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THE EFFECTS OF TAI CHI TRAINING ON THE
CARDIOVASCULAR HEALTH AND POSTURAL
CONTROL OF OLDER ADULTS—A MIND-
BODY PERSPECTIVE

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DEPARTMENT OF REHABILITATION SCIENCES

THE EFFECTS OF TAI CHI TRAINING ON THE
CARDIOVASCULAR HEALTH AND POSTURAL
CONTROL OF OLDER ADULTS—A MIND-BODY
PERSPECTIVE

BY
LU Xi

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DOCTOR OF PHILOSOPHY

Sept 2012

STATEMENT OF ORIGINALITY

The idea for the present investigation originated from Dr. William Tsang and Professor Christina Hui-Chan and the author. The design of the study, the planning of the experiment and data interpretation resulted from the discussions between the author and Dr. William Tsang.

All experiments in the present investigations were completed solely by the author.

The author declares that the work presented in this thesis is, to the best of the of the author's knowledge and belief, original, except as acknowledged in the thesis, and that the material has not been submitted previously either in whole or in part, for a degree at this university.

LU Xi

September 2012

ABSTRACT

Aging is a worldwide phenomenon which causes health, social and economic problems. Healthy aging has been the focus of many scholarly investigations, particularly with regard to cardiovascular disease and postural control problems causing falls.

Arterial compliance is an index reflecting artery function, and it is closely related to cardiovascular health. Decreased arterial compliance is associated with aging and many kinds of cardiovascular disease. This makes strategies directed at improving arterial compliance important for improving the health of older adults. Aerobic exercise is beneficial for arterial compliance. Improving and maintaining muscle strength through resistance exercises is also known to be beneficial for older adults, but it has been found to decrease arterial compliance. Therefore, exercise protocols which combine muscle strength training with improved arterial compliance are needed.

Falls often occur when older adults attempt dual-tasking such as postural control with concurrent cognitive tasks. Modern falls prevention programmes focus on improving postural control while dual-tasking. Stepping down is a common functional task which is quite demanding in terms of postural control, and negotiating stairs concurrently with a cognitive task is a common setting for falls among older adults. Therefore, exercises which could enhance older adults' handling of dual motor-cognitive task performance would be useful.

Tai Chi requires good mind and body coordination. It trains both cognitive and physical functioning. Previous studies have explored the effects of Tai Chi training on postural control or on cognitive performance, but never the two perspectives combined together. In other words, research on the interaction of Tai Chi's mind and body elements is lacking. Since there is an urgent need to develop an exercise programme which would promote BOTH physical and mental/cognitive health, this study was launched to investigate the mind and body effects of Tai Chi on cardiovascular function, muscle strength, and dual postural-cognitive task performance.

Three different experimental series/designs were adopted to examine five inter-related study objectives. In experimental series 1, a cross-sectional study was conducted to compare older Tai Chi practitioners with healthy older adults. The objectives were to investigate the extent to which older Tai Chi practitioners had 1) better arterial compliance and muscle strength, and 2) better cognitive performance and/or postural control when dual-tasking than healthy controls similar in age, gender, height and weight. In experimental series 2, a randomized control trial (RCT) was conducted to examine whether 16 weeks of short-form Tai Chi training improved 3) the arterial compliance and lower limb muscle strength and 4) the cognitive performance and postural control during dual-task performance in older adults when compared with control subjects who attended music, English and handicrafts classes. This was followed by a pilot single-case study 5) which compared Tai Chi with arm ergometer cycling (exercise with no cognitive component) with respect to modulating the autonomic nervous control and prefrontal activity during exercise.

The investigation involved five studies. Study 1 was a cross-sectional study which compared a group of experienced older Tai Chi practitioners (n=29, mean age of 73.7 years) and a group of older healthy control adults (n=36, mean age of 71.4 years). The arterial compliance (both larger arterial compliance [C1] and small artery compliance [C2]) and concentric and eccentric knee extensors and flexors muscle strength were measured. The second study was a RCT in which 31 older women (aged more than 60 years) were randomly assigned to receive either Tai Chi training or an interest, three sessions per week for 16 weeks. The arterial compliance (both C1 and C2) and knee muscle strength were measured before and after training. Study 3 was a cross-sectional study comparing the dual-tasking performance between older experienced Tai Chi practitioners (n=28, means age of 73.6 years) and healthy older controls (n=30, means age of 72.4 years). The dual-tasking involved a stepping down balance task and an auditory Stroop test. The sway parameters of center of pressure (COP) including total sway path and sway area while the auditory task included reaction time and error ratio. Study 4 was a RCT which investigated the effects of 16 weeks short-form of Tai Chi training on the dual-tasking paradigm. The fifth one was a pilot study investigating the heart rate variability and cranial oxyhaemoglobin level while a Tai Chi master performing Tai Chi and arm ergometer cycling with similar exercise intensity.

Findings from Study 1 showed that experienced older Tai Chi practitioners had significantly better arterial compliance in both C1 and C2 index when compared with controls (14.7±4.4 versus 10.5±2.8, $p<0.001$; 3.5±1.5 versus 2.7±1.2, $p=0.002$, respectively). They also had better muscle strength than those of controls as indexed by

the peak torque-to-body weight ratio; being stronger in concentric knee extensors (1.17 ± 0.42 versus 0.96 ± 0.33 , $p=0.026$), eccentric knee extensors (1.68 ± 0.62 versus 1.31 ± 0.49 , $p=0.01$) and flexors muscle strength (0.89 ± 0.35 versus 0.71 ± 0.31 , $p=0.03$). The results of Study 2 confirmed the training effects of Tai Chi. Older Tai Chi participants showed significant improvements in their arterial compliance (pre-training: 10.3 ± 2.7 , 2.8 ± 1.3 for C1 and C2, respectively while after-training, the value increased to 13.0 ± 3.8 , 3.3 ± 1.1 ; both $p < 0.05$) and lower limb muscle strength (with eccentric knee extensors increased to 21.3%, $p < 0.05$) after training while controls did not.

For the dual-tasking performance, the cross-sectional Study 3 showed that experienced Tai Chi practitioners achieved better performance in a dual motor-cognitive-task test involving stepping down and an auditory Stroop test than healthy older controls. Tai Chi practitioners had faster response time ($1.58s \pm 0.46s$ versus $1.87s \pm 0.48s$, $p=0.023$), made fewer mistake ($13\% \pm 12\%$ versus $26 \pm 15\%$, $p=0.001$) for the auditory Stroop tasks, less COP sway as indicated by the total sway path ($258.3mm \pm 41.8mm$ versus $293.1mm \pm 74.9mm$, $p=0.033$) and sway area ($9.0 \pm 2.5cm$ versus $11.3 \pm 4.9cm$, $p=0.034$). Study 4 was a RCT conducted in the healthy older adults with one group underwent 16 weeks of Tai Chi training while another group served as a control group. After training, older women in the Tai Chi group made fewer errors ($25.8\% \pm 15.5\%$ to $16.3\% \pm 14.5\%$ pre and post, respectively, $p < 0.05$) and incurred less attentional cost (post-training: 0.5 ± 0.4 versus pre-training: 0.6 ± 0.5 , $p < 0.05$). The Tai Chi subjects also improved their postural control in both single- and dual-tasking conditions after training (both COP total sway path and sway area, $p < 0.05$) while the

controls did not. The Study 5 was a pilot study which showed that at similar exercise intensity, an older subject showed more prefrontal oxygenation and higher parasympathetic control during Tai Chi practice than during arm ergometer cycling.

The better arterial compliance and greater muscle strength achieved through Tai Chi practice may be related to its mind-body characteristics. The mental concentration during Tai Chi's physical movements may shift the autonomic nervous system to parasympathetic control. This may prevent arterial stiffness and counterbalance the strength training effects on the arteries. This idea was suggested by the findings of Study 5 which showed that Tai Chi practice involves parasympathetic dominance compared with arm ergometer cycling.

The better postural control after stepping down while dual-tasking may also be explained by the training effects of both the mind and body components of Tai Chi practice. The Tai Chi drills may have improved both attention and postural stability, which might be reflected in dual-tasking performance. The increased prefrontal activity observed during Tai Chi practice might be related to improve mental capacity.

These findings show that Tai Chi could be a suitable exercise for improving the arterial compliance and muscle strength of the older adults. Moreover, it could enhance older adults' dual-tasking performance and may help to prevent falls.

LIST OF RESEARCH OUTPUT DURING THIS CANDIDATURE

Manuscripts

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CHAPTER I
INTRODUCTION

1.1 Aging and aging problems

1.1.1 Aging population

The average age of the world's population is increasing rapidly. According to the World Health Organization, the number of people aged more than 60 years will double between 2000 and 2050 to 22% of all age groups. That means an absolute increase from 605 million to 2 billion (World Health Organization, 2012). The number of people aged more than 80 years will increase four times from 2000 to 2050, reaching 395 million. These fast increases are more profound in developing countries like China. China's population over 60 years old will increase from 129 million to 389 million between 2000 and 2050, from 10.2% to 25.8% of the whole population (Li & Zhang, 1998). People aged more than 65 years old will be 30% of all age group in 2041 when compared with 13% in 2011 (Hong Kong Statistic Bureau, 2012). The sharp growth of the elderly population is predicted to cause physical and socio-economic problems.

1.1.2 Cardiovascular problems in older adults

1.1.2.1 Definition and epidemiology of cardiovascular diseases

An important problems caused by aging is cardiovascular disease—non-communicable diseases of the heart and blood vessels, including heart disease, cerebrovascular disease, peripheral arterial disease, rheumatic heart disease, and deep vein thrombosis and pulmonary embolism (World Health Organization, 2011). Even

today cardiovascular disease is a leading threat to human health and one of the major causes of mortality and morbidity world-wide. Globally, cardiovascular disease is the number one cause of death and is projected to remain so. An estimated, 17.5 million people died from cardiovascular disease in 2005, representing 30 % of all global deaths (De Meersman and Stein, 2007; World Health Organization, 2007). In the USA, an estimated 80.7 million people suffered from cardiovascular diseases in 2005, and cardiovascular disease was involved in 36.3 percent of total deaths in 2004 (American Heart Association, 2008). The situation in developing countries is even worse, as two thirds of deaths arising from cardiovascular disease occur in such countries (Yusuf et al., 2001a,b). In China, cardiovascular disease was involved in 12.1% of deaths in 1957, but this had increased to 35.8% by 1990 (World Health Organization, 1998). The cardiovascular disease in Hong Kong is the second leading cause of death for many years (Hong Kong Statistic Bureau, 2007). If current trends continue, by 2015 an estimated 20 million people will die from cardiovascular diseases annually.

1.1.2.2 Incidence of cardiovascular diseases in older adults

It has been well-established that aging per se is a major risk factor for cardiovascular disease. Numerous studies have shown that the risk of developing cardiovascular disease generally rises with age (Remsberg & Siervogel, 2003). The incidence of initial coronary events increases with age, rising from 26/1000 per year for men aged 65–74 years to 39/1000 for those aged 85–94. The incidence among women rises from 12/1000 to 24/1000 for the corresponding ages (Kannel, 2002). At the same

time, the entire cardiovascular system deteriorates as one grows older (Priebe, 2000), as displayed particularly by hypertrophy of the left ventricle (Gerstenblith et al., 1977) and a decreased efficacy of β -adrenergic modulation of both the heart and vasculature (Lakatta, 1993).

1.1.3 Balance problems in older adults

Balance control is complex process which involves sensory inputs, integration of sensory information in central nervous system and motor output using postural muscles. The central nervous system integrates signals from the somatosensory, visual and vestibular systems and evokes action from the postural muscles via descending pathways (Shumway-Cook & Woolocott, 2001; Tsang and Hui-Chan, 2008). It is known that aging is related to deterioration of the sensory-motor system and that this contributes to decreased balance control in older adults. These changes, together with important environmental factors, are causing increased fall risk for the older population (Carter et al., 2001; Rubenstein, 2006). Indeed, falls have been identified as one of the major causes of morbidity and mortality in older adults (Tinetti, 2003).

1.2 Cardiovascular health

1.2.1 Arterial compliance

1.2.1.1 Artery function

The normal artery system is composed of the large elastic arterial conduits and the small arterioles and capillaries which provide the resistance. An artery wall has three concentric layers—the tunica intima, tunica media and tunica adventitia from the inner to the outer. The tunica intima is covered by an endothelial cell and is in direct contact with the flowing blood. The medial layer is elastic tissue and smooth muscle, while the adventitia is made up by connective tissue. The arterial system has two major functions in circulation—a capacitance function and a conduit function (Lim & Townsend, 2009).

1.2.1.2 Definition of arterial compliance and arterial stiffness

Spencer & Denison (1963) have defined arterial compliance as the change in the arterial blood volume due to a given change in arterial blood pressure. In another words, arterial compliance refers to an artery's ability to expand and contract with cardiac pulsations and relaxation (Arnett et al., 1994). It reflects the ratio of change in volume to change in pressure (Cohn et al., 1995), which could be indexed as the artery's elasticity. With good arterial compliance the artery should yield to different pressures without disruption, while an artery with poor compliance would not sustain the change in pressure properly. If an artery fails to distend or rebound in response to pressure changes, this is usually considered as arterial stiffness (Arnett et al., 1994).

1.2.1.3 Measurements of arterial compliance

Invasive and non-invasive measurements of arterial compliance are well-developed (Jani & Rajkumar, 2006). The present thesis focused on pulse wave velocity

(PWV), an augmentation index (AI), systemic arterial compliance (SAC), and Pressure Pulse Contour Analysis, all non-invasive measurements.

- a) The pulse wave velocity technique measures the velocity of a pressure pulse traveling a certain distance between two points on the vasculature pathway. Values can be obtained from any arterial segment accessible to palpation (Zoungas & Asmar, 2007). Mathematically, $PWV = \text{Distance (D)} / \text{Time delay } (\Delta T)$.
- b) An augmentation index is estimation of the effects of reflection of a pressure wave on the amplitude of the pulse pressure. The calculation is $(P_2 - P_1) / pp$, where P_1 is the inflection pressure, P_2 is the peak systolic pressure and pp represents the pulse pressure (Jani & Rajkumar, 2006; Lim & Townsend, 2009).
- c) Systemic arterial compliance is a surrogate measure of central arterial compliance (CAC) using a Doppler flow velocimeter placed over the suprasternal notch to detect the arterial blood flow and using applanation tonometry over the right common carotid artery to estimate the aortic driving pressure (Zoungas & Asmar, 2007).
- d) Pressure Pulse Contour Analysis method is based on use of the modified Windkessel model which represents the vasculature as contains a capacitive compliance element (larger artery elasticity index), and a reflective or oscillatory compliance element (small artery elasticity index), an inductance and a resistance (systemic vascular resistance), during the diastolic decay portion of the cardiac cycle. (Figure 1.1) (Cohn et al., 1995; Hypertension Diagnostics Inc., 2005).

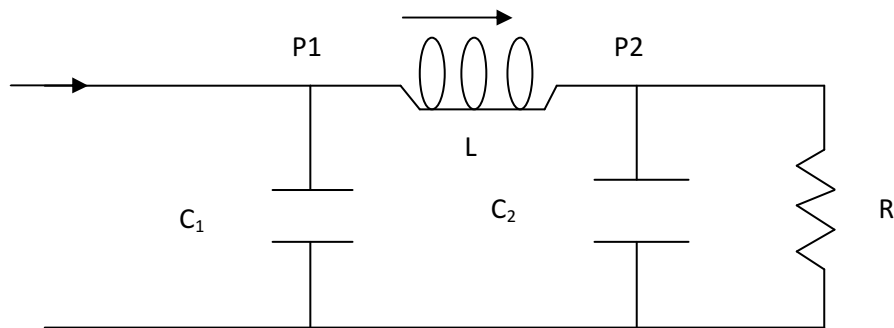


Figure 1.1: An analog model of analyzing vascular properties: P1, proximal pressure; P2, distal pressure; L, inductance; R, resistance; C₁, large arterial compliance; and C₂, small arterial compliance. (Modified from Cohn et al., 1995)

The shape of this decay in this model could be represented as the solution to a third order differential equation of the Windkessel circuit models with 6 unknown “A” parameters (Hypertension Diagnostics Inc., 2005). The equation is:

$$\mathbf{P(t) = A_1 \exp(-A_2t) + A_3 \exp(-A_4t) \cos(A_5t + A_6)}$$

The “A” parameters were determined by a curve fitting approach and a proprietary selection procedure for determining the appropriate set of ‘A’ parameter values. Mathematical relationships existed which related the model values of C₁ and C₂, to the “A” parameters and R. R was calculated independently as the mean arterial pressure (mmHg) divided by the estimated cardiac output (liters per minute) as followed equation (Hypertension Diagnostics Inc., 2005).

$$R = \text{MAP}/\text{CO}$$

$$C_1 = \frac{2A_4 [(A_2 + A_4)^2 + A_5^2]}{RA_2 (2A_4 + A_2) (A_4^2 + A_5^2)}$$

$$C_2 = \frac{1}{R (2A_4 + A_2)}$$

1.2.1.4 Arterial compliance and risks factors for cardiovascular diseases

The World Health Organization (2011) has classified the risk factors for cardiovascular diseases into the behavioral risk factors, metabolic risk factors and underlying determinants. The behavioral factors are the most important risk factors for developing cardiovascular diseases, which account for 80% of coronary heart disease and cerebrovascular diseases combined. The factors include unhealthy diet, physical inactivity, smoking and excessive consumption of alcohol. The behavioral risk factors lead to increased body weight, elevated blood pressure, and higher blood sugar which are termed the metabolic or “intermediate” risk factors for cardiovascular diseases. The underlying determinants refer to socio-economic changes like population aging, urbanization, and stress (Kivimäki et al. 2002; Bunker et al., 2003; World Health Organization, 2011).

Smoking is now widely accepted as having detrimental effects on human health, including cardiovascular health. Ockene and Miller (1997) have estimated smoking dose relationship with coronary heart disease, and that it doubles the risk of ischemic stroke

and increases the risk for peripheral vascular disease and many other diseases. On the other hand, smoking cessation benefits cardiovascular health. Studies have found that long-term middle-aged smokers have significantly poorer small artery compliance (as measured by pressure pulse contour methods) than non-smokers (McVeigh et al., 1996). Oren and colleagues investigated 60 middle-aged (around 40 years old) habitual smokers and found that after 6 months of smoking cessation treatments, 23 of the subjects had stopped smoking and their small artery compliance had improved significantly (from about 5.1 to 6.3). Their average augmentation index had also decreased significantly (Oren et al., 2006). Similar results were found in more recent studies of an Asian populations (Takami & Saito, 2011; Yu-Jie et al., 2012). The proposed mechanisms involved in smoking's effects on arterial stiffness have been summarized by Doonan and colleagues. They showed that smoking causes changes in lipid metabolism which lead to structural changes in arterial walls, including tunica intima and tunica media thickening and atherogenesis; Smoking-related changes in oxidative stress alter vascular tone and increase arterial stiffness; Inflammation caused by smoking results in vascular calcification and the release of matrix metal proteinases, causing vascular remodeling; And finally, they also found endothelial dysfunction measured by flow-mediated dilation in smokers, and this was associated with arterial stiffness as measured by the PWV and AI (Doonan et al., 2010).

Excessive body weight is related to poor arterial compliance or arterial stiffness. Studies of both young and older adults have verified this. A group led by Wildman has shown that in both young and older populations, obesity as indicated by body mass

index (BMI) is highly correlated with PWV results, and this correlation is independent of age, race, sex or blood pressure in both groups (Wildman et al., 2003). This finding in older adults is in line with that published by Sutton-Tyrrell after studying a group of older adults (mean age of 74 years). Their PWV readings were positively associated with body weight, abdominal circumference, abdominal subcutaneous fat, abdominal visceral fat, thigh fat and total fat (Sutton-Tyrrell et al., 2001). All of these relationships were statistically highly significant, but abdominal visceral fat showed the strongest association with PWV values. Using other measurements of arterial compliance, Acree and colleagues (2007) found that in older adults (mean age 62 years) both large and small artery compliance (C_1 and C_2) were lower in overweight and obese adults, even when adjusting for body surface area, sex, hyperlipidemia and hypertension. Although the pathology of obesity and decreased arterial compliance is not yet fully understood, the potential observed relationships could be due to low-grade inflammation caused by increased weight which could result in the stiffening of the artery wall (Weyer et al., 2002). Secondly, obesity-related leptin release has been shown to stimulate smooth muscle proliferation and angiogenesis and to increase sympathetic nervous activity, which together may cause decreased arterial compliance (Oda et al, 2001; Sierra-Honigmann et al, 1998; Safar et al., 2006). Thirdly, obesity-induced insulin resistance could result in the stiffening of arterial walls (Wildman et al., 2003).

Hypertension is a strong risk factor for vascular disease and is responsible for various cardiovascular events like cerebrovascular accidents and ischemic heart disease. Hypertension and arterial compliance is strongly related. Hypertension could cause

arterial stiffness through structural and functional changes, as arterial stiffness is certainly worsened by hypertension. A group led by Prisant has studied middle-aged adults (mean age 49 years) including subjects with normal blood pressure and no family history of hypertension, normotensive subjects with a family history of hypertension, treated hypertensive subjects with good blood pressure control, untreated hypertensive subjects without proper control of blood pressure. They found blood pressure to be linearly associated with both large arterial and small artery compliance (both C_1 and C_2) after controlling for age and body surface area. They concluded that as hypertension worsens, large and small artery elasticity both decreases (Prisant et al., 2001). The predictive value of arterial compliance in relation to hypertension has also been investigated. Studies have found that in subjects with hypertension, arterial compliance measured by the aortic PWV method is a good independent predictor of all-cause and cardiovascular mortality (Laurent et al., 2001). The same group of researchers also found that aortic PWV is an independent predictor of fatal stroke in subjects with essential hypertension (Laurent et al., 2003). But does arterial compliance have predictive power for subjects without hypertension? Investigations led by Liao studied a cohort of 6992 normotensive adults aged between 45 to 64 years for 6 years. They found that an arterial elasticity decrease of one standard deviation was associated with a 15% increase in the risk of developing hypertension, independent of other risk factors and the baseline blood pressure (Liao et al., 1999). Similar results have also been found with those aged between 35 and 92 years—aortic stiffness was a predictor of future hypertension after correcting for other risk factors like age, sex, SBP, BMI, HR, and

smoking (Dernellis & Panaretou, 2002). No matter whether hypertension causes arterial stiffness or arterial stiffness causes hypertension, the two factors were mechanically bi-directional (Franklin, 2005) since stiff arteries causes the premature return of reflected waves in the late systole, which will increase the central aortic pressure resulting in the elevation of afterload. All these alterations end with elevated blood pressure (Tomiyama & Yamashina, 2012). The elevated blood pressure concurrently stimulates the arterial wall, resulting in decreased arterial compliance.

