectives of this research. The objective of the basic research conducted in typical uninjured participants is to understand plasticity in motor coordination of integrated arm and leg movements. The main objective of the applied research conducted with people who have experienced disease or injury of the nervous system is to implement the observations from the basic studies to help modify and improve movement control after stroke, spinal cord injury, multiple sclerosis, and Parkinson’s Disease.

Research of this type is important because it will help reveal how movements of the arms and legs are controlled and how to use the neural connection and whole-body movement to enhance balance function in clinical populations. This will provide a principled basis for therapies and rehabilitation when coordination of movement is severely challenged, such as after spinal cord injury, stroke, orthopaedic or impingement injury.

You participating in this study either because you have no history of neurological disorders or because you have suffered a stroke or spinal cord injury or have a diagnosis of multiple sclerosis or Parkinson’s Disease. These present some challenges to your control of movement and activities of daily living.

If you volunteer to participate in this research, there will be three baseline tests, five weeks of training and one post-test after the training. During baseline tests and post-test, activities of your muscles will be measured with electrodes placed on the skin of the arms and legs. Small sensors will be placed across the joints of your arms and legs to record movement. Small electrodes will be placed on the skin over nerves that go to skin areas or innervate muscles. Brief pulses of electrical stimulation will be delivered to these nerves via these electrodes. This stimulation is used to evoke reflexes measured as changes in muscle activity. The sensation of stimulation will be brief (~2/100 of a second) and will feel like strong tingling in the hand or foot. The stimulation should evoke a strong sensation but should not be painful. During a given movement task, we will stimulate a nerve ~150-200 times. You may feel what the stimulation is like and decide if you wish to continue.

During baseline and post-test, balance assessments and social psychological questionnaire will also be performed. Balance assessment will be performed using a modified WBB with body-weight support harness to ensure the safety. Social psychological questionnaires will assess your psychological status in terms of depression, illness, stress etc. You are free to not answer all the questions if you feel uncomfortable. Although the risks for psychological discomfort are highly unlikely, the research group will provide support to participants as needed for external support through organizations like the Victoria Mental Health Centre, Victoria Support Groups (eg. Through the Heart and Stroke foundation or the Parkinson's Wellness project) or other trained mental health care professionals.

It will take about 1-1.5 hour to complete the neurophysiology and balance tests, and 1-1.5 hour to complete the questionnaires. Questionnaires will be filled only once before and after the training. Considered the time each measurement requires, questionnaires can be completed in a separate session.

There are some potential risks to you by participating in this research including two main physical risks. Firstly, you could fall during karate kata training and during the balance assessment during baseline and post-test (this is particularly a concern for participants with stroke or spinal cord injury). Secondly, because electrical equipment is used and connected to you there is a risk of accidental shock. To prevent or to deal with these risks the following steps will be taken. To minimize the risk of falling, spotters will always be beside participants during training and balance tests. Further, an overhead safety harness that eliminates the risk of falling will be used for participants with stroke or spinal cord injury during balance tests. To minimize the risk of accidental shock the equipment is connected such that participants are electrically isolated. That is, there is no direct electrical contact between the wall socket into which the equipment is plugged and the electrodes placed on your body for recording muscle activity or stimulating nerves. Because of this, the risk of accidental shock is very low. In twenty-five years of conducting research projects like this, we have never had such an accident. In addition, providing medical history records is preferred but not required to participate in this study.

The potential benefits of your participation in this research include improving the state of knowledge concerning how the nervous system coordinates our movements before and after injury. It is hoped that some of this research may be used to guide new therapeutic avenues for improving motor coordination of movement after injury to the nervous system.

As a way to compensate you for any inconvenience related to your participation, you will be given a commemorative T-shirt and your travel/parking expenses will be paid. It is important for you to know that it is unethical to provide undue compensation or inducements to research participants and, if you agree to be a participant in this study, this form of compensation to you must not be coercive. If you would not otherwise choose to participate if the compensation was not offered, then you should decline.

Your participation in this research must be completely voluntary. If you do decide to participate, you may withdraw at any time without any consequences or any explanation. If you do withdraw from the study the information we obtain from you will still be included unless you state that you would like your data removed from the study. Further, as we separate your identity from your data during analysis, it may not be possible to fully remove your data from the study.

To ensure the protocol is safe and suitable for your health status, and to better analyze your results, we may contact your physician(s) to request information relevant to your neurological status. A separate consent form will be provided.

In terms of protecting your anonymity, once the data is gathered, your data will become part of the whole data set with no identifiers. However, the principal investigator and those involved in data collection and analysis would still be able to figure out that certain subjects participated in the experiments. At no time during public disclosure of the data (e.g. at conferences, in publications) will individual subjects be identified.

Your confidentiality and the confidentiality of the data will be strictly protected. Research assistants and graduate students involved in data acquisition will have a signed confidentiality agreement with the principal investigator. Data arising from your participation in the research will be kept in a locked office for 5 years after which time it will be destroyed.

It is anticipated that the results of this study will be shared with others in the following ways: presentation at scholarly meetings and conferences, in academic journal publications, and books, blogs and other communication media.

In addition to being able to contact the researcher at the above phone numbers, you may verify the ethical approval of this study, or raise any concerns you might have, by contacting the Human Research Ethics at the University of Victoria (250-472-4545; ethics@uvic.ca).

Your signature below indicates that you understand the above conditions of participation in this study, that you have had the opportunity to have your questions answered by the researchers, and that you consent to participate in this research project. Although the consent form is only signed once, this is an ongoing consent agreement that can be altered throughout the duration of the study.

______________________________	______________________________	____________
Name of Participant	*Signature*	*Date*

A copy of this consent will be left with you, and a copy will be taken by the researcher.

Appendix G: Recruitment Poster

Rehabilitation Neuroscience Lab at UVic is looking for participants in a martial arts training study!

- *We are studying the effect of a mind-body exercise (Karate Kata) on balance and inter-limb coordination in people with and without neurological disorders.*
- *5 weeks of Karate kata training (3 times each week) will be performed at University of Victoria.*
- *Muscle activation, strength, reflex coordination, and psychological outlook will be measured before and after training.*
- *Potential physical risk is minimal, details will be provided when contacted.*

Who can help?

- Adults between ages 19 and 90
- With or without Parkinson's disease, post-stroke, spinal cord injury, or Multiple Sclerosis
- Able to stand independently without assistant
- Not wearing a pace-maker

How much time? The study will last 9 weeks in total, including:

- Pre-test: 3 pre-training lab visits: about 2.5 hours per visit.
- Training: 5 weeks; 3 sessions/week; 1 hour per session.
- Post-test: 1 post-training visits: about 2.5 hours.

Where? Rehabilitation Neuroscience Lab McKinnon Building RM172

Contact: Aimee Harrison, MSc student; Hajer Mustafa, MSc student

Dr. Paul Zehr, Principal Investigator

Phone: 250-472-5487 Email: rnl@uvic.ca