Diabetes mellitus (DM) and impaired glucose tolerance are also associated with significant cardiovascular mortality (de Veegt et al., 1999). Megnien and colleagues found that the brachial artery compliance of DM patients as measured by PWV was lower compared to control subjects without DM. Similar results were found when CAC was the parameter assessed (Megnien et al., 1992). Cameron and colleagues (2003) found the CAC and all measures of PWV were poorer in DM patients when compared with controls despite of the patients being younger. Arterial stiffness is also associated with type II DM and impaired glucose metabolism. The stiffness of the carotid artery, but not peripheral arteries, increases from the impaired glucose metabolism in type II-DM (Henry et al., 2003). Furthermore, the aortic PWV could be an independent predictor of mortality in both DM and glucose intolerant populations (Cruickshank et al., 2002). The underlying mechanisms may involve DM-related changes in the connective tissue of the artery walls, such as increased collagen cross-linking or damaged endothelial function. Both functional and structural changes could lead to artery stiffness (Cameron & Cruickshank, 2007).

Although studies directly investigating the relationship between stress and arterial compliance are not well advanced, there have been studies concerning mental stress, sympathetic activity and arterial elasticity. Tsai and colleagues found that during stressful mental activity, normotensive subjects and subjects with mild hypertension both had significantly decreased arterial compliance (Tsai et al., 2003). Not only acute mental stress but also the chronic stress can impair arterial elasticity. Vital exhaustion (VE) is a psychological state of chronic stress characterized by heightened irritability, unusual tiredness, a loss of physical and mental energy, and a demoralized feeling (Appels & Mulder, 1989). Chumaeva's group used a VE assessment scale to reflect chronic stress status and found that young adults with high VE scores were at risk of atherosclerosis and impaired endothelial function (Chumaeva et al., 2009, 2010). Mechanisms have been proposed by Everson-Rose and Lewis (2005). They involve increased sympathetic nervous activity activating the hypothalamic pituitary-adrenal (HPA) axis, serotonergic dysfunction, and secretion of the pro-inflammatory cytokines. All these would act on artery structure and function to decrease arterial compliance and increase arterial stiffness.

Aging effects on arterial compliance have been extensively reviewed since the 19th century. Pioneers in research on artery function and aging created the aphorism "a man is only as old as his arteries" by William Osler in 1898. Aging effects on vascular structure and function have been intensively investigated by researchers and physicians, as arterial stiffness has long been seen as a hallmark of normal aging. Animal studies with beagles have shown that despite any other risk factors, aging per se is related to

decreases in systemic arterial compliance in older dogs (Haidet et al., 1996). Human studies have also found advancing aging to be associated with decreased arterial compliance or increased arterial stiffness (Arnett et al., 1994; Tanaka et al., 1998). A large scale prediction study found that age was the strongest independent predictor of significant arterial stiffness (Song et al., 2010). The structural changes in arterial walls during the aging process suggest that changes in the expression, architecture and/or bioactivity of proteins in the walls of large elastic arteries are involved (Seals et al., 2009). These alterations include hypertrophy of the vascular smooth muscle (McEniery et al., 2006), replacement of viable cells with connective tissue, and increased cross-linking of connective tissue (Joyner, 2000). There is also increased collagen deposition and its cross-linking, fraying and fragmentation of elastin (Lakatta & Levy, 2003), and the total number of elastin diminishes with age (Zieman et al., 2005). In addition to the structural changes, functional changes in the arterial system also contribute to increased arterial stiffness. Firstly, the endothelium changes with aging through the increased production of endothelin—a potent vasoconstrictor and pro-coagulant (Donato et al., 2009)—and decreased synthesis of nitric oxide, an important vasodilator (Taddei et al., 2001). Secondly, besides the hypertrophy of the vascular smooth muscle, increased vascular smooth muscle tone with aging also contributes to increasing arterial stiffness (Gates&Seals, 2006; Seals et al., 2009). Thirdly, the oxidative stress that acts on smooth muscle tone also could be a reason for increased arterial stiffness (Zhou et al., 2012).

1.2.1.5 Arterial compliance and cardiovascular diseases

A group led by Sutton-Tyrrell conducted a 239 week longitudinal investigation and found that baseline aortic PWV is significantly related to the incidence cardiovascular mortality, coronary heart disease, and stroke in generally healthy, community-dwelling old adults (Sutton-Tyrrell et al. 2001). The Rotterdam Study further supported this finding that in apparently healthy subjects, aortic PWV is an independent predictor of coronary heart disease and stroke (Mattace-Raso et al., 2006). A recent report from the Framingham Heart Study demonstrates that higher aortic stiffness as measured by the PWV was associated with increased risk for a first cardiovascular event (Mitchell et al., 2010). Pressure pulse contour analysis also shows that decreased small artery compliance (C_2) is significantly associated with cardiovascular events independent of age in the general population (Grey et al., 2003). In a more elderly population (average age more than 70 years), the aortic PWV is a strong independent predictor of cardiovascular death (Meaume et al., 2001). Furthermore, when assessed in patients, arterial stiffness may be a predictor of more severe conditions for a clinician. Herrington and his colleagues (2003) investigated patients referred for cardiac catheterization and found that lower arterial compliance was associated with the presence of significant coronary stenoses (Herrington et al., 2003). This finding could give clinicians more information for subsequent prevention and treatment measures. In patients undergoing coronary angiography, arterial compliance measurements could be used as a diagnostic marker for atherosclerotic processes (Syeda et al., 2003). Even in end-stage renal disease patients, increased aortic artery stiffness

has been found to be a strong independent predictor of all-cause and mainly cardiovascular mortality (Blacher et al., 1999).

1.2.1.6 Exercise effects on cardiovascular diseases

With the prevalence of cardiovascular diseases, effective ways to prevent and treat them need further investigation. Regular exercise and life style modification are the essential ways to minimize the risk factors so as to prevent the occurrence of the cardiovascular diseases.

Once an incident has occurred, Western rehabilitation methods are usually based on regular aerobic exercise utilizing a treadmill or stationary bicycle with an intensity of 50% to 70% of the predicted maximum heart rate. Such cardiac rehabilitation exercise programs have been shown to be effective in decreasing cardiac risk factors such as blood pressure and blood lipids, and in controlling body weight (Khot et al., 2003; Wenger et al., 1995). Such exercise protocols are beginning to be accepted by Chinese populations, but the cost and the equipment required still limit their popularity.

Several large-scale epidemiological studies have reported that elderly persons who participate in regular physical activity have better cardiovascular outcomes than their age-matched sedentary counterparts (Powell et al. 1987; Rosengren & Wilhelmsen, 1997). Exercise training further shows its effectiveness in improving functional capacity, body fat percentage, body mass index and serum lipids in some patients with cardiovascular problems (Lavie & Milani, 2001; Hung et al., 2004). The exercise discussed here includes physical activity as well as exercise as normally defined

exercise. Physical activity is any bodily movement produced by skeletal muscles that results in increased energy expenditure (Caspersen et al., 1985), while exercise normally means planned, structured and repetitive bodily movements performed to improve or maintain physical fitness (Francis, 1996).

1.2.1.7 Exercise effects on arterial compliance

Studies found that red clover isoflavones (Nestle et al., 1999), fish oil supplement (Mcveigh et al., 1994) and aerobic exercises favorably influenced arterial compliance. Physical exercise is always the recommendation for fitness, but it can be particularly important for arterial compliance. There are aerobic exercise effects and distinct resistance exercise effects.

1.2.1.7.1 Effects of aerobic exercises on arterial compliance

Vaitkevicius and colleagues studied healthy adults aged from 21 to 96 and found that decreases in arterial compliance with age could be mitigated by better physical conditioning as indexed a person's maximal oxygen consumption (VO_{2max}) (Vaitkevicius et al., 1993). In subsequent interventional studies researchers have verified this finding. With 3 months aerobic training (primarily walking), 20 middle aged sedentary men (mean age of 53 years) increased their central arterial compliance significantly (Tanaka et al., 2000). Similar results were found with post-menopausal women (average age 58) (Moreau et al., 2003). A recent study of sedentary older adults aged over 65 found that one year of progressive and vigorous aerobic exercise training they too improved their total arterial compliance (Fujimoto et al., 2010). Studies of

adults with hypertension have shown similar improvements. Only 12 weeks of upper-limb aerobic exercise training has been shown to improve small artery compliance in the elderly (Westhoff et al., 2008).

1.2.1.7.2 Effects of strength (or resistance) exercises on arterial compliance

Resistance training is important for bone health and muscle strength, but with older adults it is especially important for balance. However, studies have found that strength training may have some unfavorable effects on arterial compliance since strength training typically improve skeletal muscle toning and hypertrophy which may at the same time cross-over to strengthening the arterial wall that caused the reduction of arterial compliance. Studies done by Bertovic's group found that young adults who underwent strength training for a minimum of 12 months developed lower arterial compliance than matched sedentary controls (Bertovic et al., 1999). Subsequent studies of men by Miyachi's team found that 1) the resistance training habit was connected with smaller central arterial compliance; 2) age-related decreases in arterial compliance were greater in their resistance training group than in normal sedentary adults; 3) after 4 months of resistance training, healthy younger subjects had decreased central artery compliance (Miyachi et al., 2003, 2004). However, not all studies of strength training have resulted in negative findings. Among older men engaged in a unilateral resistance training program for 10 weeks, no decreases in central or peripheral arterial compliance were observed (Poelkens et al., 2007). In middle-aged and older adults, 13 weeks of moderate strength training did not reduce central artery compliance (Cortez-Cooper et

al., 2008). Similar results were found with pre-menopausal women after 12 weeks of strength training (Fjeldstad et al., 2009). The authors have attributed the different results of strength training to the different durations of the strength training programmes studied (Poelkens et al., 2007), the various intensities compared with Miyachi's strenuous activity (Cortez-Cooper et al., 2008) and a lack of upper limb training (Fjeldstad et al., 2009).

1.2.1.7.3 Combining strength and aerobic training effects on arterial compliance

Although pure strength training's effects on arterial compliance remain elusive, clinicians are trying to find an exercise mode which can balance resistance training's benefits against its arterial stiffening effects. Kawana and his colleagues added aerobic training to resistance training with young healthy men and found that combining the two modes of exercises led to no decrease in arterial compliance (Kawana et al., 2006). In this connection, investigators have shown that rowing, an exercise mode combining aerobic and strength training, did not decrease the arterial compliance of middle aged and older adults after 5 years of practice when compared with healthy controls (Cook et al., 2006).

1.2.2 Autonomic control of the cardiovascular system

The autonomic nervous system plays an important role in cardiovascular diseases. De Meersman (2007) has summarized how cardiovascular disease is associated

with a common denominator—“the perturbed autonomic balance”— in which there is either an increase in sympathetic modulation, a decrease in parasympathetic modulation or a combination of both. Borchard (2001) believes that sustained sympathetic nervous system activation induces functional and structural changes in various organs leading to cardiovascular disease. The activation of the sympathetic nervous system also seems to be of prime importance in mechanisms attributed with increasing cardiac risk (Esler & Kaye, 2000). Buch has summarized that the association between cardiac vagal activity and mortality and concluded that lack of cardiac vagal activity may directly and adversely influence the natural history of cardiac disease (Buch et al., 2002). To summarize, it seems that over-activity of the sympathetic and reduced activity of the parasympathetic system have potential negative effects on cardiovascular health.

1.2.2.1 Aging effects on autonomic function

Previous studies have shown that there is a reduction in the parasympathetic control of heart rate with age (De Meersman, 1993; Seals et al., 1994; Sinnreich et al., 1998), a increase in the sympathetic activation of cardiac response (Lipsitz,et al., 1990; Schuit et al., 1999) and a decrease in the range of parasympathetic and sympathetic nervous system responses to physiological stress (Carter et al., 2003). The decline in the autonomic nervous system is associated with increased mortality among older adults (Lauer et al., 1999; Dekker et al, 2000). Although this has been thoroughly studied, the exact mechanism of the relationship between autonomic control and mortality and the prognosis for cardiovascular disease is still not clear. There are some possible effects of

vagal influence of cardiac work. For example, stimulation of the vagal nerve can have a significant negative inotropic effect in humans (Lavie et al. 2001). Vagal activity can reduce the heart's vulnerability to potentially lethal ventricular arrhythmia (Buch et al., 2002). In normal aging the autonomic control of the cardiovascular system favours heightened cardiac sympathetic tone with parasympathetic withdrawal, have further magnify the effects of concomitant cardiovascular disease (Kaye & Esler, 2008). Preserving cardiac autonomic balance can therefore prevent cardiovascular disease and reduce the risks of it in older adults.

1.2.2.2 Exercises effects autonomic control of cardiovascular system

The effects of exercise on autonomic control of the cardiovascular system have been extensively studied. Many studies have indicated that long-term endurance training increases parasympathetic activity and decreases sympathetic activity in humans at rest (Smith et al., 1989; Shi et al., 1995; Goldsmith et al. 2000; Yamamoto et al., 2001).

1.2.2.3 Mindful skills effects on autonomic control of cardiovascular system

Such concentration and mindful meditation itself has significant neurophysiological benefits. Brain mapping using functional magnetic resonance maging (fMRI) has indicated that meditation activates neural structures involved in attention and control of the autonomic nervous system (Lazar et al., 2000). Early in 1977, Benson found that meditation tends to evoke relaxation, which has salutary effects in treating hypertension. In a prospective randomized control study, Curiati and his colleagues treated 19 patients with congestive heart failure using 12 weeks of meditation

therapy. The meditation group subjects showed reduced sympathetic activation with a decrease in blood norepinephrine levels and improved quality of life (Curiati et al., 2005). On the other hand, researchers have found that relaxation can evoke enhanced parasympathetic tone as shown by the fact that the high frequency components of heart rate variability increase only during relaxation instead of with other controlled resting (Sakakibara et al., 1994). Besides, researchers compared meditation, progressive muscular relaxation and listening to an audiotape of a popular novel in counterbalanced order and found that during meditation subjects showed greater increases in respiratory sinus arrhythmia (RSA)—an indicator of parasympathetic tone—than with other relaxation methods (Ditto et al. 2006). Unexpectedly, they found that meditation could override a powerful adrenergic stimulus provided by the pharmacological infusion. During a standard isoproterenol challenge test, a subject's heart rate decreased after meditation started while in the same test environment when the subject was instructed not to meditate the performance showed the normal response of increased heart rate (Dimsdale & Mills, 2002).

1.3. Balance control and falls

1.3.1 Falls in older adults

Falls are the second leading causes of accidental injury and death worldwide (World Health Organization, 2010). The World Health Organization estimates the annual mortality caused by falls to be about 42,400 globally, and more than 80% of this

occurs in low- and middle-income countries. In addition, 37.3 million falls are at the level of requiring medical attention.

Adults older than 65 suffer the greatest number of fatal falls among all age groups (World Health Organization, 2010). Falls have been recognized as one of the major causes of morbidity and mortality in older adults (Tinetti, 2003). The financial costs resulting from falls are therefore enormous. Evidence from Western countries has shown the heavy cost of fall injuries (World Health Organization, 2010). So prevention of falls among older adults is always a concern for clinicians.

1.3.2 Sensory and motor integration for balance control in older adults

Apart from the external environmental reasons for falls, the internal factors that contribute to falls by older adults are within the scope of clinicians and researchers. Among all the internal factors, impaired or degraded postural control is the major cause of falls among the elderly (Carter et al., 2001; Shumway-Cook and Woollacott, 2000). Postural control or balance control is a complex process involving multiple sensori-motor systems and their integration, and even involving cognition (Tinetti et al., 1988; Anstey et al., 2006). Deficits or improper control in any of these systems increases the risk of falling. The systems involved include the sensory input system, the motor output system and the central integrating system (Shumway and Woollacott, 2001). Tsang and Hui-Chan (2008) have created a diagram to illustrate the three main systems in postural control (see Figure 2).

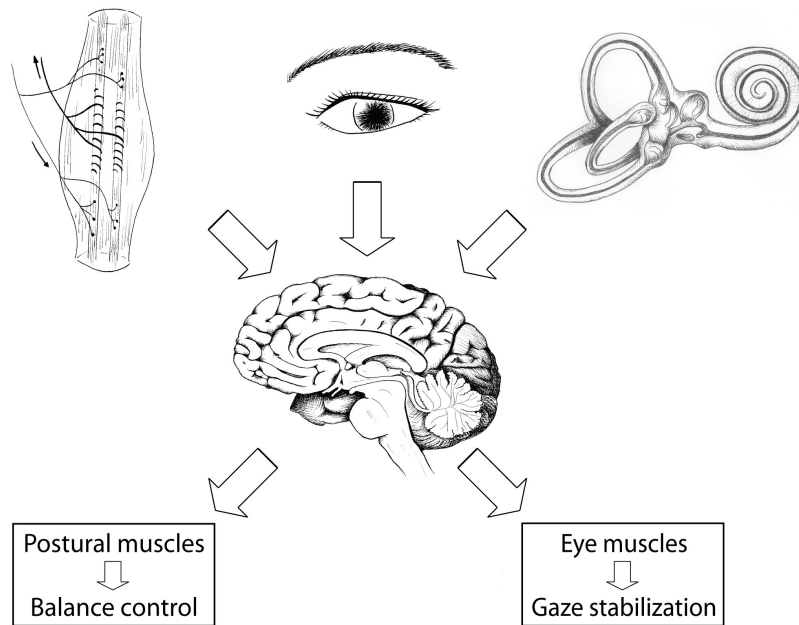


Figure 1.2. Sensory-motor organization of postural control (From Tsang and Hui-Chan, 2008)

The aging process causes the deterioration of the three postural control systems which affect static and dynamic balance and even the walking ability of older adults.

1) The sensory input system

The sensory input system includes the somatosensory, vestibular and visual systems (Figure 1.2). Attenuation of the three sensory input systems due to aging has been demonstrated in previous studies. Decreased visual acuity, reduced visual contrast and glare sensitivity, poor depth perception and slow dark adaptation in the visual system are all known to be related to the increased

prevalence of falls in older populations (Harwood, 2001; Sturnieks et al., 2008). Structural decreases in the counts of hair cell in the inner ear also lead to poorer balance (Herdman et al., 2000; Rauch et al., 2001). Faded limb proprioception is also related to aging, as are joint and ligament pathologies and central nervous system disorders like stroke. Tsang and Hui-Chan (2005) employed a passive knee joint repositioning test to show that even healthy older adults have significantly larger repositioning errors than younger subjects. This impaired proprioception is another independent risk factor for falls (Lord et al., 1992). Therefore, degeneration of these three sensory systems with age leads to decreased sensory input for balance control in older adults.

2) The motor output system

Decreased muscle fiber counts, especially of type II muscle fibers, reduced muscle size and decay of the relevant neuromuscular functions all progress with age (Vandervoort, 2002). Structural changes in the motor system certainly cause functional alteration of muscle strength, reaction time and the speed of body movements. Age related decrements of concentric and eccentric muscle strength are well documented (Hurley, 1995; Porter et al., 1995; Vandervoort, 2002). The reduced muscle contraction time of older adults compared with that of young adults also contributes to increased fall risk (Schultz et al., 1997). Lord and his colleagues (1994) further found that increased reaction time contributed to an increased risk of falls among community-dwelling older adults. In summary,

structural and functional changes in the motor output system are another factor causing falls in older adults.

3) The central integration system

The ability of the central integration system is usually assessed in a conflicting or blunted sensory input environment. Hay and his colleagues (1996) found that older subjects have difficulty in using proprioception sense recovered after tendon vibration (a method for disturbing proprioception input) though younger adults could handle it well. The sensory organization test (SOT) assesses skill in selecting and integrating appropriate sensory information at the level of the central nervous system (Nashner, 1994). Deficits in selecting and integrating proper sensory information to produce appropriate postural responses increase the risk of falling. Older fallers have been shown to sway more than non-fallers under conflicting sensory input condition using the SOT (Wallmann, 2001).

1.3.3 Stair negotiation in the older adults

Good postural and balance control in functional movements is crucial in negotiating stairs, escalators and curbs. Falls during stair negotiation account for more than 10% of older adults' fatal falls (Startzell et al., 2000). Stair walking, especially descending, is difficult for many older adults and descending accounts for most stair falls (Startzell et al., 2000). But negotiating stairs is important for most older adults in

their daily life. Despite this, the studies concerning the postural performance of the elderly during stepping down have been few.

1.3.4 Dual-task performance among the elderly

Fall prevention should be approached not only from a physical but also from a cognitive perspective (Anstey et al., 2006; Teasdale et al., 1993; Tinetti et al., 1988; van Schoor et al., 2002). Academics have therefore developed dual-task protocols for assessing postural control performance. They use a concurrent cognitive task as a secondary domain when investigating physical performance (Shumway-Cook et al., 1997; Teasdale and Simoneau, 2001). Such dual-task designs can be used to compare the postural control of younger and older adults using different postural requirements and various kinds of cognitive tasks.

Upright standing is relatively a simple postural task. Nevertheless, when a simultaneous cognitive task is added to the task of maintaining an upright posture, older adults show decreased postural stability (Teasdale et al., 1993; Maylor and Wing, 1996; Marsh and Geel, 2000; Melzer et al., 2001; Jamet et al., 2007; Swanenburg et al., 2009). The decrease occurs whether the cognitive task is as simple as responding to a visual or auditory stimulus or a demanding task like mathematical calculation or responding to Stroop tasks. The decreased postural stability in these kinds of studies is reflected in center of gravity (COG) measurements.

In a more demanding postural task like standing under reduced or conflicting sensory conditions, older subjects demonstrate even poorer postural performance. In this connection, Shamway-Cook and Woollacott (2000) found that even healthy older adults showed decreased postural stability when the visual and somatosensory cues were either removed or conflicted and with an additional auditory reaction task; the situation worsened when older adults with balance impairment were tested. However, young adults show little difference in postural sway when an auditory task is added (Shamway-Cook and Woollacott, 2000). A group led by Redfern generated similar findings by adopting either a visual or auditory task as the secondary task (Redfern et al., 2001), and again younger adults were not affected.

On the other hand, Swan's group found that standing on a foam surface with the eyes closed was the most difficult balance task they tested, but in that situation older adults showed decreased postural sway with either a concurrent spatial or non-spatial task. They proposed that the stiffening of the stance may have been due to decreased over-responding because the secondary task diverted attention from the remaining sensory (Swan et al., 2004). Melzer's group also found when standing on a narrow base of support and performing a modified Stroop task, older adults showed decrease in postural sway. They explain that the older adults activated a co-contraction strategy of postural control around the ankle joints due to the perceived danger to their postural stability (Melzer et al., 2001). By using such dual-task protocols researchers have found that maintaining postural stability is attentional demanding for older adults even in upright standing.

Maintaining stability under perturbation is of course even more challenging. A group led by Brown applied perturbation during stance with maintaining balance as the primary task and counting backwards or subtraction as the secondary cognitive task. They found that maintaining postural control under external perturbation was more attentionally demanding for older than for younger adults (Brown et al., 1999; Rankin et al., 2000). This is more pronounced in balance impaired than in healthy older adults (Brauer, Shumway-Cook and Woollacott, 2001; 2002). A recent study investigated the force-time relations of younger and older adults during a stepping reaction to an external tap on the heel under single- and dual-task conditions. The results showed that the older adults took longer to generate peak force in preparation for stepping and during the swing phase of the stepping response than the young adults when a visual Stroop task was performed concurrently (Melzer et al., 2010). Maki and McIlroy (2007) have summarized that in older adults balance recovery demands cognitive resources. Change-in-support strategies for maintaining balance like stepping require more cognitive resources than fixed-support strategies like ankle and hip strategies. All these findings suggest that any increased attentional demand when dealing with a perturbation may contribute to an increased risk of falling, especially among the elderly.

Walking is a more dynamic postural task during which the center of mass oscillates and the base of support is continuously changing. Walking was previously considered to be autonomically controlled, but recent studies have found that it is attentionally demanding motor rather than reflexive. When walking on level ground, studies have shown that older adults decrease their gait speed and increased their stride

time variability when dealing with a concurrent cognitive task. This indicates that walking demands attention resources (Dubost et al., 2006; Fraulknner et al., 2006; van Iersel et al., 2007; Priest et al., 2008). When older adults are asked to walk and negotiate obstacles while dual-tasking, they show more clumsy performance than younger adults, which should relate to fall risk (Siu et al., 2008, 2009; Harley et al., 2009; Hawkes et al., 2012). Beauchet and his colleagues have summarized how changes in walking while dual-tasking are significantly associated with increased risk of falling amongst older adults, especially the frail ones. The elderly showed poorer performance than young adults at different walking speeds, turning and walking on a narrow base (Beauchet et al., 2008). Shumway-Cook's group found that slow performance in the timed up & go test with or without a concurrent cognitive task could be a predictor of falls among the elderly (Shumway-Cook et al., 2000). Stop walking while talking test was also found to be a good indicator of unstable and fall-prone elderly subjects as indicated by their slower walking speed and unstable trunk control (de Hoon et al., 2003).

1.3.5 Theories underlying dual-tasking interactions

Four theories have been proposed theories to explain the interference observed in dual-tasking. They are logically distinct but not necessarily mutually exclusive (Pashler, 1998).

- 1) Capacity theory

This theory was first proposed by Kahneman in 1973. He suggested that interference occurs because the processing of the two tasks shares a common pool of mental resources. The two tasks are processed in parallel, and people can vary the allocation of resources between the two tasks at will (Pashler, 1998).

2) Bottleneck theory

This is also called “single channel theory”. Bertelson (1966) proposed that when two tasks were performed together they are queued for processing. The processing sequencing is affected by the difficulty of the task and the extent to which the person has practiced it.

3) Crosstalk and task similarity theory

This theory attributes interference to “outcome conflict”. One task produces outputs, throughputs, or side effects that are influencing to the processing of the other task (Navon and Miller, 1987).

4) Neural structure interference theory

This theory proposes that tasks which are processed in the same brain structures could be more difficult to handle simultaneously than tasks processed in separate brain structures. In another words the interference arises from competing demands for specific neural pathways (Maki and McIlroy, 2007).

All of these theories predicts that dual-tasking should cause a decrease in the performance as is usually observed, but some studies have not shown the same findings—subjects improved their balance performance when dual-tasking (Deviterne et

al., 2005; Prado et al., 2007; Swan et al., 2004). Although the reasons may lie in the different types of cognitive and postural tasks tested and the complexity and cognitive requirements of the secondary task, researchers have tried to further elucidate the dual-tasking effects associated with different levels of task complexity. In this connection, a group led by Lacour tested three models of interaction between the two tasks during dual-tasking: 1) a cross-domain competition model; 2) a U-shaped nonlinear model; and 3) a task prioritization model. The first and third were similar to the models previously outlined, but the U-shaped linear interaction model suggests that postural performance could be either improved or degraded by adding a cognitive task (Lacour et al., 2008). This effect has been demonstrated in older adults. Postural sway during stance has been observed to decrease with a simple secondary task (for example, a simple choice reaction task) but to increase when the task is more demanding (for example, a 2 digits back working memory test) (Huxhold et al., 2006). The difficulty of the secondary cognitive task is therefore very important.

1.3.6 Cognitive tasks for assessing posture with dual-tasking

Aging involves declining cognitive processing ability (McDowd & Craik, 1988; Salthouse et al., 1995). The U-shape model proposes a special explanation for the findings of improved postural control with a secondary task. Researchers have also found that with aging, the beneficial range of the cognitive task is reduced, while the detrimental range is increased due to cross-domain resource competition (Lacour et al.,

2008). Different cognitive tasks have different influences on balance and gait due to using different central processing tracts and their different attentional requirements. So far, there is no consensus on the best cognitive task for evaluating the effects of dual-tasking on postural control and gait.

The cognitive tasks in the dual-tasking can be visual-spatial or non-visual-spatial tasks. Verbal response to an auditory tone, mental calculation and backward counting task are all examples of non-visual-spatial tasks; responding to a visual stimulus and different levels of Brooks' visual-spatial tasks are visual-spatial. Since postural control requires specific visual-spatial information, cognitive tasks which need or do not need visual-spatial information should have different interactions during dual-tasking according to the above theories. But the effects of the two categories of cognitive tasks on postural control and gait remain obscure. The conflicting results observed so far may be related to the different assessment procedures and modalities used for the cognitive task, the difficulty of the cognitive task and/or the difficulty of the postural task (Huxhold et al., 2006). Also, cognitive performance during dual-tasking is often not fully reported in dual-tasking studies. Visual-spatial tasks certainly interfere with postural control (Maylor and Wing, 1996; 2001; Swan et al., 2004; Huxhold et al., 2006; Jamet et al., 2004, 2007), but whether it is the sharing of the common processing stream that is helping or inhibiting postural stability remains elusive.

The underlying theory of structural inference (Kahneman, 1973) asserts that limits intervene or interference arises when two concurrent tasks depend on the same

specialized system (Gazzaniga, 2004). To assess capacity interference in older adults as their general capacity decreases with age, cognitive tasks that involve structure interference should be excluded. Non-visual-spatial tasks are therefore more suitable (Siu et al., 2008). Among the possible non-visual-spatial tasks, performance in backward counting or mental calculation may be related to a subject's working memory (Hittmair-Delazer et al., 1994) or may overstress older adults if they have inadequate education. Studies have found that when concurrently performing such tasks, older adults' postural stability during standing and walking can be compromised (Brown et al., 1999; Jamet et al., 2004; Sturnieks et al., 2008; Beauchet et al., 2005; van Iersel et al., 2007; Priest et al., 2008; Hausdorff et al., 2008). However, the verbalization during counting and calculation tasks may also contribute to increased perturbation during postural control, as studies have demonstrated that articulation itself can disturb postural control (Swanenburg et al., 2009). Besides, during the articulation of the response, the head movement involved might contribute to the postural sway. Siu has proposed that if the secondary task does not require head stabilization, the primary balance task would not increase postural sway. Auditory tasks are therefore often chosen for assessing postural control among older adults while dual-tasking.

1.3.6.1 The auditory Stroop task

The auditory Stroop task has been modified from the visual Stroop word test (Stroop, 1935) named after John Ridley Stroop. In its original form the word test measured reactions when the name of a color is printed in another color (e.g. the word

“red” is printed in yellow rather than red). In such situations subjects react to the color more slowly and commit more errors than when the color and the word align. Stroop’s simple test has been popular for many years for assessing neuropsychological capacities. It is commonly used to measure selective attention, cognitive flexibility and processing speed and it is used also to evaluation the brain’s executive functioning (Lezak et al., 2004). EEG and functional MRI have confirmed that Stroop tasks activate the frontal lobe and more specifically the anterior cingulated cortex and dorsolateral prefrontal cortex of the brain.

Executive functioning broadly encompasses a set of cognitive skills used for planning, initiating, sequencing and monitoring complex goal-directed behavior (Royall et al., 2002). It is associated with the frontal lobes and related brain networks (Yogev-Seligmann et al., 2008). Executive functioning involves high level of attentional processing like sequencing, inhibition and conflict resolution, all of which may be required during dual-tasking. Studies have found that the quality of executive function is related to gait performance when dual-tasking (Coppin et al., 2006; Springer et al., 2006; Yogev-Seligmann et al., 2008). Furthermore, poor executive function could be a predictor of falls in older adults, even those without balance impairment (Buracchio et al., 2011).

The auditory Stroop test uses an auditory tone as the stimulus in place of Stroop’s colored words. The required response is a pitch judgment. The stimulus tone is presented at either high or low pitch, and a word which may or may not be congruent

with the pitch which they presented (Cohen and Martin, 1975). This protocol does not call on the visual or somato-sensory system, and so should not produce structural interference with balance control. But the task is attentionally demanding and the cognitive processing involved taps the executive control function.

1.4. Tai Chi

Tai Chi, a traditional Chinese martial art, is deeply rooted in the philosophy of Taoism and breathing technique. During its hundreds years of development, different forms of Tai Chi practice have been developed, some of the most popular today being the Chen, Wu (or Jian Qian), Yang, Sun and Wu (or He Qin) styles. Chen style is the oldest, but the Yang style is the most popular today (China Sport, 1983) and well accepted by older adults. During Tai Chi practice, deep breathing and mental concentration are required to achieve harmony between body and mind (Hong et al., 2000). A Tai Chi routine consists of a series of postures and movements performed in continuous, coherent and graceful flow.

Now, more and more researchers regard Tai Chi as one kind of mind-body exercise. Research on Tai Chi nowadays can be tackled in its physical as well as mind characteristics.

1.4.1 The characteristics of Tai Chi

Tai Chi is popular in China and in many Western countries for health promotion, especially for older adults. It combines psychological and physical training in one exercise routine.

1.4.1.1 The “mind” characteristics of Tai Chi

Tai Chi requires its practitioners to let the mind lead the body. One of the central concepts of Tai Chi emphasizes is the concentration and focus of mind while researchers translate these statements into that the mind becomes unified in its purpose for an extended period of time (Chuckrow, 1998). Researchers consider teaching and learning Tai Chi moves without concentration or attention is much less beneficial for health (Wayne & Kaptchuk, 2008). Developing the interaction between mind and body has long been regarded as more important than the development of any martial arts skills (Li et al., 2001). This kind of statement further echoes the importance of mind element in Tai Chi practice. The detailed physical movements, breathing techniques, visualization and focused internal awareness of a Tai Chi routine have been shown to strengthen the body and relax the mind (Wayne & Kaptchuk, 2008).

1.4.1.2 The “body” characteristics of Tai Chi

Tai Chi practice can also be considered an aerobic exercise as has been confirmed by heart rate measurements and calculations of metabolic equivalents expended during practice (Lan et al. 2001, 2004). It has also been shown to benefit for postural control. Its continuous, slow, and even tempo facilitates sensory awareness of the speed, force, trajectory, and execution of the movements, as well as awareness of the

external environment (Wayne et al., 2004). The moves emphasize postural alignment, weight shifting and relaxed circular movements (Yeh et al., 2004). Figure 3 illustrates how one Tai Chi maneuver which encourages the weight transfer. Unilateral and bilateral shifts of body weight and progressive flexion of the knees improve dynamic standing balance and lower-extremity strength (Li et al., 2001). Figure 4 shows another maneuver which demands single-leg standing its execution. The symmetrical, diagonal, circular and spiraling movements promote joint flexibility (Wolf et al., 1997).

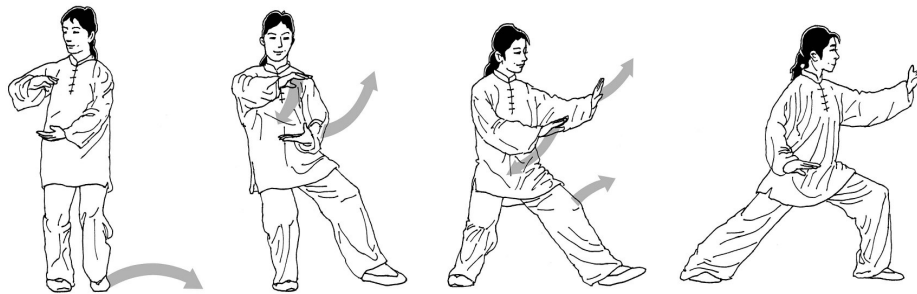


Figure 1. 3. “Part the wild horse’s mane” maneuver (from Tsang & Hui-Chan 2005).

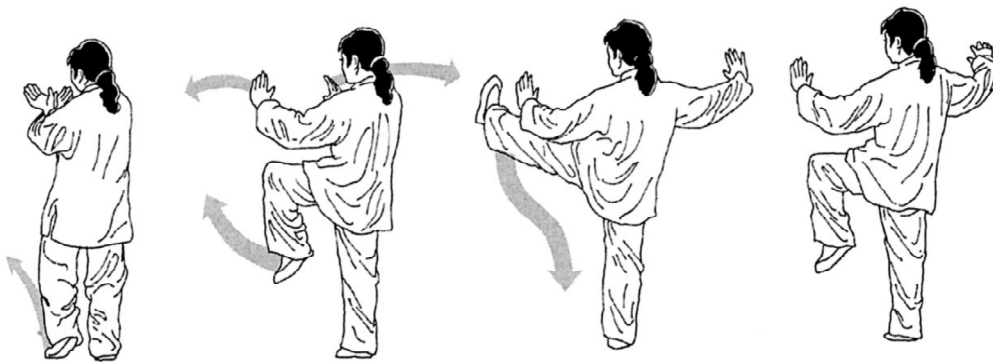


Figure 1.4. “Kick with the heel” maneuver (from Tsang & Hui-Chan 2005).

1.4.1.3 The combined “mind-body” characteristics of Tai Chi

Tai Chi requires elegant movement simultaneous with deep respiration and concentration (Sports Department, 1983; Liu et al., 2005). This combination is also called for in yoga, *qigong* and other mind-body exercises. The International Mind-Body Fitness Committee refers to them as "...physical exercise executed with a profound inwardly directed focus" (cited in La Forge and Ralph, 1997). Mind-body exercise demands a meditative mind-set and inwardly focused contemplation. Adepts claim ultimately to achieve greater self-control and empowerment (La Forge and Ralph, 1997). Unlike exercise which solely emphasizes physical performance such as jogging or aerobics, Tai Chi calls for self-monitoring of perceived effort, controlled breathing, and nonjudgmental awareness. There is no cuing entirely on an exercise leader or peer influence as in a group exercise class (La Forge and Ralph, 1997). This mind-body feature corroborates Tai Chi's effects on improving emotional well-being and physical health as the fundamental intention of Tai Chi practicing "the mind (yi) leads the qi, and qi moves the body"(以意导气, 以气运身).

1.4.2 Effects of Tai Chi exercise

1.4.2.1 Physical effects of Tai Chi exercise

This review will be confined to Tai Chi's scientifically demonstrated effects on the cardiovascular and balance control systems.

1.4.2.1.1 Effects of Tai Chi exercise on cardiovascular system

Significant improvement in cardiopulmonary function (measured by VO_{2max}) has been demonstrated in Tai Chi practitioners compared with matched, sedentary controls involving both middle-aged and older adults (Lai et al., 1995; Lan et al., 1998; Hong et al., 2000). Tai Chi has also been shown to improve the cardiopulmonary function of patients with cardiac problems such as chronic heart failure (Barrow, et al., 2007), and after coronary artery bypass surgery (Lan et al., 1999). A group led by Tsai has shown that after 12 weeks Tai Chi training, the total serum cholesterol decreased and high density lipoprotein cholesterol increased in middle-aged subjects with borderline hypertension (Tsai et al., 2003). In a randomized and controlled trial, 62 sedentary older persons with borderline hypertension were assigned to practice either Tai Chi or aerobics. After 12 weeks training, both groups achieved similar reductions in average blood pressure (Young, et al., 1999). In another study, Tai Chi practitioners demonstrated better cutaneous microcirculation than sedentary controls as indicated by higher skin blood flows and nitric oxide in plasma at rest and during exercise (Wang, et al., 2001). Other researchers have studied the effects of Tai Chi training on cardiopulmonary function after coronary artery bypass surgery (Channer et al., 1996), the blood pressure of patients recovering from myocardial infarction (Channer et al., 1996), and the symptom scores (Barrow et al., 2007), quality of life and functional capacity (Yeh et al., 2004) of patients after heart failure. Some studies have even found that practicing Tai Chi may influence the autonomic control of the heart. Lu and Kuo (2003) found that regular Tai Chi practice could enhance vagal modulation and tilt the sympathovagal balance toward decreased sympathetic modulation in older persons. A

group led by Väänänen found an immediate effect of Tai Chi practice in increasing parasympathetic activity in both young and elderly healthy males by studying heart rate variability (HRV), an index of autonomic function (Väänänen et al., 2002). Some researchers also consider Tai Chi an adjunct exercise for chronic cardiovascular disease (Taylor-Piliae, 2003).

1.4.2.1.2 Effects of Tai Chi exercise on balance control

The effects of Tai Chi practice on balance have been studied comprehensively since the 1990s. A group led by Kutner has shown that after 15 weeks of training, Tai Chi practice can change one's sense of balance more than conventional balance training (Kutner et al., 1997). Wolf and his colleagues in 1997 compared Tai Chi exercise with computerized balance training for improving the postural stability of older adults. After exercising twice a week for 15 weeks, the members of the Tai Chi group reported less fear of falling and experienced a delayed onset of falls. In a cross-sectional study, elderly Tai Chi practitioners have shown significantly better balance confidence than age-matched controls as measured using the Activities-specific Balance Confidence scale (ABC) (Tsang and Hui-Chan, 2005). The same scale was used in an intervention trial which studied the effects of Tai Chi training with frail adults 70–97 years old. After 48 weeks of training the mean ABC score was significantly higher (decreased fear) in the Tai Chi cohort (Sattin et al., 2005).

Static single-leg standing tests have been widely used in Tai Chi studies. The standing time has been shown to be strongly related to the incidence of falls in older population (Gehlonson et al., 1990; Brown et al., 1993). Single leg standing is a widely

used test because it requires no special equipment. Since Tai Chi movements include lots of single leg standing, single-leg standing studies of Tai Chi tend to give conclusive results. Tse and Bailey (2003) employed single leg standing to evaluate the balance performance of Tai Chi practitioners. They found that elderly Tai Chi practitioners (with more than a year of recent experience) had significantly longer single leg standing times on both legs with their eyes open than matched controls. Hong's group similarly found that Tai Chi practitioners (n=28) achieved significantly longer single-leg standing times than control subjects (n=30) with their eyes closed. This time the Tai Chi practitioners had an average of 10 years of experience (Hong et al., 2000). Schaller (1996) conducted a 10-week Tai Chi intervention with 24 older adults and found that their average single leg standing time improved more than 50% whereas that of the controls (n=22) decreased 2%. Another study by Song and his colleagues of arthritic older women found that after 12 weeks of Tai Chi training their average single leg standing time had increased significantly. Their symptoms and physical functioning improved as well (Song et al., 2003). A group led by Li subsequently demonstrated that 6 months of Tai Chi training improves single leg standing time significantly more than simply stretching (Li et al., 2005).

The laboratory based assessments of standing balance usually use a force plate to measure postural control under different conditions.

1) Sensory Organization Test

The sensory organization test was developed by Nashner, and is widely used in assessing the sensory organization ability of older subjects. Studies using the SOT have shown that fallers sway significantly more when standing on a force plate which sways in the same direction and with the same magnitude as the subject (Wallmann, 2001). A group led by Wong used the test to compare 25 elderly Tai Chi practitioners with 14 healthy controls and found no difference in their average static postural control, but under more challenging conditions (eyes closed with swaying surface, or a swaying visual surround with a swaying surface) the Tai Chi practitioners swayed significantly less than the control subjects (Wong et al., 2001). Their findings show that Tai Chi practitioners achieved better balance when relying on vestibular inputs. Similar results were found in Tsang and Hui-Chan's study. Tai Chi practitioners had better balance control under conditions that relied on the vision and vestibular systems (Tsang and Hui-Chan, 2001) and their performance can even be comparable to that of young, healthy control subjects (Tsang et al., 2004). A prospective study by the same research group and found that after 2 months of intensive Tai Chi training the average vestibular ratio was 22% greater than that of a control group which received only wellness education (Tsang & Hui-Chan 2004), while in another study with 6 months of training the average ratio increased by 47% compared with the control subjects (Yang et al., 2007).

2) Limits of stability test

The limits of stability test is a dynamic test that assess subjects' voluntary weight shifting in different directions within their base of support, and their ability to briefly maintain stability in those positions (Tsang and Hui-Chan, 2003). A force plate records the displacement of the subject's center of pressure during the intentional weight shifting. Conventionally, the subject's reaction time, maximum excursion and directional control are measured to reflect dynamic balance performance. Previous studies have shown that the older Tai Chi practitioners react faster, can lean farther without losing their balance and maintain better control of their leaning trajectory than matched controls. Indeed, their maximum excursions and directional control are comparable with those of young, healthy control subjects (Tsang and Hui-Chan, 2004). In a prospective study, after intensive Tai Chi training (1.5 h per session, 6 times/week for 4 weeks) practitioners improved significantly in the control of their leaning trajectory and their performance was comparable to that of experienced Tai Chi practitioners (mean experience = 10 years). Also, the improved balance performance lasted up to 4 weeks after the training had stopped (Tsang and Hui-Chan, 2004).

3) Perturbed single leg standing test

Perturbed single leg standing is a comparatively challenging test of balance. It is based on the idea that falls rarely happen from double leg standing and in daily life people are often called upon to stand on an unstable platform. Tai Chi movements involve a lot of single leg standing which the participants must practice in a closed kinetic chain. The leg muscles are required to co-contract in order to stabilize and maintain balance in such

postures. Increased muscle strength in the lower limb facilitates better balance in single leg standing. Whether these benefits extend to dynamic conditions was answered by another study conducted by Tsang and Hui-Chan (2005). The investigators measured their subjects' muscle strength and their control of body sway angle during single-leg stance on a moving platform. The results showed that Tai Chi practitioners had less anteroposterior body sway than their counterparts, and the muscle strength of the knee was negatively correlated to the body sway angle in the perturbed single leg standing tests.

Tse and Bailey (2003) found that experienced Tai Chi practitioners took significantly more steps in a tandem walking test than non-practitioners. However, in some interventional studies Tai Chi practitioners demonstrated no faster 8-meter walking velocity (Wolfson et al., 1996) and their time to complete a 50-meter walk was similar to that of controls (Hartman et al., 2000). These results may be explained by the short duration of those intervention studies and the slow speed of Tai Chi movements. In a randomized and controlled trial, 256 physically inactive, community-dwelling adults aged 70 to 92 years were taught either Tai Chi or stretching exercises 3 times a week for 6 months. The Tai Chi subjects improved their Berg Balance Scale scores, dynamic gait index values and functional reach significantly more than the stretching group (Li et al., 2005).

1.4.2.2 Psychological effects of Tai Chi training

1.4.2.2.1 The emotional alteration by Tai Chi exercises

Early studies by Jin found that Tai Chi training could reduce tension, depression, anxiety and emotional stress as measured by urine noradrenaline levels and salivary cortisol levels (Jin, 1989; 1992). Brown and his coworkers subsequently conducted a randomized clinical trial to compare Tai Chi with other aerobic exercises. Women in their Tai Chi group showed significantly greater improvements in depression than the members of the other aerobic exercises groups (Brown et al., 1993). Tai Chi participants gained higher levels of health perceptions, life satisfaction, positive affect, and well-being as well as lower levels of depression, negative affect, and psychological distress after 6-month of practice (Li et al., 2001). Tsai later organized another randomized clinical trial and found that after 12 weeks of Tai Chi training the subjects showed decreases in both trait-anxiety and state-anxiety as indicated by the State-Trait Anxiety Inventory (STAI) (Tsai et al., 2003). Another study done by Liu and colleagues (2005) found that Tai Chi practice induces a resting awakening state and exhibit a relaxing effect on both mind and body by monitoring the before and after exercise electroencephalography change and profile of mood state (POMS). Later studies have supported these beneficial psychological and wellness effects of Tai Chi with all kinds of patients including older adults with osteoarthritis (Hartman et al., 2000), individuals with traumatic brain injury (Gemmell and Leathem, 2006) and cancer survivors (Mustian et al., 2004).

1.4.2.2.2 Cognitive function gains with Tai Chi training

One session of either Tai Chi or yoga can decrease anxiety levels as measured by the State-Trait Anxiety Inventory and increase the speed and accuracy of a 7 item series

of subtractions (Field et al., 2010). Matthews and Williams (2008) found that after 30 sessions of training, their elderly Tai Chi subjects showed significant improvements in executive brain function as indicated by their performance on trail making and clock drawing tasks. Experienced Tai Chi practitioners also pay better attention as measured by the Color Trails Test (CTT), the Trail Making Test (TMT) and the Rivermead Behavioral Memory Test (in this case the Chinese version, so the RBMT-CV) (Man, Tsang and Hui-chan, 2010). In a randomized clinical trial, subjects in a Tai Chi training group showed significantly greater improvements in their cognitive functioning as measured by the backward digit-span test when compared with a group trained with Western exercises (a combination of aerobic, strength and flexibility training) or with a control group. And that improvement maintained even after 6 months of de-training (Taylor-Piliae et al., 2010). A year of Tai Chi training with older adults at risk of cognitive decline produced better average clinical dementia ratings (CDRs), sum-of-boxes scores, delayed recall and Cornell depression in dementia scores than those of a control group trained with stretching and toning exercises (Lam et al., 2012).

1.4.3 The objectives of the present study

Tai Chi requires good mind and body coordination (Wayne and Kaptchuk, 2008). Previous studies have explored the effects of Tai Chi training on postural control or on cognitive performance, but never both together. In fact, though, an exercise programme which can promote both physical and mental/cognitive health is badly needed. This

study was launched to investigate the mind and body effects of Tai Chi on cardiovascular function, muscle strength, and posture during dual-tasking with a cognitive task.

It involved three series of experiments. In the first series cross-sectional study was conducted to compare elderly Tai Chi practitioners with healthy controls similar in age, gender distribution, height and weight. The testing compared their arterial compliance, muscle strength (Chapter 2), cognitive performance and postural control when dual-tasking (Chapter 4). In the second series a randomized and controlled trial (RCT) tested whether or not 16 weeks of Tai Chi could improve arterial compliance, lower limb muscle strength (Chapter 3); cognitive performance and postural control during dual-tasking (Chapter 5) compared with attending music, English and handicrafts classes. A subsequent single-case study (Chapter 6) compared Tai Chi with arm ergometer cycling (an exercise with no cognitive component) with respect to modulating autonomic nervous control and prefrontal activity during exercise.

This set of experiments was designed to test the following hypotheses:

- 1) Experienced older Tai Chi practitioners have significantly better arterial compliance and better lower limb muscle strength than matched healthy controls.
- 2) Older women can show improvements in their arterial compliance and lower limb muscle strength after 16 weeks of short-form Tai Chi training significantly greater than those in untrained controls.

- 3) Older experienced Tai Chi practitioners perform better than matched healthy controls in a dual motor-and-cognitive-task test involving stepping down while performing an auditory Stroop test.
- 4) Sixteen weeks of Tai Chi training can improve older adults' postural control in both single- and dual-tasking conditions.
- 5) At similar exercise intensity, an elderly subject will show more prefrontal oxygenation and greater parasympathetic control during Tai Chi practice than during arm ergometer cycling.

CHAPTER 2

TAI CHI, ARTERIAL COMPLIANCE AND MUSCLE STRENGTH IN OLDER ADULTS

Publication

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2.1 Abstract

Background Aerobic exercise can alleviate the declines in arterial compliance common in older adults. However, when combined with strength training, aerobic exercise may reduce arterial compliance. Tai Chi practice has been found to improve muscle strength and cardiopulmonary function in older subjects, but whether or not it improves arterial compliance is not known. The primary aim of this study was to investigate whether Tai Chi practitioners have better arterial compliance and muscle strength.

Design Twenty nine older Tai Chi practitioners (73.7 ± 4.5 years) and 36 healthy control subjects (71.4 ± 6.6 years) participated in this cross-sectional study.

Methods The participants were independent in their daily living activities. They were screened for apparent cardiovascular disease and underwent arterial compliance testing and isokinetic knee muscle strength testing at $30^\circ/s$.

Results Tai Chi practitioners showed significantly better hemodynamic parameters than the controls as indexed by larger and small artery compliance. They also demonstrated greater eccentric muscle strength in both knee extensors and flexors.

Conclusion The findings of better muscle strength without jeopardizing arterial compliance suggests that Tai Chi could be a suitable exercise for older persons to improve both cardiovascular function and muscle strength.

Key words: aging, arterial compliance, muscle strength, Tai Chi

2.2 Introduction

Arterial compliance describes an artery's ability to expand and contract with cardiac pulsations and relaxation (Arnett et al., 1994). When an artery fails to distend or rebound in response to pressure changes, it is considered to be stiff. Arterial stiffness has been found to be closely associated with cardiovascular diseases such as hypertension (Liao et al., 1999; Boutouyrie et al., 2002), heart disease (Mattace-Raso et al., 2006), and stroke (Laurent et al., 2003). How poor arterial compliance causes cardiovascular diseases has been discussed by Gates and Seals (2006). Changes in the arteries might contribute to the increased blood pressure and pulse pressure, reduced cardiovascular baroreflex sensitivity, increased aortic input impedance, left ventricular hypertrophy and diastolic dysfunction, and atherosclerosis. Arterial compliance can be an important predictor of cardiovascular mortality in the elderly (Meaume et al., 2001; Sutton-Tyrrell et al., 2005). Therefore, good arterial compliance is an important therapeutic target for physical exercise in the prevention of cardiovascular disease (Gates & Seals, 2006).

Cross-sectional studies show that age-related arterial stiffness is absent in physically active women (Tanaka et al., 1998) and men (Tanaka et al., 2000). Studies have shown that after 3 months of aerobic training arterial compliance may improve to the level of endurance-trained subjects (Tanaka et al., 2000; Moreau et al., 2003). Muscle strength training is common nowadays and often employed to counteract aging, but this form of training has led to a decrease in arterial compliance (Miyachi et al., 2003; 2004). Any change in arterial compliance caused by strength training in middle-

aged and older subjects is still elusive. A recent randomized clinical study by Cortez-Cooper and colleagues (2008) with adults aged 50 and above found that, after 13 weeks of intervention, only subjects in the stretch training group showed improved arterial compliance, while subjects in the strength training and combined strength and aerobic training groups did not. However, strength training is an important prescription for older persons, especially those with osteopenia or balance problems. Consequently, exercise which can improve both arterial compliance and muscle strength would be a preferred mode of training for older persons.

Tai Chi is a Chinese mind-body exercise usually regarded as aerobic (Lan et al., 2002). Significant improvement in cardiopulmonary function has been found in Tai Chi practitioners when compared with sedentary control subjects middle-aged and older (Lai et al., 1995; Lan et al., 1998; Hong et al., 2000). Tai Chi training can also improve cardiopulmonary function in patients with cardiovascular diseases like chronic heart failure (Yeh et al., 2004; Barrow et al., 2007) and myocardial infarction (Channer et al., 1996). In fact, the effects Tai Chi training in lowering the blood pressure of subjects with hypertension has been extensively reviewed (Yeh et al., 2008; Lee et al., 2010). It is known that Tai Chi practice includes a great deal of stretching movements. The latter has been found by Cortez-Cooper and colleagues (2008) to increase arterial compliance in older adults. However, the effect of Tai Chi practice on arterial compliance has not been investigated in older subjects. Having shown experienced Tai Chi practitioners to have better leg strength than their healthy counterparts (Tsang & Hui-Chan, 2005), we wonder if Tai Chi practitioners would have also achieved greater arterial compliance as

a result of performing the stretching movements embedded in its many styles. This study was therefore designed to investigate whether experienced Tai Chi practitioners have 2) better arterial compliance and 2) greater knee muscle strength than older controls.

2.3 Methods

2.3.1 Subjects

In this cross-sectional study, a total of 65 community-dwelling subjects participated. They were all independent in the activities of daily living. Twenty-nine Tai Chi practitioners (9 males and 20 females, mean age 73.7 ± 4.5 years) were recruited from local Tai Chi clubs. All of them had practiced Tai Chi for a minimum of 1.5 hour per week for at least 3 years (average Tai Chi experience = 6.7 ± 4.6 years). Another 36 control subjects (6 males and 30 females, mean age 71.4 ± 6.6 years) with no previous Tai Chi experience were recruited from several elderly centers. They involved either in morning walk, leisure hiking or house-hold work. Subjects were excluded for diagnosed neurological disorder, severe lung disease, any coronary artery disease, a history of myocardial infarction or other heart failure, significant atrial or ventricular arrhythmia, cerebral artery disease or any peripheral vascular disease. Subjects with diagnosed hypertension or diabetes were accepted but recorded separately for further analysis. This study was approved by the Ethics Committee of The Hong Kong Polytechnic University.

The procedures were fully explained to all subjects, and a written informed consent (see Appendix I) was obtained from them.

2.3.2 Measurements

All subjects were asked to abstain from taking caffeine and alcohol the night before assessment. However, their daily exercise routine was advised to be maintained. To ensure a similar experimental environment, participants were tested during the same time period, and the room temperature was kept constant at 24°C. Subjects' height and weights were recorded and body mass index (BMI) index was calculated accordingly.

Each subject was asked to complete a modified Minnesota Leisure Time Physical Activity Questionnaire (Van Heuvelen et al., 1998) (see Appendix II). The questionnaire categorized these older subjects' daily activities (household chores, hobbies and sports) into 3 different physical levels according to metabolic index units (METs): light (<4 METs), moderate (4-5.5 METs), and heavy (> 5.5 METs) in order to rate their energy expenditure. This approach has been used to compare physical activity levels among older subjects in previous studies (Tsang & Hui-Chan, 2005; 2006).

2.3.2.1 Arterial compliance

An HDI PulseWave CR-2000 research cardiovascular profiling system (Hypertension Diagnostics Inc., Eagan, MN, USA) was used to measure the subjects' arterial compliance. This has been shown to be a reliable and valid instrument for

measuring arterial compliance (Resnick et al., 2000; Zimlichman; 2005). It uses a modified Windkessel model to calculate an electrical analog model which contains a capacitive compliance element (larger artery elasticity index), a reflective or oscillatory compliance element (small artery elasticity index), inductance and resistance (systemic vascular resistance) (Cohn et al., 1995). A blood pressure (BP) cuff was placed around each participant's left upper arm to measure the BP of left brachial artery and a piezoelectric acoustic sensor was placed over the strongest pulse point of the radial artery in the right arm. The right hand and arm were stabilized by a rigid plastic stabilizer to avoid any skin and arm movements during measurement. BP was measured using a linear dynamic deflation method. Once the waveform shown on the screen was stable, the radial artery BP waveform data over a 30-second period were recorded for compliance analysis. The analysis involves equations which can be found in the work of Cohn and colleagues (1995) (Cohn et al., 1995). Since heart rate and BP are involved in the calculation of arterial compliance, these parameters would be treated as co-variate in data analysis if significant difference was found between the two groups. Three trials were performed to yield mean values for the large artery and small artery elasticity indices. A 1-minute rest was given between trials. The measurements included systemic blood pressure (SBP), diastolic blood pressure (DBP), pulse pressure (PP), pulse rate, large artery elasticity index (C1), small artery elasticity index (C2), as well as systemic vascular resistance (SVR), and total vascular impedance (TVI).

2.3.2.2 Knee joint muscle strength

Both concentric and eccentric knee muscle strengths were measured, because a large part of a Tai Chi routine is performed in a semi-squatting position. The concentric and eccentric knee extensors and flexors of each subject's dominant leg were measured using a Cybex Norm dynamometer (Cybex International Inc., Ronkonkoma, NY) at an angular velocity of 30°/s. The slow testing speed was adopted to achieve "velocity specificity" (Tsang & Hui-Chan, 2005) mimicking the slow movements of Tai Chi. Subject's dominant leg was considered to be the one that subject used to kick a ball. Muscle testing was performed in a sitting position with a stabilizing strap over the trunk and with the hips held at 70° of flexion. The lateral femoral epicondyle of the subject's dominant leg was in line with the rotation axis of the dynamometer. The starting position of the knee was 90° of flexion, ending at full knee extension. Before testing, subjects were asked to perform a 10-min warm-up which included stretching of the knee muscle groups supervised by a physical therapist. Familiarization trials were given with three submaximal repetitions for both concentric and eccentric trials before formal testing. Each subject was then asked to give five maximal contractions of the knee extensors and flexors in both concentric and eccentric modes. All five trials were recorded for offline analysis. The peak torque-to-bodyweight ratio of the concentric and eccentric measurements was calculated as average of the three highest peak torques from the five trials and normalized with respect to the subject's body weight (Chan et al., 1996)

2.3.3 Statistical analysis

All the analyses were performed using Statistical Package for the Social Sciences (SPSS) software version 17.0 (SPSS., USA). The continuous data were expressed as mean \pm standard deviation. Age, weight, height and BMI were compared between the Tai Chi subjects and controls using independent *t*-tests. A chi-square test was used to compare the groups' gender distributions, physical activity levels and number of subjects with hypertension and diabetes mellitus. Multivariate analysis of variance (MANOVA) was used to compare the two groups' results in the arterial compliance test and the concentric and eccentric muscle strength tests. If statistically significant differences were found in the multivariate tests, univariate tests were conducted for each of the measures. A significance level (α) of 0.05 was chosen for statistical comparisons.

2.4 Results

Subjects with hypertension and diabetes mellitus reported that they kept their medications when the measurements were taken. The control subjects and experienced Tai Chi practitioners did not differ significantly in their average age, height, weight and physical activity level, but control subjects had a significantly higher average BMI than the TC subjects ($P=0.044$; Table 2.1).

Table 2.1. Demographic data of older control and Tai Chi practitioners

	Control subjects (n=36)	Tai Chi subjects (n=29)	P
Age (years)	71.4±6.6	73.7±4.5	0.108
Gender	6M,30F	9M,20F	0.172
Height (cm)	153.1±6.4	154.5±8.1	0.418
Weight (kg)	57.8 ±8.4	55.0 ±9.6	0.206
BMI (kg/m ²)	24.6±3.1	23.0±3.5	0.044*
Physical activity level			0.269
Light (≤4METs)	22	13	
Moderate (≤ 5.5METs)	14	13	
Heavy (> 5.5METs)	0	3	
No. of subjects with hypertension	22/36	11/29	0.063
No. of subjects with diabetes mellitus	4/36	2/29	0.56

* Denotes a difference significant at the P<0.05 level using an independent t-test.

Table 2.2 presents the arterial compliance data. Since the average BMI of the two groups was significantly different, BMI was used as a covariate in the statistical analysis of the arterial compliance results. The Tai Chi subjects were significantly better than the control subjects in all the hemodynamic parameters (overall MANOVA, $P<0.001$) except the pulse rate ($P=0.420$). Previous studies have shown that higher blood pressure may cause stiffness on the arterial wall (McEniery et al., 2007). A correlation analysis was also performed in the present study and there were significant negative correlations found between the systolic blood pressure and large arterial compliance (C1) (Pearson product-moment coefficient of correlation, $r= -0.329$; $P=0.007$) and small arterial compliance (C2) ($r= -0.569$; $P<0.001$). The higher proportion of subjects having hypertension in the control group (61% versus 38% in the Tai Chi group) and the significant higher systolic blood pressure of control subjects ($P=0.004$) might confound the findings on C1 and C2. Therefore, further statistical analysis using MANCOVA on the arterial compliances between the two groups with the systolic blood pressure as covariate was performed. The MANCOVA showed an overall significant difference ($P<0.001$) with Tai Chi practitioners still achieved significant higher C1 ($P<0.001$) and C2 ($P=0.037$) when compared to the control subjects.

Table 2.2. Hemodynamic observations of older control and Tai Chi practitioners

	Control	Tai Chi	
	subjects	Subjects	
	(n = 36)	(n = 29)	P
SBP (mmHg)	126.9±14.7	116.4±11.3	0.004**
DBP (mmHg)	69.8±9.2	64.1±7.5	0.019*
Pulse Pressure (mmHg)	57.1±9.5	52.5±6.9	0.028*
Pulse Rate (bpm)	64.2±9.3	62.6±8.0	0.420
Larger artery compliance index	10.5±2.8	14.7±4.4	<0.001***
(C1) (ml/mmHg×10)			
Small artery compliance index	2.7±1.2	3.5±1.5	0.002**
(C2) (ml/mmHg×100)			
Systemic vascular resistance	1974.6±346.8	1792.9±332.7	0.006**
SVR (dync·sec·cm-5)			

* Denotes a difference significant at the P<0.05 level; ** P<0.01 level; *** P<0.001 level using a univariate test.

Though MANOVA showed no statistically significant overall difference in concentric muscle strength between groups, univariate testing revealed that the Tai Chi practitioners had higher average concentric knee extensor strength ($P=0.026$; Table 2.3). Eccentric knee muscle strength showed a significant overall difference between the

controls and the Tai Chi group in multivariate analysis ($P<0.05$). Univariate analyses demonstrated that the Tai Chi subjects had greater average eccentric muscle strength in both their knee extensors ($P=0.01$) and flexors ($P=0.03$; Table 2.3).

Table 2.3. Concentric and eccentric knee muscle strength

peak torque-to-body weight ratio (N·m/kg)		Control subjects (n = 36)	Tai Chi subjects (n = 29)	P
Concentric	Extensors	0.96 ± 0.33	1.17± 0.42	0.026*
	Flexors	0.37 ±0.17	0.45± 0.21	0.085
Eccentric	Extensors	1.31±0.49	1.68±0.62	0.01*
	Flexors	0.71±0.31	0.89±0.35	0.03*

*Denotes a difference significant at the $P<0.05$ level using a univariate test;

2.5 Discussion

2.5.1 Arterial compliance and Tai Chi training

Our findings show that older subjects who practice Tai Chi regularly had better arterial compliance than the controls similar in age and gender. This is in line with the findings of Tanaka and colleagues (1998), who found that physically active post-

menopausal women had better arterial compliance than sedentary controls. In their subsequent study (Tanaka et al., 2000) on middle aged (around 50 years) and older men (around 65 years), endurance- trained groups showed arterial compliance 20% to 35% better than the inactive group, when the common carotid artery was tested using ultrasound and a β -index. Better arterial compliance (by 33–43%) has also been observed in postmenopausal women who participated in endurance training (Moreau et al., 2003).

In this study, the larger artery compliance index (C1) and small artery compliance index (C2) were 40- 44% higher in the Tai Chi practitioners than the controls. In previous studies, the controls recruited have usually been sedentary subjects. In this study, there was no significant difference in physical activity levels between the Tai Chi and control subjects (Table 2.1), so the observed difference in arterial compliance might not be due to their physical activity levels. Longitudinal studies have found that three months of aerobic exercise training, a self-implemented walking program, can decrease the age-related decline in arterial compliance in middle aged and older men (Tanaka et al., 1998) and postmenopausal healthy women (Tanaka et al., 2000) to a level similar to that of endurance trained men or premenopausal women. In a recent study, investigators also found that sedentary older subjects (age around 70 years) who underwent 1 year of progressive jogging training could improve their total arterial compliance to the level of master athletes (Fujimoto et al., 2010). It seems that in seniors it takes longer (1year in older subjects vs. 3 months in middle age) to achieve the vascular health benefits of endurance exercise training. The results of this study show

that older persons who have been practicing Tai Chi for on average 6 years had better arterial compliance than the healthy controls. These findings were also in line with those of previous studies on aerobic exercise training.

Previous studies have shown that Tai Chi practice could reduce blood pressure in subjects with or without hypertension (Yeh et al., 2008; Lee et al., 2010). In the present study, both systolic and diastolic blood pressures of Tai Chi practitioners were lower than the control subjects (8.3% and 8.2%, respectively). The blood pressure lowering effect of Tai Chi practice may have an effect on the arterial compliance since the systolic blood pressure and arterial compliance had been found to be significantly correlated in the present and previous studies (McVeigh et al. 1991; Cernes et al, 2008). Therefore, Tai Chi could be an attractive form of exercise for older adults. However, a prospective randomized clinical study is needed before a valid conclusion could be drawn.

2.5.2 Arterial compliance and muscle strength

The experienced Tai Chi participants had better arterial compliance and knee muscle strength than the healthy controls. Previous cross-sectional studies of strength training of young athletes have found that their arterial compliance was lower than that of sedentary young controls (Bertovic et al., 1999; Michachi et al., 2003). In a longitudinal study, Miyachi and colleagues recruited young subjects with mean age of 22 years and conducted 4 months of resistance training (80% to their 1 RM) and 4

months of detraining. Although there was an improvement in the strength of all their main muscle groups, there was a significant decrease in arterial compliance after four months of training. Compliance returned to the baseline value only after four months of detraining (Miyachi et al., 2004). So strength training might be harmful to vascular health in young subjects. With older subjects, Cortez-Cooper and colleagues (2008) found that in adults with mean age of 52 years, 13 weeks of strength training (70% to their 1 RM) caused slight decrease in carotid artery compliance although not reaching a statistically significant difference. Only stretch training led to improvements in arterial compliance. The difference between findings of Miyachi and Cortez-Cooper in the decrease of the arterial compliance may be explained by different age, resistance intensity and duration of training. These results suggest that although strength training improved muscle strength, they showed a tendency to reduce arterial compliance. In the study by Cortez-Cooper and colleagues (2008), the combined strength and aerobic training produced no harmful effect on the carotid arterial compliance of the participants. Another cross-sectional study done by Cook and colleagues (2006) also found that in the middle aged rowers, the central arterial compliance was higher than their control counterpart while their handgrip strength was also higher than the controls. The investigators suggested the endurance training components of rowing counteracts the stiffening arterial compliance effects of its strength training (Cook et al., 2006).

Miyachi and colleagues have discussed the interaction mechanisms strength training and arterial compliance (Miyachi et al, 2000; 2004). They suggest that the acute elevation in blood pressure in the cardiothoracic region during strength training could

cause a chronic increase in the smooth muscle content of arterial wall and the load-bearing properties of collagen and elastin. Increased sympathetic nervous system activity in resistance training could also provoke greater sympathetic adrenergic vasoconstrictor tone in the arterial walls, leading to reduced arterial compliance. These proposed mechanisms were derived from observation of the structural changes in the arterial wall during strength training using an animal model. High blood pressure was found in dogs along with thickening of the arterial walls (Dobrin et al., 1995) resulting in a decrease in arterial compliance.

Unlike strength or endurance training, Tai Chi requires mental concentration and calm meditation during movement (Wayne & Kaptchuk, 2008). Previous studies have shown that its practitioners demonstrate higher parasympathetic nervous system activity before, during and immediately after Tai Chi practice (Väänänen et al., 2002; Lu & Kuo, 2003; Lu et al., 2010). Physiological shifting of the autonomic system to the parasympathetic system may prevent arterial constriction despite the strength training involved in keeping the body weight in a semi-squatting position for prolonged time periods during practice (Lee et al., 2010). Tai Chi practice also includes lots of stretching movements, which a group led by Cortez-Cooper (2008) has shown to increase arterial compliance and decrease pulse pressure. This may explain why the Tai Chi practitioners in this study showed better lower limb muscle strength and better arterial compliance. Recently, investigators have been trying to find an exercise paradigm that could combine both aerobic and strength training components so that strengthening will not cause a detrimental effect on arterial compliance (Cook et al.,

2006; Kawano et al., 2006). From the present findings, Tai Chi may be a good training mode for older adults to improve both their vascular health and muscle strength.

Tai Chi subjects had higher eccentric knee muscle strength than the healthy controls (Table 2.3). This was similar to our previous finding which employed a low isokinetic testing speed. However, their concentric knee flexor muscle strength was not significantly better. This may be because the Tai Chi subjects recruited in this study were older (73.7 ± 4.5 years vs. 69.3 ± 5.0 years) and had less Tai Chi practice experience (6.7 ± 4.6 years vs. 8.5 ± 6.7 years) than those in our previous study where better concentric knee flexor muscle strength was observed (Tsang&Hui-Chan, 2004).

With the use of a cross-sectional study design, no cause-effect relationship could be established in the present study. We have adopted a modified physical activity questionnaire for the comparison between the two groups which was simpler to administer for our elderly participants. However, such modified questionnaire has not been validated. In addition, though the average physical activity level of the two groups was not significantly different, more of the Tai Chi subjects engaged in 'heavy' physical activity. The results should be interpreted with caution. Moreover, factors like smoking habit, depression, and attitude towards health may confound the arterial compliance as those who attend Tai Chi exercise are prone to live a healthier life style. To further investigate whether Tai Chi training improves arterial compliance as well as muscle strength, a randomized clinical study has been conducted. Our findings have shown that

16 weeks of Tai Chi practice has improved the eccentric knee extensor strength and arterial compliance of elderly women (Lu et al., 2012a).

2.6 Conclusion

Older subjects who practice Tai Chi regularly have better arterial compliance and greater knee muscle strength than healthy controls. Tai Chi is an exercise that appears to benefit both muscle strength and arterial compliance for older adults.

CHAPTER 3

EFFECTS OF TAI CHI TRAINING ON ARTERIAL COMPLIANCE AND MUSCLE STRENGTH IN FEMALE SENIORS: A RANDOMIZED CLINICAL TRIAL

Publication

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Conference:

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3.1 Abstract

Background:

Exercise which can improve muscle strength while not compromising arterial compliance is especially needed for older adults. Tai Chi practitioners are known to have better than average arterial compliance and muscle strength. This study was designed to establish a cause and effect relationship between Tai Chi training and both increased arterial compliance and increased muscle strength.

Design:

In a single blind randomized clinical trial, 31 elderly women were randomly assigned to receive either Tai Chi training or an education programme, three sessions per week for 16 weeks.

Results:

After training, the subjects in the Tai Chi group showed significant improvements in arterial compliance and eccentric knee extensor strength. The subjects in the control group showed no significant improvement.

Conclusion:

Practising Tai Chi can improve the eccentric knee extensor strength and arterial compliance of elderly women. Tai Chi maybe a good exercise choice to improve the cardiovascular health and muscle strength of the elderly.

Keywords

Arterial compliance, elderly, muscle strength, Tai Chi

3.2 Introduction

According to a World Health Organization estimate in 1998, there will be more than 1,000 million people aged 60 years and older in 2020 (World Health Organization, 1998). Cardiovascular disease is one major cause of mortality and morbidity (World Health Organization, 2007), and studies have shown that the risk for developing cardiovascular disease generally rises with age (Remsberg & Siervogel, 2003). Arterial stiffness has been found to be closely associated with heart diseases (Mattace-Raso et al., 2006), hypertension (Liao et al., 1999; Boutouyries et al., 2002) and stroke (Laurent et al., 2003). Stiffness changes in the arteries may contribute to increased systolic pressure, reduced cardiovagal baroreflex sensitivity, increased aortic input impedance, left ventricular hypertrophy, diastolic dysfunction and atherosclerosis. An artery's ability to expand and contract with cardiac pulsations and relaxation is termed arterial compliance, and it is regarded as an important predictor of cardiovascular death in the elderly (Meaune et al., 2001; Sutton-Tyrrell et al., 2005).

Effective exercise programs to maintain or even improve arterial compliance are important for successful aging. Studies have found that physically active subjects have better arterial compliance (Tanaka et al., 1998; 2000). Strength or resistance training, however, has been found to have negative effects on arterial compliance (Miyachi et al., 2003; 2004). Nevertheless, strength training is an important prescription for older persons, especially those with osteopenia or balance problems. To resolve this difficulty, investigators now are trying to find an exercise program that can improve muscle strength with no harmful effect on arterial compliance (Cook et al., 2006; Kawano et al.,

2006).

Tai Chi is a Chinese mind-body exercise usually regarded as aerobic in nature (Lan et al., 2002). It is popular in both China and Western countries nowadays. Studies have shown the positive effects of Tai Chi training on various indicators of cardiovascular health with both healthy persons (Lan et al., 1998; Hong et al., 2000) and those with cardiovascular problems (Yeh et al., 2004; Barrow et al., 2007). Studies have also found that Tai Chi practitioners achieve greater leg strength than their healthy counterparts (Lan et al., 1998; Tsang & Hui-Chan, 2005). This may be because much Tai Chi practice is in a semi-squatting position.

A natural question is then whether Tai Chi practice can achieve muscle strengthening without jeopardizing the arterial compliance of older adults? A recent study in our laboratory has shown that older subjects (73.7 ± 4.5 years) who practice Tai Chi regularly have better arterial compliance (40% higher in large artery elasticity index and 29.6% higher in the small artery elasticity index) and greater knee muscle strength than healthy controls (Lu et al., 2012b). These findings suggest that Tai Chi could be an exercise which could achieve muscle training without jeopardizing arterial compliance, but no cause and effect relationship has yet been established. The present study was therefore designed to investigate whether Tai Chi training can improve both the arterial compliance and leg strength of the elderly using a single blind randomized clinical trial design.

3.3 Methodology

3.3.1 Subjects

Thirty-one community-dwelling elderly females were recruited by distributing pamphlets at two elderly community centers in Hong Kong. None of the subjects had previous experience practicing Tai Chi. All of the participants were independent in their activities of daily living. They were required to score at least 21 on the Chinese version of the Mini-mental Status Examination (Appendix III) to ensure the validity of the measurement and intervention procedures (Chiu et al., 1994). Subjects with severe cognitive impairments, symptomatic cardiovascular disease at moderate levels of exertion, poorly controlled hypertension or symptomatic orthostatic hypotension, a diagnosis of a stroke, Parkinson's disease or any other neurological disorder, peripheral neuropathy of the lower extremities, crippling arthritis, or a recent fracture of either lower limb were excluded.

By drawing lots, fifteen subjects were randomly assigned to learn 12 forms Yang style Tai Chi, while the other 16 served as a control group.

This study was approved by the Ethics Committee of the Hong Kong Polytechnic University. The procedures were fully explained to all subjects, and all gave written informed consent (Appendix IV)

3.3.2 Interventions

The subjects in the Tai Chi group underwent 16 weeks of training in 12 forms Yang style Tai Chi under an experienced instructor, with 3 sessions per week. Each session involved a 15-minute warm-up, one hour of Tai Chi practice and 15 minutes of

cooling-down. The 12 forms Yang style was selected because it is the style most widely practiced by older practitioners (Lee et al., 2011). The subjects in the control group attended a series of music, English and handicrafts classes for 16 weeks. The contact time was similar, but most of the time was spent sitting.

3.3.3 Measurements

To ensure similar experimental conditions, participants were tested during the same time period (9:00 am to noon) and the room temperature was kept constant at 24°C. The subjects' heights and weights were recorded and body mass index (BMI) index was calculated accordingly. Each subject's medical history was recorded and hypertension was classified as having been diagnosed by a physician and on daily medication for controlling blood pressure.

Each subject was asked to complete a modified Minnesota Leisure Time Physical Activity questionnaire (Van Heuvelen et al., 1998) (Appendix II). The questionnaire categorized these older subjects' daily activities (household chores, hobbies and sports) into 3 different physical levels according to metabolic index units (METs): light (<4 METs), moderate (4-5.5 METs), and heavy (> 5.5 METs) in order to rate their energy expenditure. This approach has been used to compare physical activity levels among older subjects in previous studies (Tsang & Hui-Chan, 2004; 2005).

3.3.3.1 Arterial compliance

The arterial compliance indexes were measured using an HDI PulseWave CR-2000 research cardiovascular profiling system (Hypertension Diagnostics Inc., Eagan, MN, USA). The reliability of this instrument and the validity of its readings have been verified in previous studies (Resnick et al., 2000; Zimlichman et al., 2005). It uses a modified Windkessel model to quantify electrical analog model which contains a capacitive compliance element (larger artery elasticity), and a reflective or oscillatory compliance element (small artery elasticity) (Figure 1.1) (Cohn et al., 1995).

The subject rested for several minutes lying down, and then blood pressure was measured in the left upper arm using a blood pressure cuff. The right hand and arm were stabilized by a rigid plastic stabilizer to avoid any skin and arm movements during measurement, and then a piezoelectric acoustic sensor was placed over the strongest pulse point of the radial artery of the right arm. Blood pressure (BP) was measured using a linear dynamic deflation method. Once the waveform shown on the screen was stable, the radial artery BP waveform data was recorded over a 30-second period for the arterial compliance analysis. Three trials were performed to yield mean values for the large artery elasticity index (C1) and the small artery elasticity index (C2). A one-minute rest was given between trials.

3.3.3.2 Knee joint muscle strength

Concentric and eccentric knee muscle strength of the dominant leg was also measured in this study because a large part of most Tai Chi routines is performed in a semi-squatting position. The subject's dominant leg was considered to be the leg that

subject said they would use to kick a ball. The measurement was done using a Cybex Norm dynamometer (Cybex International Inc., Ronkonkoma, NY) at an angular velocity of 30°/s. The slow testing speed was adopted to achieve “velocity specificity” (Tsang&Hui-Chan, 2005) with respect to the slow movements of Tai Chi. During the measurement, the subject sat with a stabilizing strap over the trunk and the hips held at 70° of flexion. The lateral femoral epicondyle of the subject’s dominant leg was in line with the rotation axis of the dynamometer. The starting position was 90° of knee flexion, ending at 0°. A 10 minute warm-up (stretching of the knee muscle groups) was supervised by a physical therapist before testing. Familiarization trials involving three submaximal concentric and eccentric repetitions were completed before the formal testing. Each subject was then asked to give five maximal contractions of the knee extensors and flexors in both concentric and eccentric modes. All twenty trials were recorded for offline analysis. The “peak torque-to-body weight” ratio of the concentric and eccentric measurements was calculated using the average of the three highest peak torques and normalized using the subject’s body weight (Chan et al., 1996).

3.3.4 Statistical analysis

All the analyses were performed using Statistical Package for the Social Sciences (SPSS) software version 17.0 (SPSS Inc., USA). The continuous data were expressed as mean and standard deviation. Age, weight, height and BMI were compared between the Tai Chi subjects and controls using independent *t*-tests. A chi-square test

was used to compare the groups' physical activity levels. Repeated measures analysis of variance (group \times time) with intention-to-treat was used to compare the two groups' results in the arterial compliance test, and the concentric and eccentric muscle strength tests. The "last observation carried forward" was used to handle the data of the subjects who dropped out during intervention (Lachin, 2000). If statistically significant interaction differences were found, univariate tests were conducted for each of the measures. A significance level (α) of 0.05 was chosen for the statistical comparisons.

3.4 Results

The average attendance of the interest classes was 78%, and 85% for the Tai Chi training sessions. One person dropped out of the Tai Chi group due to family issue, and 3 dropped out of the control group—one because she fractured her arm during daily activity and two due to family issues (Figure 3.1). The participants' characteristics are presented in Table 3.1. Before training, there were no inter-group differences in average height, weight, body mass index, cognitive status or physical activity level. The average age of the two groups did, however, show a significant difference, so age was treated as a co-variate in the statistical analyses. All the subjects reported no change of their medications during the intervention period.

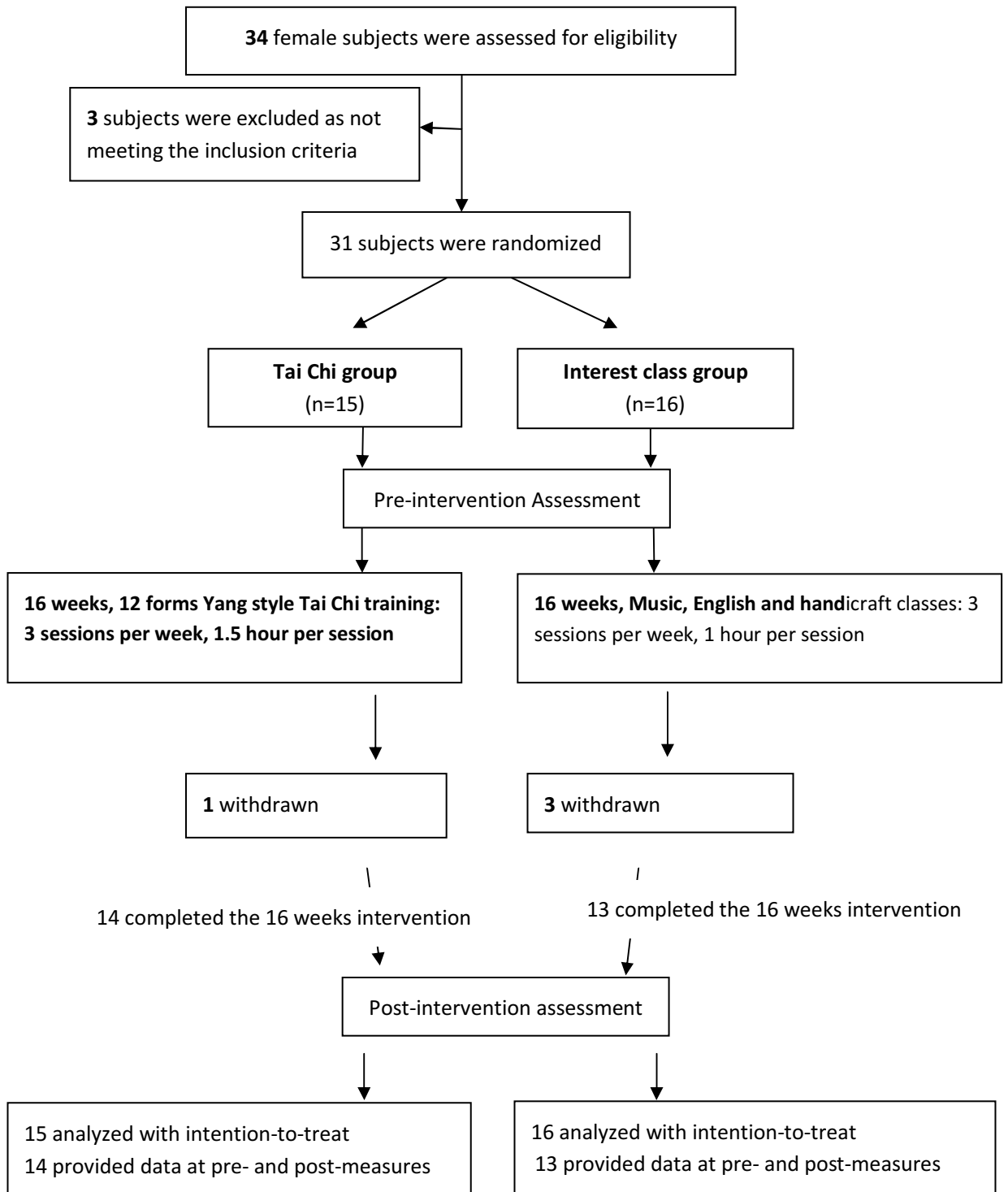


Figure 3.1. Flow diagram of subjects being recruited to the study

Table 3.1. Demographic characteristics of the participants

	Interest class group (n=16)	Tai Chi group (n=15)	p
Age	68.9±5.8	73.9±6.6	0.034*
Height (cm)	151.2±5.1	152.3±5.4	0.549
Weight (kg)	56.8±8.8	57.1±8.4	0.927
Body mass index (kg/m²)	24.8±3.3	24.6±3.1	0.850
MMSE score	27.3±1.9	26.1±3.1	0.189
Number with hypertension	7/16	11/15	0.095
Physical activity level before intervention			0.644
Light (≤4.0METs)	12	9	
Moderate (≤5.5METs)	4	6	
Heavy (>5.5METs)	0	0	

* denotes a difference significant at the $p < 0.05$ level of confidence.

MMSE denotes the Chinese version of the Mini Mental Status examination

3.4.1 Arterial compliance

The overall repeated measure MANCOVA (age as the co-variate) showed a significant interaction (group* time) effect ($p=0.003$). univariate test showed both C1 and C2 had a interaction effect too ($p=0.039$ and 0.011 respectively). Average large and small artery compliance increased significantly at 26.2 % ($p=0.039$) and 17.9% ($p=0.011$) respectively after Tai Chi intervention. The control group recorded decreases in both large and small artery compliance, but they were not statistically significant (Table 3.2).

Table 3.2. Arterial compliance before and after intervention

	Control group		Tai Chi group	
	Pre	Post	Pre	Post
Large artery compliance index (C1) (ml/mmHg×10)	10.1±2.7	9.6±3.8	10.3±2.7	13.0±3.8*
Small artery compliance index (C2) (ml/mmHg×100)	2.6±1.3	2.3±1.1	2.8±1.3	3.3±1.1*

* denotes a pre to post difference significant at the $p < 0.05$ level.

3.4.2 Lower limb knee muscle strength

The concentric and eccentric knee extensors and flexors in the Tai Chi group showed percentage strength changes of from 4.6% to 21.3%, but only the changes in eccentric knee extensor strength were statistically significant ($p=0.01$). For the control group subjects the percentage changes were from 1.2% to 10.5% and none were significant (see Table 3.3).

Table 3.3. Knee strength before and after intervention

Peak torque-to-body weight ratio (N·m/kg)		Control group			Tai Chi group		
		Pre	Post	% change	Pre	Post	% change
Concentric	Extensors	0.86±0.21	0.87±0.23	1.2%	0.87±0.35	0.91±0.42	4.6%
	Flexors	0.38±0.11	0.39±0.16	2.6%	0.34±0.22	0.37±0.21	8.8%
Eccentric	Extensors	1.14±0.36	1.26±0.41	10.5%	1.22±0.44	1.48±0.56	21.3%*
	Flexors	0.61±0.24	0.66±0.24	8.2%	0.71±0.32	0.79±0.29	11.3%

* indicates a pre to post difference significant at the 5% level of confidence.

3.5 Discussion

3.5.1 Tai Chi training and arterial compliance

After 16 weeks of Tai Chi training, these elderly women achieved significant improvements in both large and small artery compliance (26.2% and 17.9%, respectively). The 12 forms Yang style Tai Chi used in the intervention is considered to be aerobic in nature (Lee et al., 2011) and the results are in line with those of previous studies on aerobic exercise. Tanaka and colleagues (2000) investigated the effects of aerobic exercise on arterial compliance in middle aged men. After 3 months of training, their arterial compliance improved from 20% to 35%. In another study on postmenopausal women, Moreau and colleagues (2003) showed that improvements could reach 33-43% after 3 months of aerobic training. Fujimoto and colleagues (2010) studied subjects aged 70 and older and showed that after 1 year of progressive aerobic training the participants' total arterial compliance improved around 27%, leaving it similar to that of trained athletes of the same age.

Our group has reported a cross-sectional study using a group of experienced Tai Chi practitioners ($n = 29$, mean age = 73.9 years, mean Tai Chi experience = 6.7 years). By comparing with their average larger arterial compliance index = 14.7 ± 4.4 ml/mmHg $\times 10$ and small arterial compliance = 3.5 ± 1.5 ml/mmHg $\times 100$ (Lu et al., 2012b), there were significant differences in both parameters ($p = 0.001$ and 0.044 , respectively) with our Tai Chi subjects before intervention, but no significant difference after the 16-week of Tai Chi intervention ($p = 0.809$ and 0.338 , respectively).

It is of course well known that aerobic exercise improves arterial compliance, but the underlying mechanism remains poorly understood. Enhanced endothelial dilatation has been shown in both animal (Spier et al., 2007; Durrant et al., 2009) and human studies (DeSouza et al., 2000). On the other hand, Cortez-Cooper and colleagues (2008) found that participants in a stretching group showed significant improvements (23%) in arterial compliance. Those improvements could have been related to the improved functioning of the endothelium of the arterial wall. The longitudinal stretching of the muscles with which the arteries are attached could increase endothelial cell replication, leading to improved arterial compliance (Jackson et al., 2002). Tai Chi practice involves significant stretching movements, and sustained stretching of muscles all over the body could improve the arterial compliance through such a mechanism.

3.5.2 Tai Chi training and muscle strength

The 16 weeks of Tai Chi training significantly improved the average eccentric strength of the participants' knee extensors (21.3%, please refer to Table 3.3). This was in line with the finding by Audette's group (2006) that knee eccentric strength was improved after Tai Chi intervention. As Tai Chi practice is in large part performed in a semi-squatting position, it is not unexpected that eccentric control of the knee extensors would be trained. At the beginning of the training, the trunk must be properly aligned with the limb movements; otherwise an improper semi-squat position will cause an increase in the cardio-thoracic pressure with possible adverse effects on cardiac health.

3.5.3 Arterial compliance and muscle strength

Strength training has been shown to decrease arterial compliance (Miyachi et al., 2003; 2004). Several possible mechanisms have been proposed. One suggestion is that the acute elevation in blood pressure in the cardiothoracic region during strength training could cause a chronic increase in the smooth muscle content of the arterial walls to exploit the load-bearing properties of collagen and elastin. Another suggestion is that increased sympathetic nervous system activity in resistance training could provoke greater sympathetic adrenergic vasoconstrictor tone in the arterial walls, leading to reduced arterial compliance (Miyachi et al., 2003; 2004).

Although Tai Chi training is not regarded as a muscle strengthening regimen, studies have found that the positive effects of Tai Chi on leg strength arise mainly because practitioners maintain a semi-squatting position during much of the practice (Lan et al., 1998; 2002; Tsang & Hui Chan, 2005; Auddete et al., 2006). Tai Chi also requires a calm mind and deep, slow breathing. This should tend to decrease blood pressure and tilt autonomic regulation toward parasympathetic modulation and away from sympathetic modulation (Lu & Kuo, 2003). Slowness and evenness of movement are also emphasized (Wayne & Kaptchuk, 2008). Our group has shown (Lu et al., 2010) that during Tai Chi practice, parasympathetic activity dominates (as compared with arm ergometer cycling). We also showed that prefrontal activity, especially on the left side, was elevated, and this is associated with the mindful relaxation required during Tai Chi practice. This too promotes dominant parasympathetic control (Lu et al., 2010). Taken together, these findings may explain why Tai Chi practice can improve the eccentric

knee extensor strength while not jeopardizing arterial compliance.

3.5.4 Limitations

This study recruited only elderly women, so the results may not be applicable to males. Only the pre and post assessments were performed, so no long term effects could be established. Due to the limited number of subjects studied, the significant results on muscle strength parameters probably were confined to one muscle group only.

3.6 Conclusions

Tai Chi training can improve the arterial compliance and knee muscle strength of elderly women. Tai Chi may be a good exercise choice for older adults, both for vascular health and for muscle strengthening.

CHAPTER 4

TAI CHI PRACTITIONERS HAVE BETTER POSTURAL CONTROL AND COGNITIVE PERFORMANCE IN STEPPING DOWN WITH AND WITHOUT A CONCURRENT AUDITORY RESPONSE TASK

Submitted:

Lu X, Ka-Chun Siu, Siu N. Fu, Hui-Chan, C. W. Y. and Tsang, W. W.N Tai Chi practitioners have better postural control and cognitive performance in stepping down with and without a concurrent auditory response task. Submitted to Eur J Appl. physiol.

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4.1 Abstract

Background

Stepping down is a common activity of daily living. The ability to maintain postural stability after stepping down is important for older adults' personal safety, especially when they are required to perform a concurrent cognitive task. The purpose is to compare the performance of older experienced Tai Chi practitioners and healthy controls in dual- versus single-task paradigms, namely stepping down with and without performing an auditory response task.

Methods

Cross-sectional study was conducted in the Center for East-meets-West in Rehabilitation Sciences at The Hong Kong Polytechnic University, Hong Kong. Twenty-eight Tai Chi practitioners (73.6 ± 4.2 years) and 30 healthy control subjects (72.4 ± 6.1 years) were recruited. Participants were asked to step down from a 19cm high platform and maintain a single-leg stance for 5 seconds with and without a concurrent cognitive task which was an auditory Stroop test in which the participants were required to respond to different tones of voices regardless of their word meanings. Postural stability after stepping down under single- and dual- task paradigms in terms of excursion of the subject's center of pressure (COP) and cognitive performance were measured for comparison between the two groups.

Results

The Tai Chi practitioners showed significantly less body sway after stepping down during both single- ($p=0.014$ for COP area) and dual-task testings ($p=0.033$ and 0.034

for COP path and area, respectively) than those of controls. When the auditory Stroop test was conducted alone, they also demonstrated a lower error rate ($p=0.001$) but not faster response time. During dual-tasking, however, the Tai Chi practitioners showed both faster response times and lower error rates ($p=0.023$, 0.001 , respectively).

Conclusion

Older Tai Chi practitioners demonstrate better postural stability after stepping down than healthy controls and also in an auditory response task under both single- and dual-task paradigms.

Keywords: older adults, dual-task, postural stability, auditory Stroop test, stairs

4.2 Introduction

The incidence of falls increases with age and the resulting annual health cost in the UK escalates from £0.3 million per ten thousand population at age 60 to 64 to £1.5 million among those aged more than 75 (Scuffham et al., 2003). Aside from medical cost, falls in older adults lead to physical and psychological consequences such as decreased quality of life, fear of falling and related inactivity, and social isolation (Zijlstra et al., 2008). Therefore, falls among the elderly are gaining increasing attention among researchers and clinicians. Previously, fall risk factors were only considered in terms of physical aspects such as attenuated sensory inputs, decreasing muscle strength, and deficits in balance control. During the past decade more and more investigators have come to believe that cognitive elements also contribute significantly to fall risk (van Schoor et al., 2002; Anstey et al., 2006).

Dual-task designs for assessing postural control with concurrent cognitive processing have been adopted to compare younger with older adults performing a specific cognitive task while standing (Shumway-Cook & Woollacott, 2000; Hauer et al., 2003), walking (van Iersel et al., 2007; Kelly et al., 2008; Siu et al., 2008, 2009), or in response to postural perturbation (Rankin et al., 2000; Maki et al., 2001; Redfern et al., 2002; Zettel et al., 2008). The findings from such dual-task studies show that older subjects manifest both physical and cognitive deterioration when compared with younger subjects.

Negotiating stairs is a difficult daily activity for many older subjects (Startzell et al., 2000; van Iersel et al., 2003). More specifically, more than 10% of fatal falls among

older adults occur while descending stairs (Startzell et al., 2000). Studies have found that older adults need more motor arousal during stair descent (Hortobagyi & DeVita, 2000), which is related to their relative lack of attention to such tasks. For example, Ojha and colleagues (2009) found that older subjects required more attentional resources than healthy young adults while negotiating stairs. If so, would descending stairs affect the performance of a cognitive task in older subjects?

The positive effects of Tai Chi training on postural control have been demonstrated in terms of improved muscle strength, joint proprioception, and sensory organization ability, all of which contribute to postural control (Tsang & Hui-Chan, 2004; Li et al., 2005; Chen et al., 2012). Tai Chi is a mind-body exercise that demands motor planning in performing very precisely a prescribed sequence of movement patterns (Tsao, 1995). For example, Tai Chi practice requires the mind to concentrate on the ordering of coordinated eye-limb (hand and leg) and eye-body (neck and trunk) movements in a smooth sequence (Li et al., 2001). Previous findings in our own laboratory have shown that Tai Chi practitioners have better attention and memory than controls (Man et al., 2010). Also, a recent prospective study found that after 3 months of Tai Chi practice, older subjects achieved improvement in global cognitive function and delayed recall, and had fewer subjective cognitive complaints. Further, improvements in visual span and Clinical Dementia Rating scores were only observed among the Tai Chi group, not among those practicing stretching as controls (Lam et al., 2011).

The mental and physical demands of Tai Chi suggest that Tai Chi practitioners may have training both physical and cognitive performance. A question naturally arose:

Could Tai Chi practitioners maintain better postural control during stepping down and also better cognitive performance while performing a dual stepping down with a concurrent cognitive task which was auditory in nature? Though older subjects are known to require more attentional resources than younger subjects when negotiating stairs (e.g. Ojha et al. 2009), we hypothesize that since an auditory task is processed by a different cortical area involving the temporal lobe (Cohn & Martin, 1975), there should have no “occlusion” effect on the separate cognitive cortical processing demands between stepping down and response to an auditory test. This study therefore set out to determine whether Tai Chi practitioners might show better postural control and also better cognitive performance than healthy controls during a stepping down activity with and without a concurrent auditory task.

4.3 Methods

4.3.1 Participants

This was a cross-sectional study with a total of 58 healthy and active older participants. The subjects were all independent in their activities of daily living. Among them, 28 were Tai Chi practitioners (9 males and 19 females) who were recruited from two local Tai Chi clubs. All of them had practiced Tai Chi for a minimum of 1.5 hours per week for at least 3 years (average Tai Chi experience = 6.7 ± 4.6 years). The other 30 control subjects (7 males and 23 females) were recruited from elderly centers and had no Tai Chi experience. Candidates were excluded if they had any neurological disorder,

myocardial infarction, heart failure, uncontrolled diabetes or hypertension, any deformity of a hip or knee, or any cognitive or hearing problem. Subjects who suffered dizziness on the day of data collection or who could not follow verbal commands were also excluded. This study was approved by the Ethics Committee of The Hong Kong Polytechnic University. The procedures were fully explained, and written, informed consent was obtained from all of the participants (Appendix I).

4.3.2 Procedures

Each participant underwent an auditory Stroop test, and then completed a stepping down task with and without a concurrent auditory Stroop test, as described below.

4.3.2.1 Auditory Stroop test

The color-word version of the test was first used by Stroop in 1935. He was able to demonstrate that when the name of a color was displayed in a color not corresponding to the name, naming the color of the word took longer and people made errors more readily. The test has since clearly been shown to demand executive attention (Siu et al., 2008), so the auditory version of the test was chosen in the present study. The tests included two Cantonese words meaning “high” and “low” and were pronounced at either a high or low pitch. (Cantonese is a tonal language, so the subjects, all native speakers of some Chinese language, can be assumed thoroughly sensitive to pitch differences.) The subjects were asked to press the right hand thumb switch when hearing

a high pitch pronunciation and press the left thumb switch on hearing a low pitch pronunciation, disregarding the meaning of the word pronounced.

Four familiarization trials were practiced for each combination of meaning and pitch were conducted with the subject sitting in a quiet room before testing began. During the subsequent testing, reaction time (RT) was defined as the time from the appearance of the sound to the time when the subject pressed the button. If a subject pressed the right-hand button when the pitch was low or the left-hand button when the pitch was high, it was counted as an incorrect response. Altogether 16 trials were conducted with each participant and the average reaction time and error rate (percentage of wrong responses) for each group were calculated.

4.3.2.2 Stepping down task

The subjects were asked to step onto a force plate (Model OR6-5-1000, Advanced Mechanical Technologies Inc., Newton, MA) from a 19cm high platform leading with their dominant leg. The dominant leg was defined as the leg that was used to kick a ball (Tsang & Hui-Chan, 2005). The force plate measured the ground reaction force and postural sway at a sampling frequency of 1,000Hz. The subjects were asked to look at a fixed visual target 2 meters away from the center of the force plate before performing a stepping down task to standardize their attention. They were instructed to step down onto the force plate using their dominant leg in response to an audio cue, and then remain in single-leg stance for 10 seconds (Figure 4.1). They were asked to keep their non-dominant leg clear of the platform throughout.

In order to determine the influence of pressing the thumb switch on posture control, the subjects were asked to press a thumb switch (without any Stroop test) during the stepping down task, from hearing the audio cue to the moment of landing on the force plate. Familiarization trials were again given before data recording. Rests were provided as needed. A total of four trials were conducted.

The data were recorded and analyzed using version 8.6 of the Lab-View (NI USB 621, National Instrument Corp., Austin, TX, USA). Group averages were computed for comparison between the two subject groups.

4.3.2.3 Stepping down with a concurrent cognitive task

Under the dual-tasks paradigm, subjects were asked to respond to the auditory Stroop test while performing the stepping down task. They were instructed to maintain their balance on one leg while responding to the auditory test as quickly and as accurately as possible. A total of eight trials were conducted with each subject. The subjects were told that Stroop test word might be heard at any time during the stepping down process.

The center of pressure (COP) trajectory during the first 5 seconds of the single leg stance was recorded. The 5 second duration was adopted because the average single leg stance time of such older subjects was known to be about 6 to 7 seconds (Li et al., 2005). Two body sway measures were used to evaluate balance control performance after stepping down: 1) total sway path of the COP; and 2) the sway area, which was the area under the maximum sway excursion. The time needed to stepping down was also recorded. This was defined from the moment when the leading leg left the step to when

it stepped onto the force plate. The sequencing of the different conditions during the trials was randomized.



Figure 4.1 The experimental set-up.

4.3.3 Statistical analysis

All the analyses were performed using version 17.0 of the commercially available Statistical Package for the Social Sciences (SPSS) software (IBM Corp., Armonk, NY, USA). Continuous data were expressed using their mean and standard deviation. Age, weight, and height were compared between the experienced Tai Chi practitioners and the control subjects using independent *t*-tests. A chi-square test was used to compare the sex distributions and physical activity levels of the groups.

Repeated measures (two task conditions: single versus dual) multi-variate analysis of variance (MANOVA) was used to compare the results observed in the stepping down task, the auditory Stroop tests, and the dual stepping down and auditory tasks between the Tai Chi and control subjects. If a statistically significant overall difference was found, univariate tests were conducted for each of the measures. A significance level (α) of 0.05 was chosen for statistical comparisons.

4.4 Results

4.4.1 The test re-tests reliability of the tests

The intra-rater test re-test reliability of the testing protocol was performed in 17 healthy older adults (with mean age, 71.8 ± 6.3 years). The subjects were asked to come to the laboratory twice with 7 days apart to do the same assessments. The ICC values of response time and wrong answer under single task and dual tasks were 0.706, 0.877, 0.867, and 0.739, respectively. ICC values of the center of pressure path and area under single task was 0.788 and 0.813; and the value under dual-task was 0.717 and 0.698. The reliabilities of the stepping down assessments with and without a secondary cognitive task were from moderate to high (Lu et al., 2012d).

4.4.2 Participants

Fifty-eight older adults participated in this study. Table 4.1 shows that the controls and the experienced Tai Chi practitioners did not differ significantly in terms of their average age, height, weight, Mini-Mental Status Examination (MMSE) score, or physical activity level (all $p>0.05$). The Tai Chi practitioners had an average of 6.7 years of experience.

Table 4.1: Demographics of the controls and Tai Chi subjects

Characteristics	Control subjects (n=30)	Tai Chi subjects (n=28)	p-value
Age (years)	72.4±6.1	73.6±4.2	0.369
Height (cm)	154.0±6.6	154.6±8.2	0.757
Weight (kg)	58.5±8.3	55.4±9.9	0.197
Sex (male/female)	7/23	9/19	0.453
MMSE score	26.8±2.1	26.8±2.0	0.919
Physical activity level (n)			0.262
Light ≤4	5	4	
Moderate ≤4–5.5	25	23	
Heavy >5.5	0	1	

Values are mean ± SD

4.4.3 Auditory Stroop test

Repeated measures MANOVA showed an overall group x task difference ($p=0.043$) in the groups' auditory Stroop test results. Univariate analysis demonstrated that there was a statistically significant difference in the group x task in reaction times but not in the error rates (Table 4.2). Paired-t tests showed that all the participants had increased average reaction times and error rates in the dual- versus single-task. Independent t-tests showed that while the average error rates in the auditory Stroop test manifested significant between-group differences in both the single task and dual task conditions, average reaction time showed a significant between-group difference only in the dual tasks condition (Table 4.2).

Table 4.2: Auditory Stroop test under single- and dual-task conditions

	Control subjects (n = 30)			Tai Chi subjects (n = 28)			p-value		
	Single- task	Dual- task	% change	Single- task	Dual- task	% change	Single- task	Dual- task	Group x task
Reaction time (s)	1.04±0.31	1.87±0.48*	80%	0.98±0.35	1.58±0.46*	61%	0.523	0.023#	0.046**
Error rate (%)	16±12	26±15*	63%	6±7	13±12*	117%	0.001#	0.001#	0.112

** indicates a group x task interaction significant at the p<0.05 confidence level in an univariate test.

* indicates a within-group difference when compared with single-task significant at the p<0.05 confidence level.

indicates a between-group difference significant at the p<0.05 confidence level.

4.4.4 Stepping down performance with single- and dual-task paradigms

The time required to step down under single- and dual-task conditions showed no significant between-group difference ($p=0.921$ and $p=0.320$, respectively; data not tabulated). Since the two groups used similar time to complete the stepping down task, it was therefore not treated as a co-variate in the subsequent analysis.

Repeated measures (under two different tasks) MANOVA showed no significant group x task difference in the stepping down results ($p>0.05$). The total sway path of the COP under dual-task did show a significant between-group difference ($p=0.033$; Table 4.3) but not while single-task. The sway area with both single- and dual-task both showed a significant between-group difference ($p=0.014$ and 0.034 , respectively (Table 4.3)).

Table 4.3. Center of pressure changes during single- and dual-task stance

	Control subjects (n = 30)		Tai Chi subjects (n = 28)		<i>p</i> -value		
	Single- task	Dual- task	Single- task	Dual- task	Single- task	Dual- task	Group x task
COP path (mm)	289.6±116.3	293.1±74.9	252.8±57.7	258.3±41.8	0.136	0.033#	0.265
COP area (cm ²)	10.6±3.8	11.3±4.9	8.4±2.6	9.0±2.5	0.014#	0.034#	0.200

indicates a between-group difference significant at the $p < 0.05$ confidence level.

4.5 Discussion

The aim of this study was to investigate the performance of older Tai Chi practitioners in a stepping down task with and without a concurrent cognitive task and compare it with the performance of controls similar in age and physical activity level. Based on previous findings, Tai Chi practice can improve postural control (Tsang & Hui-Chan, 2004, 2005), as well as cognitive function in community-dwelling older adults (Man et al., 2010) and those with cognitive impairments (Lam et al., 2011). However, whether Tai Chi practitioners would show better postural control than healthy controls while stepping down was unknown. Whether they would show better performance in stepping down while doing a cognitive task was also tested.

4.5.1 Cognitive performance

The results show that the Tai Chi practitioners had response times similar to those of healthy controls when the auditory Stroop test alone was administered while seated ($p = 0.523$; Table 4.2). When an additional postural task was being performed simultaneously, both groups showed significantly slower response times, but the Tai Chi practitioners showed significantly faster response times than the controls on average ($p = 0.023$; Table 4.2). In this connection, Ojha and collaborators (2009) combined a verbal response task with a stair walking (both up and down) and found that healthy older subjects responded more slowly to an auditory tone during stair walking. The magnitude of the increase, which they termed “attentional cost”, was about 53%. In this study the response time of the Tai Chi practitioners increased by

61% on average, while that of the controls increased by 80% when compared with single-task performance. The larger increase observed in this study could be due to the difference in complexity of the cognitive tasks between the two studies. In the study by Ojha's group, the cognitive task was a direct reaction to a voice, which would have involved relatively simple cognitive processing. In contrast, the Stroop test conducted in this study called on the executive function of the cortex (Siu et al., 2008), which Royall and his colleagues (2002) describe as involving planning, initiation, sequencing and monitoring of complex goal-directed behavior. The Stroop test, especially the incongruent test during which the meaning of the word did not match the pitch of the voice, requires subjects to inhibit a direct response and react with a substituted response (Siu et al., 2009). Compared to a direct response to a voice, the task requires more attentional processing, which may lead to an increase in the response time.

The Tai Chi practitioners made significantly fewer mistakes than the healthy controls in both the single- and dual- task Stroop tests (both $p=0.001$, Table 4.2). In a previous study, experienced elderly Tai Chi practitioners displayed significantly better attention and memory than other healthy elderly with or without regular exercise training (Man et al., 2010). The auditory Stroop test requires executive attentional resources which demand that subjects selectively inhibit an automatic response (Siu et al., 2009). This cognitive process involves one kind of selective attention (Gazzaniga, 2004). Combined with Man's finding that Tai Chi practitioners pay better attention (Man et al., 2010), this may explain why the Tai Chi subjects showed a lower average error rate than the healthy controls.

4.5.2 Stepping down performance

Neither group showed a significant increase in body sway during dual-task compared with their single-task performance. Previous studies investigating postural control using a dual-task paradigm have shown conflicting results. Some investigators have found that with the addition of a cognitive task, postural control deteriorates in either a perturbed (Redfern et al., 2001) or un-perturbed condition (Shumway-Cook & Woollacott, 2000). Their proposed explanation is that postural control and cognitive activity compete for attentional resources, so during dual-task performance postural control performance is constrained by the sharing of limited attentional resources (Kahneman, 1973; Tsang et al. 2011). In contrast, other investigators have found improved balance control in dual-task situations (Melzer et al., 2001; Deviterne et al., 2007). Huxhold and colleagues (2006) have suggested that the efficacy of cognitive processing in postural control could be influenced by the difficulty, modality and stimulus of the concurrent cognitive task, and also any postural constraints affecting the concurrent cognitive task. In the present study the subjects were required to perform a comparatively difficult postural task and a cognitive task with high attentional demands. The results show that the subjects' cognitive performance was being affected significantly more (Table 4.2) than their postural control performance, which was negligibly affected during dual-task versus single-task performance (Table 4.3). This could demonstrate that the older adults prioritize postural control. Such a conclusion would be in line with previous findings that older adults prioritize postural control by sacrificing cognitive processing in dual-task performance, especially when the demand of the postural task is high. In

this study, excessive body sway in stepping down could have led to falling (Brown et al. 2002; Lacour et al., 2008).

4.5.3 The stepping down performance of the Tai Chi practitioners

This has been the first published study to investigate the relationship between Tai Chi practice and postural control during stepping down using a dual-task paradigm. Under single-task condition the Tai Chi practitioners demonstrated less body sway in terms of the COP area generated during the single-leg stance period after stepping down compared with the healthy controls (Table 4.3). They also performed better in the dual-task condition in terms of both COP path and area. Practicing Tai Chi has been found to improve postural control in older adults as measured by single-leg stance time (Schaller, 1996; Song et al., 2003; Li et al., 2005; Gyllensten et al., 2010). It follows that during single-leg stance after stepping down (the single-task condition), the Tai Chi practitioners should have demonstrated better postural performance than the healthy controls, and this was indeed shown by their smaller average COP area (Table 4.3). One would expect the difference to be even more significant during dual-task, and indeed Table 4.3 shows that the Tai Chi practitioners had significantly shorter COP paths and smaller areas, on average, than the healthy controls similar in age, height, weight, gender distribution, and physical activity level (Table 4.1). The mind-body principle of Tai Chi aims to train up motor planning and movement sequencing during the different Tai Chi forms (Wolf et al., 1997). Unless the auditory test taxes the same cortical area for cognitive processing as the single leg stance after stepping down leading to “occlusion” effects, the

demand for mental concentration during Tai Chi practice might be expected to help practitioners achieve better performance in both postural and cognitive tasks during dual-task performance, as shown by the findings here.

4.5.4 Limitations

This was a cross-sectional study, so no cause-effect relationship could be established using these protocols. No young healthy subjects were recruited for comparison, so the aging effects on stepping down and auditory response could not be investigated.

4.7 Conclusions

This study has been the first investigating postural control after stepping down with both single- and dual-task. The main finding is that older adults who practice Tai Chi perform consistently better in the stepping down task whether or not there is a concurrent auditory task. Their cognitive performance was also better under both conditions.

CHAPTER 5

EFFECTS OF TAI CHI TRAINING ON POSTURAL CONTROL AND COGNITIVE PERFORMANCE WHILE DUAL-TASKING – A RANDOMIZED CLINICAL TRIAL

Submitted:

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Tai Chi training on postural control and cognitive performance while dual-tasking
— A randomized clinical trial. Ready for submission

5.1 Abstract

Background

Clinicians consistently recommend exercise for falls prevention, but falls prevention is no longer considered to result from physical capability alone, but also from cognitive skill. Exercise which can improve postural control while performing concurrent cognitive and physical tasks is therefore beneficial for older adults.

To investigate the effects of practicing Tai Chi on the postural control and cognitive performance of older women while dual-tasking.

Methods

A randomized clinical trial was conducted in thirty-one older women took 16 weeks of Tai Chi training or 16 weeks of general interest classes. Before and after this intervention, their balance was tested in single leg stance after stepping down from a step. The test was conducted with and without a concurrent auditory response task.

Results

The Tai Chi subjects made fewer errors than the controls in the auditory response task in the dual-task condition. They also showed significant improvement in their postural control after training in both single- and dual-task conditions. The subjects in the control group did not show any significant improvement in dual-task condition after the intervention.

Conclusion

Tai Chi training improves the cognitive and postural control performance of older women when dual-tasking.

Key words: Postural control; Cognition; Dual-tasking; Tai Chi; Older adults

5.2 Introduction

Falls incidence is increasing with population aging, and the health cost is huge (Carter et al., 2001; Rubenstein, 2006). Among older adults, falls have both physical and psychological consequences including decreased life quality, increased fear of falling, reduced socially activity and isolation (Zijlstra et al., 2008).

Strategies for fall prevention are therefore important for older adults. Prevention should be approached not only from a physical but also from a cognitive perspective (Tinetti et al., 1988; Anstey et al., 2006).

More than 10% of fatal accidents among older adults occur while descending stairs (Startzell et al., 2000), a common functional activity. Investigators have found that older subjects require more attentional resources than younger subjects when negotiating stairs (Ojha et al., 2009), in particular when descending. This implies that older subjects need more motor arousal related to attention than those who are younger (Hortobagyi & DeVita, 2000). Dual-task balance performance has been used to predict falls in older adults (Beauchet et al., 2002; Faulkner et al., 2007). Exercises which could improve performance under dual-task conditions are therefore of special interest in falls prevention during stair walking.

Tai Chi is effective in improving the postural control of older adults (Tsang & Hui-Chan, 2004; Li et al., 2005; Chen et al., 2012). The underlying mechanisms have been proposed by Tsang and Hui-Chan (2008) and they involve the sensori-motor control of balance. Better limb and trunk proprioception (Tsang & Hui-Chan 2003; Li et al., 2008; Tsang et al., 2009); improved limb muscle strength (Tsang & Hui-Chan, 2005) and better integration of sensory information leads to improved

postural control among Tai Chi practitioners (Wong et al., 2001; Tsang et al., 2004). Tai Chi is a mind-body exercise which requires sequencing of movement patterns and motor planning (Tsao, 1995). Practicing Tai Chi therefore demands the interaction of mind and physical movement during the sequential and highly controlled movements (Li et al., 2001). Tai Chi practice thus trains both cognitive and physical components of posture and movement control. In a cross-sectional study, older Tai Chi practitioners have been shown to demonstrate better postural control and cognitive performance than healthy controls in a stepping down activity with a concurrent auditory response task (Lu et al., 2012c).

The objective of this study was to investigate whether a Tai Chi training program could improve cognitive and postural control performance while stepping down and attending to a concurrent cognitive task.

5.3 Methods

5.3.1 Subjects and study design

This was a single-blind, randomized clinical trial conducted in community centers for the older adults. Thirty-one community-dwelling older women were recruited by distributing pamphlets at two community centers. Qualifying respondents were randomized into either a Tai Chi group (n=15, mean age=72.8 ± 6.7 years) or a control group (n=16, mean age=67.3 ± 6.6 years) by drawing lots (see Figure 5.1).

None of the subjects had previous experience of practicing Tai Chi. All were required to score at least 21 in the Chinese version of the Mini-mental Status Examination to ensure they could understand the procedures (Chiu et al., 1994) (Appendix III). Each participant's normal level of physical activity was measured using a modified version of the Minnesota Leisure Time Physical Activity Questionnaire (Van Heuvelen, 1998) (Appendix II). The exclusion criteria were symptomatic cardiovascular disease at moderate levels of exertion, any diagnosed neurological disorder, peripheral neuropathy of the lower extremities, crippling arthritis, or a recent fracture of either lower limb. This study was approved by the Ethics Committee of the Hong Kong Polytechnic University. The procedures were fully explained to all subjects, and all gave written informed consent (Appendix IV).

5.3.2 Interventions

The subjects in the Tai Chi group underwent 16 weeks of training in 12-form Yang style Tai Chi with 3 sessions per week under a physiotherapist with experience in teaching Tai Chi. During the Tai Chi practice, visual imagery and meditation combined with breathing training were conducted as well as the physical movement training. Visual imagery is one of the essential components of Tai Chi practice. It encourages the participants use their senses to communicate between perception, emotion, and bodily change (Wayne and Kaptchuk, 2008). Tai Chi forms have names like “cloud hands” and “standing on one leg like a cock” which are intended to evoke images of certain kinesthetic, emotional and energetic state (Wayne and Kaptchuk, 2008). Towards the end of the 16 weeks, the participants were asked to

memorize the 12 Tai Chi forms in sequence and were able to play out the routine without prompting from the instructor. Each session involved a 15-minute warm-up, one hour of Tai Chi practice and 15 minutes of cooling-down. The subjects in the control group attended a series of music, English, handicrafts and fall prevention classes as well as social gatherings for 16 weeks. Their contact time was similar, but most of their sessions were spent in sitting.

5.3.3 Measurements

Before and after the intervention, each subject's performance in stepping down with and without a concurrent auditory response task was measured. The assessment was performed by another physiotherapist who was blinded to the subjects' allocation.

5.3.3.1 Cognitive task

An auditory Stroop test was employed as the cognitive task. In the test, the Chinese words signifying "high" and "low" were pronounced with either a high or low voice pitch. The subjects held two thumb switches and were asked to press the right hand thumb switch when hearing a high pitch pronunciation and press the left thumb switch on hearing a low pitch pronunciation, disregarding the meaning of the word pronounced. Because Chinese is a tonal language and all of the subjects were native speakers, they can be assumed to have been very sensitive to nuances of pitch. The reaction time (RT) and the correctness of the response were recorded for comparison. Reaction time was defined as the time from the appearance of the sound to the time when the subject pressed the button. If a subject pressed the right-hand

button when the pitch was low or the left-hand button when the pitch was high, it was counted as an incorrect response, termed as error rate (percentage of wrong answer).

5.3.3.2 Stepping down task

A force plate (Model OR6-5-1000, Advanced Mechanical Technologies Inc., Newton, MA) was positioned by the edge of a step 19cm high. The subjects stepped down onto the plate leading with their dominant leg (the leg that used to kick a ball (Tsang and Hui-Chan, 2005; Gyllensten et al. 2010). After landing, the subjects were required to stay in single-leg stance for 10 seconds with the other leg clear of the plate. The force plate recorded postural sway at a sampling frequency of 1000Hz. A fixed visual target positioned 2 meters away from the center of the force plate was used to fix the participant's gaze before stepping down.

In order to determine the influence of pressing the thumb switch on posture control, the subjects were asked to press a thumb switch (without any Stroop test) during the stepping down task, from hearing the audio cue to the moment of landing on the force plate. Familiarization trials were given before formal data recording. Resting was allowed as required. All the data were recorded using Lab-View software (National Instrument Corp., Austin, TX, USA) for off-line analysis.

5.3.3.3 Dual-task measurement

The participants were also asked to respond to an auditory Stroop test while performing the stepping down task. They were instructed to maintain postural control during single-leg stance while responding to the auditory signal with the

correct switch after stepping down. The subjects were told that the cognitive and postural tasks were to be emphasized equally.

Performance was evaluated in terms of the trajectory of the subject's center of pressure (COP) during the first 5 seconds of the single-leg stance. The 5 second duration was adopted because the average single leg stance time of such older subjects was known to be about 6 to 7 seconds (Li et al., 2005). The total sway path of the COP and the COP sway area were both recorded. The time needed to complete the stepping down task, from when the leading leg left the step until it touched the force plate, was also recorded, as it might relate to subsequent postural control during single-leg stance. The sequencing of single task and dual task trials was randomized.

5.3.4 Statistical analysis

The statistic analyses were performed with the aid of version 17.0 of the Statistical Package for the Social Sciences (SPSS) software (SPSS Inc., USA). The average age, weight and height of the two groups was compared using independent *t*-tests. A chi-square test was used to compare the baseline physical activity levels. The Mann-Whitney U test was used to compare the between group difference in pre and post intervention, while the Wilcoxon Signed Rank test was used for the within group comparison in the pre-post intervention targeting the stepping down task alone, the auditory Stroop test and the dual-task. A significance level (α) of 0.05 was chosen for the statistical comparisons.

5.4 Results

The average attendance of the Tai Chi group was 85%, and 82% for the control group. One subject from the Tai Chi group had insufficient attendance and another failed to attend the post intervention assessment. Two subjects in control group dropped out—one because she fractured her arm and another due to family problems. The participants' demographic data are presented in Table 5.1. Before the intervention, the two groups did not differ in average body weight, height, or MMSE score. Their average age was, however, significantly different, so age was treated as a covariate in the subsequent statistical analyses.

Table 5.1. Demographic data of the participants.

	Control group (n=16)	Tai Chi group (n=15)	<i>p</i> value
Age (years)	67.3±6.6	72.8±6.7	0.027*
Height (cm)	150.1±4.6	153.0±5.8	0.126
Weight (kg)	57.0±9.4	56.7±8.4	0.910
CMMSE	27.6±2.1	26.6±3.1	0.284
Physical activity level before intervention			0.645
Light (≤4.0METs)	11	9	
Moderate (4–5.5METs)	5	6	
Heavy (>5.5METs)	0	0	

*Difference significant at the $p < 0.05$ level of confidence. METs, metabolic index units; CMMSE, Chinese version of the Mini Mental Status examination.

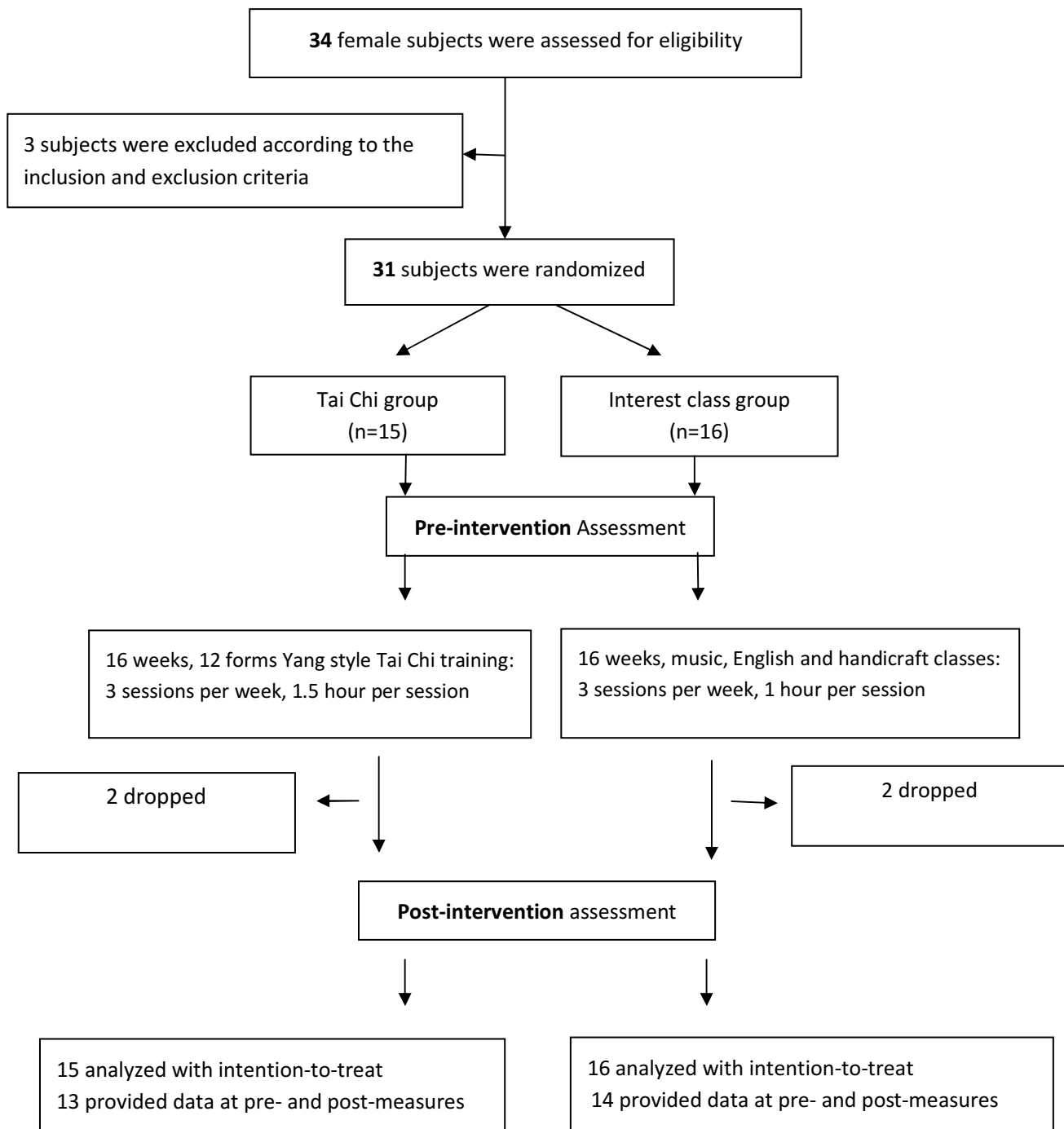


Figure 5.1. Flowchart of subjects recruited and procedure

5.4.1 Auditory Stroop test

Before intervention, the two groups showed similar performance in the auditory Stroop test under both single- and dual-task conditions. Both groups showed slower response times and higher error rates under the dual-task condition than in the single-task condition. After the intervention the Tai Chi group members showed significantly lower average error rates in both conditions than before the intervention, while the control group did not achieve a statistically significant improvement in the dual-task condition (see Table 5.2). The reaction time difference between the dual- and single- task conditions was calculated and taken to represent the attentional cost of dual-tasking; there was no significant difference between the attentional cost before and after intervention too (Table 5.2).

5.4.2 Stepping down performance

For the single-task stepping down performance, Tai Chi group showed a significant improvement in the COP total sway path and sway area ($p=0.016$, 0.001 respectively, see table 5.3) while the control group only improved in the sway area ($p=0.016$, Table 5.3) after the 16 weeks of intervention.

When the stepping down task and the Stroop test were performed together, After intervention, there was a between group difference in the groups' average COP sway areas ($p=0.036$). The Tai Chi subjects showed significantly less body sway as reflected in the average COP sway path and area ($p=0.002$ and $p=0.005$, respectively;

Table 5.4). The COP sway in the control group did not show any difference pre and post intervention (Table 5.4).

Table 5.2. Cognitive performance of control and Tai Chi subjects.

		Control			Tai Chi		
		pre	post	<i>p value</i>	pre	post	<i>p value</i>
Single	RT(s)	1.0±0.2	1.0±0.2	0.826	1.1±0.3	1.1±0.4	0.382
	ER(%)	14.8±14.7	10.9±14.7	0.355	12.9±11.2	10.4±9.9	0.399
Dual	RT(s)	1.7±0.4	1.6±0.6	0.510	1.8±0.5	1.6±0.4	0.196
	ER(%)	21.5±14.6	15.6±5.3	0.066	25.8±15.5	16.3±14.5	0.009*
Attentional cost		0.7±0.4	0.6±0.5	0.433	0.7±0.6	0.5±0.4	0.133

*indicates a pre-post difference significant at the $p < 0.05$ level of confidence. RT, reaction time; ER, error rate.

Table 5.3. Stepping down performance (single-task)

	Control			Tai Chi		
	pre	post	<i>p</i> value	pre	post	<i>p</i> value
COP path (mm)	284.6±115.2	239.5±46.4	0.064	278.9±90.2	224.5±58.1	0.016*
COP area (cm*cm)	9.6±3.8	7.6±3.6	0.016*	10.7±4.8	6.3±2.3	0.001*
Time (s)	0.7±0.3	0.7±0.4	0.183	0.9±0.4	0.8±0.3	0.753

*indicates a pre-post difference significant at the $p < 0.05$ level of confidence.

Table 5.4. Stepping down performance with dual-task paradigm

	Control			Tai Chi		
	pre	post	<i>p</i> value	pre	post	<i>p</i> value
COP path (mm)	269.3±61.9	256.9±59.5	0.730	262.4±66.8	220.1±52.4	0.002*
COP area (cm*cm)	10.7±4.8	9.3±4.0#	0.300	9.5±3.1	6.5±2.6#	0.005*
Time (s)	0.7±0.3	0.7±0.3	0.866	0.7±0.1	0.7±0.1	0.173

*indicates a pre-post difference significant at the $p < 0.05$ level of confidence;

#indicates a between-group difference significant at the $p < 0.05$ level of confidence.

5.5 Discussion

This has been the first published study to examine the effect of Tai Chi training on postural stability using a stepping down task with and without a concurrent cognitive task. The results provide evidence that 16 weeks of Tai Chi training can help older women improve their cognition and postural control, specifically when dual-tasking.

After Tai Chi training the women showed improved error rate in the dual-task condition. This was not observed among the control subjects. Tai Chi practice involves a lot of visual imagery concurrent with the physical movements. The frequent evoking of imagery may encourage subjects to divide and shift their attention between cognitive processing and physical performance. The results show that with Tai Chi training, older women tend to improve their dual-tasking performance, but not in the single-task condition.

Tai Chi training would be expected to improve postural control after stepping down, and the subjects in the Tai Chi training group did show improvements in COP total sway path and sway area (Table 5.3). These results are in line with those of a previous cross-sectional study which found that experienced Tai Chi subjects (mean Tai

Chi experience of 6.7 years) showed better postural control after a stepping down (Lu et al., 2012c). Since Tai Chi involves maneuvers such as “push down and lift one leg” and “turn and kick with the heel” which are performed on one leg, repeated practice would be expected to improve balance in single leg stance (Gyllensten et al., 2010). At the same time Tai Chi practice develops leg strength, especially in the eccentric knee extensors which are important in stepping down (Lu et al., 2012a).

When stepping down with a concurrent cognitive task the Tai Chi subjects showed decreased COP sway after the training which was not observed in the control subjects. Researchers have used such dual-task performance to predict fall risk in the elderly (Condrón and Hill, 2002; Verghese et al. 2002; Bergland et al., 2003) and it has demonstrated better predictive power than single-task protocols. Therefore, any intervention which could improve dual-task performance should be helpful for fall prevention among older adults. A group led by Silsupadol has shown that dual-task balance training has better effects than single-task balance training in improving balance performance under both single- and dual-task conditions (Silsupadol et al., 2009b).

Tai Chi is a mind-body exercise which trains both the mind and the physique. Practice involves focusing on and imagining the movement sequence. Tai Chi practice is therefore a form of dual-task training. The training specificity principle therefore predicts improvement in outcome measures involving dual-tasking. A group led by Hall investigated the effects of Tai Chi training on dual-task performance. They recruited 15 older adults and assigned them into either a Tai Chi training group or a control group for 12 weeks of training with two contact sessions per week. They found that the Tai Chi subjects showed no improvement in body sway under different sensory conditions or in obstacle-avoidance walking while dual-tasking (Hall et al., 2009). They explained the lack of significant improvement is because the Tai Chi participants might not have actively engaged in practicing visual imagery during their movements. Also, the visual imagery involved in Tai Chi practice may not be related closely enough to the dual assessment tasks (Hall et al., 2009). The different results observed in this study may be due to the training dosage. With a shorter learning and practicing duration (12 weeks, two sessions per week), the subjects might not have been able to master visual imagery. Also, Tai Chi involves complex forms that demand coordination of the limbs and trunk. Longer training is required to benefit from such advanced skills. The 16 weeks of

training with 3 sessions per week amounted to 48 training sessions, double the quantity in Hall's study. Extra practice should promote mastery in visual imaging during the movements.

A group led by Silsupadol has studied dual-task training with variable priority (shifting attention between tasks) and claims that it has advantages over fixed-priority training (placing equal attention on both tasks) for improving dual task performance (Silsupadol et al., 2009a). In that research, 3 groups of older adults underwent 4 weeks of balance training under either single-task conditions, dual-task conditions with a fixed priority or dual-task conditions with variable priority. Although all three groups showed improved balance in the single-task condition, only the variable-priority group showed both improved cognitive and balance performance while dual-tasking (Silsupadol et al., 2009a). In this connection, Tai Chi is an exercise which trains both attention and postural control during its practice without requesting the subjects to focus on either one. Such training is similar to the variable priority training as in Silsupadol and colleagues' study. This may explain the improvements in the dual-tasking performance for the Tai Chi training subjects in our study.

Only female subjects were recruited in this study, so the results may not apply equally older men. The small sample may have contributed to the lack of significant differences in some of the outcomes. Further research with a larger sample might prove fruitful.

5.6 Conclusion

Tai Chi training can benefit the cognition and postural control of the older adults when dual-tasking. Whether such improved dual-task performance influences the incidence of falls warrants further investigation.

CHAPTER 6

CHANGES OF HEART RATE VARIABILITY AND PREFRONTAL OXYGENATION DURING TAI CHI PRACTICE AND ERGOMETER CYCLING– A PILOT STUDY

Manuscript:

Lu X, Christina W.Y. Hui-Chan and Tsang, W. W.N. Changes of heart rate variability and prefrontal oxygenation during Tai Chi practice and ergometer-a pilot study. Ready for submission.

Conference presentation:

Lu RX, Jones AYM, Tsang WWN. Changes of prefrontal oxygenation and heart rate variability during Tai Chi practice and ergometer cycling. In The Seventh Pan-Pacific Conference on Rehabilitation 2010, Hong Kong, October 23–24, p. 67.

6.1 Abstract

Background: Exercise has been shown to improve cardiovascular fitness and cognitive function. How mind-body exercise alters the autonomic function and brain activity during practice is not known. The aim of this study was to compare the effects of Tai Chi (mind-body exercise) versus arm ergometer cycling (body-focused exercise) on heart rate variability and cranial oxyhaemoglobin level.

Design: One Tai Chi masters was invited to perform Tai Chi and arm ergometer cycling with similar exercise intensity on two separate days.

Methods: Heart rate variability and cranial oxyhaemoglobin level were measured continuously by a RR recorder and a near infrared spectroscopy, respectively.

Results: During Tai Chi exercise, spectral analysis of heart rate variability demonstrated a higher high-frequency power as well as lower low-frequency/high-frequency ratio when compared to during ergometer cycling. Also, the oxy-hemoglobin and total hemoglobin levels were higher than those during arm ergometer exercise.

Conclusion: The reduced sympathetic and increased parasympathetic modulation of the autonomic nervous system as well as the higher prefrontal lobe activities may be associated with Tai Chi exercise because its practice has a mindful component which may be more helpful for older adults' cardiac health and cognitive function when compared to arm ergometer cycling.

Keywords: Tai Chi; mind; heart rate variability; prefrontal activity

6.2 Introduction

Cardiovascular diseases in the older adults are often associated with perturbed autonomic balance, manifested by an increase in sympathetic modulation, a decrease in parasympathetic modulation or a combination of both (De Meersman & Stein, 2007). In aging, the autonomic control of the cardiovascular system favours heightened cardiac sympathetic tone with parasympathetic withdrawal, which can magnify the effects of concomitant cardiovascular disease (Kaye & Esler, 2008). Studies have shown that parasympathetic control of the heart during exercise is important for cardiac health (Goldsmith, 2000) and long-term physical endurance training increases parasympathetic activity and decreases sympathetic activity in humans at rest (Goldsmith et al., 2000).

Aging is often associated with changes in cognitive functioning. These changes can be normal as in normal aging or due to pathological reasons in people with mild cognitive impairment or dementia (Peterson, 2003). Much attention have been placed on interventions which attempt to reverse or slow down the progression of cognitive decline in the older adults with and without cognitive impairment (Peterson et al., 1997). Recent evidence begins to show that exercise may protect against cognitive impairments

in aging (Larson et al., 2006). One of the hypotheses is that exercise can induce angiogenesis. In animal model, exercise was found to increase blood flow in the cerebellum, motor cortex, and hippocampus after 30 days of wheel running to rats (Swain et al., 2003). In older adults reaching their retirement age, regular exercise could sustain their cerebral blood flow when compared to inactive controls (Rogers et al., 1990).

Tai Chi (TC) is regarded as a mind-body exercise, as its practice requires subjects to be “mindful” of the intrinsic energy from which s/he may ultimately perceive greater self-control and empowerment (La Forge, 1997). Like other mind-body exercises, such as yoga, qigong and aikido, TC involves meditation, imagery, concentration on the self and diaphragmatic breathing during its practice (La Forge, 2005). The question then naturally arises: Is there a difference between a mind-body exercise like TC and a body-focused exercise such as running or cycling on the autonomic control of heart? Therefore, the first objective of this study was to investigate the effects of TC versus arm ergometer cycling on the autonomic control of the heart activity. Moreover, the effect of mind-body exercise on cerebral oxyhaemoglobin level, especially in the prefrontal cortex, may be different from the effect of body-focused

exercises such as cycling. Therefore, the second objective of this study was to compare the effects of TC and arm ergometer cycling on the prefrontal cortex activity. The measurements of heart and brain activities were conducted before, during and immediate after the exercises.

6.3 Methodology

6.3.1 Subject

A healthy Tai Chi master (age 65 years, 168 cm tall, weighing 56 kg) was invited to participate in the study. She signed a written informed consent which was approved by the Department of Rehabilitation Sciences of the Hong Kong Polytechnic University (Appendix V). This Tai Chi master had been practicing and teaching Tai Chi for more than 20 years.

6.3.2 Procedures

The subject attended our laboratory on two separate afternoons at similar times to ensure constant assessment conditions. She was asked to perform a 12-form *Yang* style TC routine (Lee et al., 2011) on the first day and exercised with the arm ergometer (EGO) (Monark Electric Ergometer Model 829E, Monark AB, USA) in a similar standing position on the other day. Measurement started with subject sitting quietly for 10 min, followed by 12 min of exercise, and then another 10 min of quiet sitting. The intensity during EGO cycling was kept at the same level based on the calculated oxygen consumption during the TC practicing. Both the heart rate variability and prefrontal oxygenation were measured throughout the 10-12-10 minutes interval which will be described as follow.

6.3.3 Measurements

6.3.3.1 Heart rate variability

With measurement of heart rate variability (HRV) using the consecutive electrocardiogram, the R to R peak intervals were continuously recorded using an RR recorder attached around the chest (Polar RS800, Polar Electro Ltd., Finland) with a

sampling frequency of 1000 Hz. Pulse signals were transmitted to a Polar watch and stored for off-line spectral analysis. To standardize TC and EGO exercise intensities, breath by breath oxygen consumption, respiratory frequency and tidal volume during the two exercises were recorded with a metabolic cart (K4B2, COSMED, Pavona di Albano, Italy) which was calibrated prior to data collection. The turbine was calibrated with a 3 litre syringe.

The spectral analysis of HRV is a well developed method for assessing autonomic control of the heart. Power at high frequencies (HFs) are taken as indicating parasympathetic control, while lower frequency (LF) power has been taken as an index of sympathetic control since the method was introduced by Akselrod in 1981 (Akselrod 1981). Studies using this method have found that concentration and mindful meditation have significant neuro-physiological effects on autonomic nervous control, causing an increase in parasympathetic tone and decreased sympathetic activity (Lazar et al. 2000; Curiati et al. 2005).

6.3.3.2 Prefrontal oxygenation

The brain's prefrontal cortex controls various cognitive functions, including self-awareness and executive functions (Lundy-Ekman 2002), as reflected by neuropsychological tests of mental activation like the continuous performance test (Fallgatter & Strike 1997) and the Wisconsin Card Test (Fallgatter & Strike 1998). Oxygenation of the prefrontal area during exercise can be investigated non-invasively using near infrared spectroscopy (NIRS). It measures tissue oxygenation through comparing the light absorption spectra of oxygenated hemoglobin (O_2Hb) and deoxygenated hemoglobin (HHb) at their specific wavelengths based on the Lambert-Beer law (Perry 2008; Timinkul et al. 2008). The NIRS was employed in this study to measure the prefrontal cerebral O_2Hb and HHb levels, and to infer total hemoglobin (cHb) (the sum of O_2Hb and HHb). An NIRO 200 spectroscope (Hamamatsu Photonics, Japan) was used with the sampling frequency set at 1 Hz. Two probes were attached to the subject's forehead for measurement.

6.3.4 Data recording and analyses

Analysis of HRV was performed using a short-time Fourier transformation (STFT) of the RR intervals during exercise. The RR interval signals were transported to a computer running Polar Protrainer 5 software (Polar Electro Ltd., Oulu, Finland) through an infrared USB adapter. The artifacts and extra data detected by the system were auto-corrected. Then the RR intervals were processed using MATLAB 7.1 software (The MathWorks Inc., Natick, USA) with a tailored-made program. Since the RR intervals were not stationary during exercise, STFT was employed to calculate the frequency spectrum of the HRV (Cottin et al. 2002; Martinmäki & Rusko 2008) instead of using the conventional fast Fourier transformation (FFT) spectrum analysis to generate the power spectral density in the HF range (between 0.15Hz and 0.4Hz) and the LF range (0.04-0.15 Hz). The HF and LF power in normalized units (HF_{nu} and LF_{nu}) were also calculated according to the methods recommended by the task force on measurement standards of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology (1996) (Task Force 1996) as percentage of power with respect to total power minus very low frequency power. The two parameters emphasized controlled and balanced behavior of the two branches of the autonomic nervous system, while the LF/HF ratio, commonly regarded as an indicator of sympatho-

vagal balance (Task Force 1996), and were also computed. For comparison, the parameters were averaged in every 1 min during exercise and over 10 min in the rest and recovery periods.

Levels of O₂Hb and cHb were recorded over the 10 min of rest and then averaged, and the average was used as the baseline value to normalize the subsequent data recorded during the 12 min of exercise (averaged over each one minute), and during the 10 min recovery which followed.

6.4 Results

6.4.1 Intensity of exercise

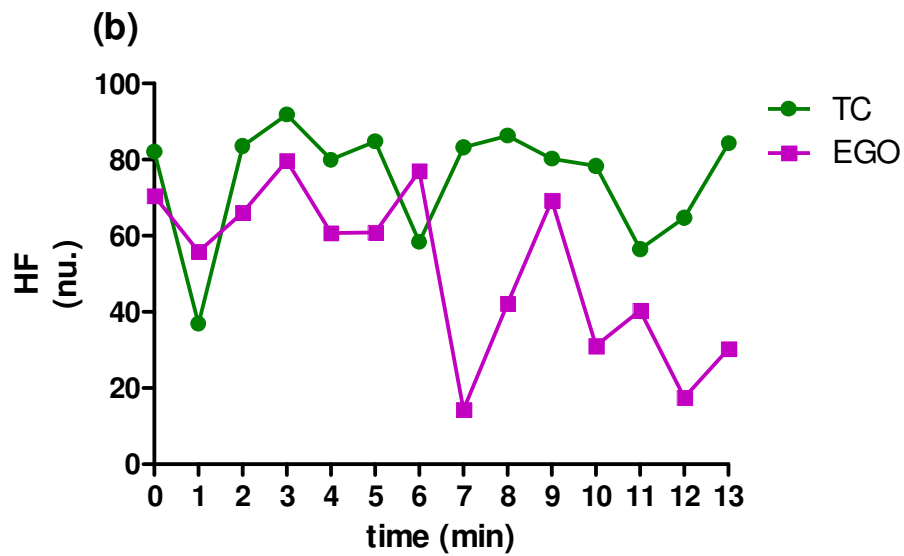
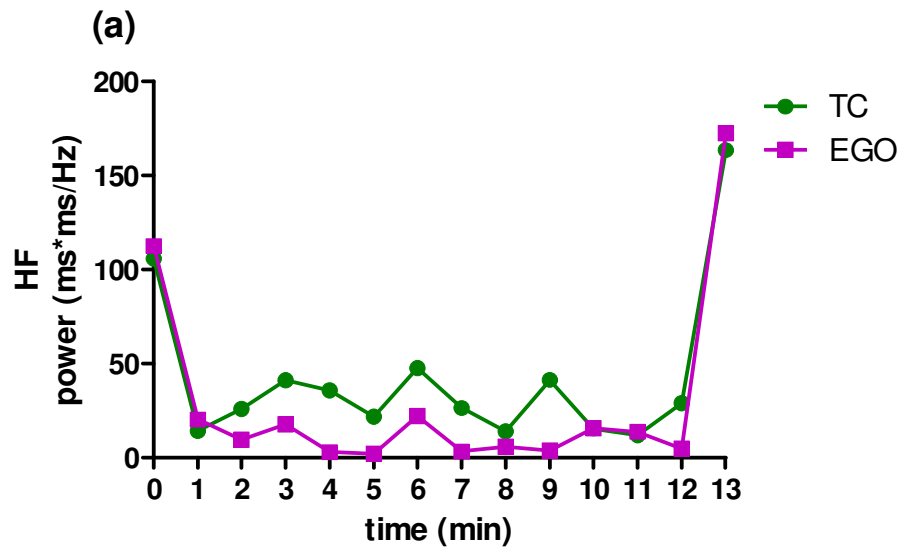
The mean intensities were 2.6 METs for TC and 2.3METs for EGO cycling. C statistic analysis (Portney & Watkins 2009) of oxygen consumption between resting and exercise gave a Z value of 4.61 for Tai Chi and 4.63 for ergometer cycling based on C statistic. These values demonstrate that the exercise intensities of the two exercises were similar.

6.4.2 Spectral analysis of heart rate variability during the two exercises

6.4.2.1 HF power

The HF power spectrum decreased at the start of both exercises and increased in the recovery phase (Figure 6.1a). The Z scores were 3.3 for TC and 3.46 for EGO. The between exercises comparison showed that during TC, the decrease in HF power was less than during EGO. The overall display also shows that during TC the HF power in normalized unit was generally higher than during EGO (Figure 6.1b).

Comparing the two exercise periods, HRV during TC had higher HF power than that during ergometer cycling, as shown in figures 6.1c and 6.1d. The two figures show the changes during the 12 min exercise periods without the baseline and recovery periods.



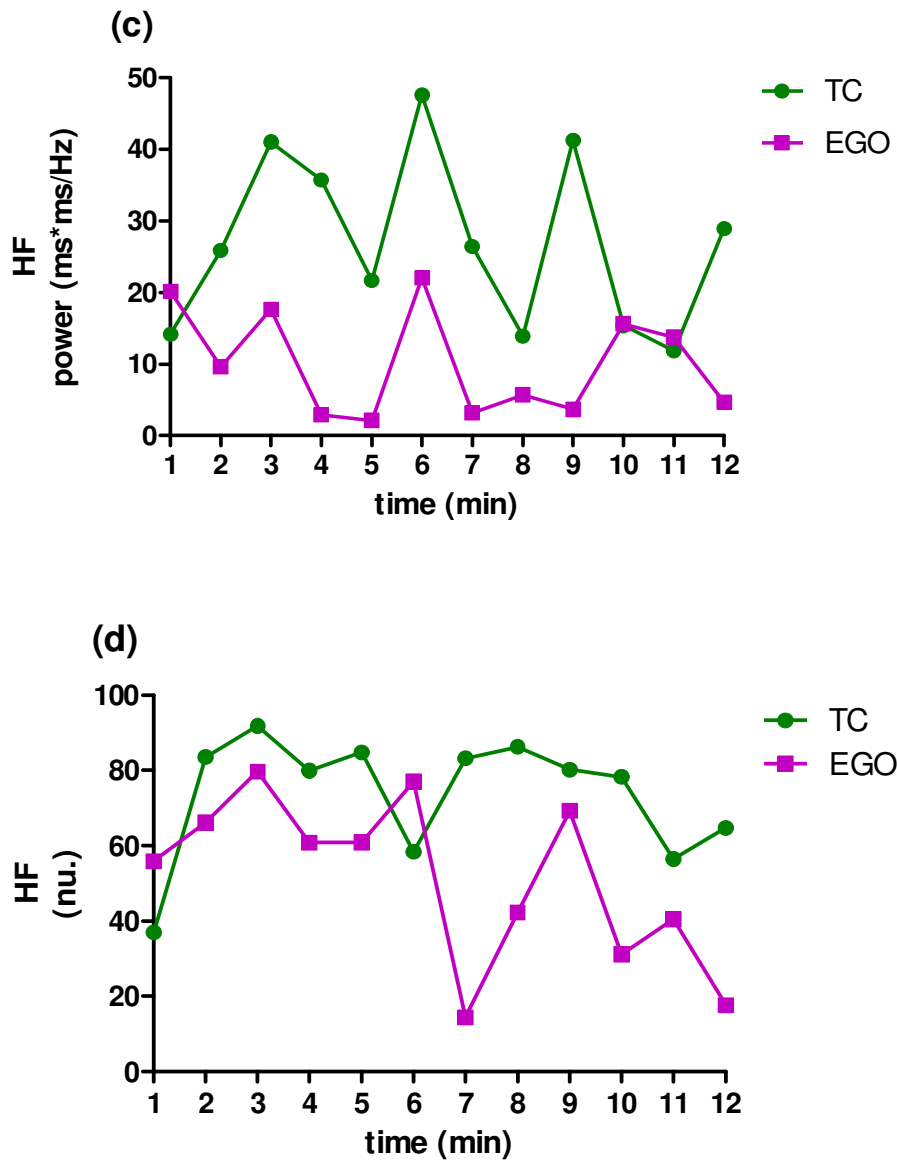


Figure 6.1. HF power (a) and normalized HF power (b) during the 2 exercise conditions.

The time“0” value represents the average value during 10 min at rest, and “13” the 10 min recovery periods. HF power (c) and normalized HF power (d) during two 12min exercises.

6.4.2.2 LF/HF ratio

The LF/HF ratio was higher in ergometer cycling than in Tai Chi, especially from the 7th minute onwards (Figure 6.2).

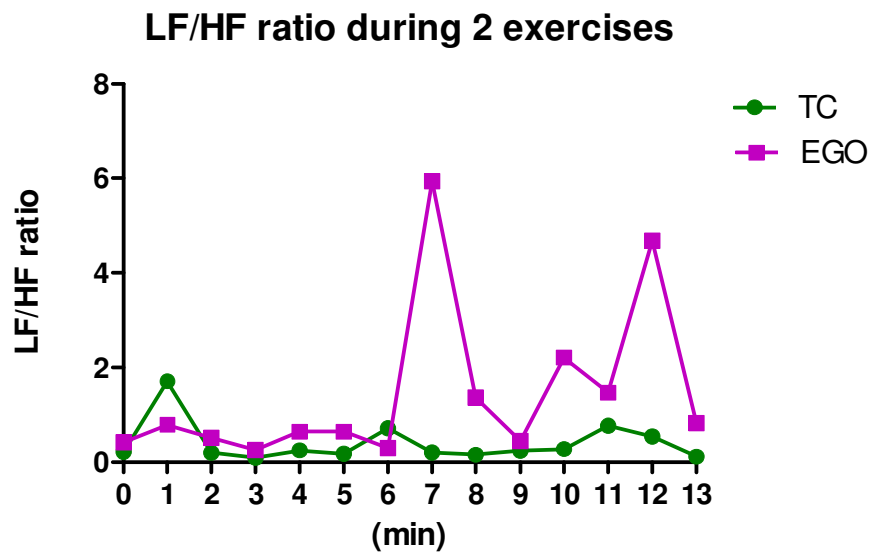
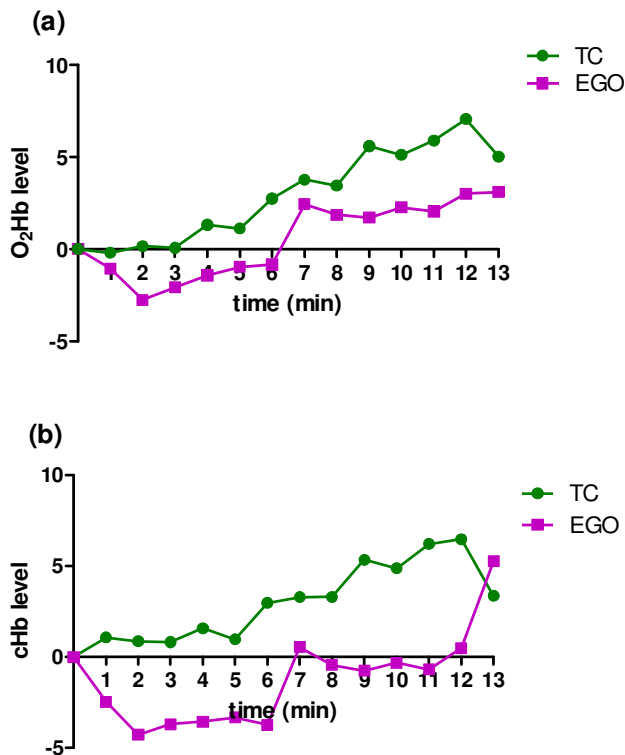


Figure 6.2, LF/HF ratios during the two exercises. The time“0” value represents the average value during 10 min at rest, and “13” the 10 min recovery periods.

6.4.3 Changes in O₂Hb, cHb during exercise

The O₂Hb and cHb levels gradually increased during the TC routine. However, both levels initially decreased, then increased in the later phases of EGO exercise (Figure 6.3a, b). The Z values were 4.06 and 3.81 for TC and EGO respectively based on C statistic. Both exercises showed overall increased oxygenation of the prefrontal area. The left /right hemisphere difference in O₂Hb during the two exercises is shown in Figure 6.3c, d. The figures clearly show that the difference between exercises was more obvious in the left hemisphere.



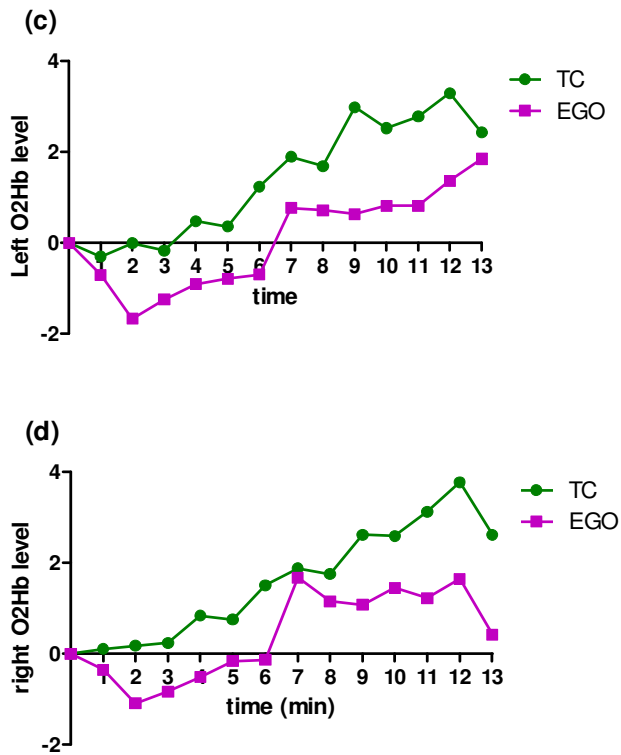


Figure 6.3. O₂Hb (a) and cHb (b) during the two exercises. Left (c) and right hemispheric (d) O₂Hb activities during the two conditions. Time “0” represents the averaged value during 10 min at rest, and “13” the 10 min recovery periods.

6.5 Discussion

6.5.1 Spectral analysis of HRV during exercises

In a cross-sectional study, Lu and Kuo (2003) observed that experienced Tai Chi practitioners had higher HF power and lower LF/HF ratios, implying more dominant

parasympathetic control of the heart. Their protocol included 20 minutes of Tai Chi, a 10 min warm-up and 10 min of cooling down. However, they investigated only before and after Tai Chi practice without looking into HRV during the exercise. Also, there was no control exercise to compare the autonomic control of the heart with Tai Chi practice. In this study, the Tai Chi master displayed higher HF power and a lower LF/HF ratio in HRV during TC than during EGO cycling at similar exercise intensity, suggesting more parasympathetic control of the heart during TC compared with cycling.

Dimsdale and Mills (2002) found that meditation could override a powerful adrenergic stimulus (isoproterenol) administered through blood infusion. We theorized that Tai Chi's mind component might similarly override the tendency of the exercise to tip the sympathetic-vagal balance towards more vagal mediation. The mechanism might be that a TC master exercises in a meditative manner resulting in relaxation which might lead parasympathetic control of the heart to dominate, unlike cycling. Our results indeed show that during Tai Chi practice the subject might have had greater parasympathetic control of the heart than during cycling at similar intensity.

6.5.2 Cranial O₂Hb and cHb during exercise

Cranial O₂Hb is one of the valid parameters reflecting cortical activation during movement (Perrey, 2008). Timinkul and colleagues (2008) showed that mild intensity exercise increased oxygenation of the prefrontal area in young subjects while they performed incremental exercise cycling. Their results were similar to those of this present study. Intensity of only about 2.5 METs can increase cerebral oxygenation in the older subject.

The prefrontal activity monitored in this study showed that TC and EGO caused different oxygenation despite of their similar exercise intensity. The comparatively greater O₂Hb and cHb increases during TC may suggest that the subject had more neuronal activation than when EGO cycling. As the physical intensities of both forms of exercise were similar, it may be that the additional prefrontal activation during TC might result from the requirements of TC's mental involvement. Litscher and colleagues (2001) found that during qigong, another mind-body exercise, there were increased O₂Hb and cHb levels in the practitioners' frontal area while they were sitting without

any physical movement. However, that study did not involve a physical component and did not have another body-focused exercise for comparison.

6.5.3 Asymmetry of the prefrontal activity during exercise

The results show that the left prefrontal area showed more obvious difference between the two exercises, although differences were observed on both sides. The left prefrontal area was activated more during TC than the right side especially after 7th minute. The TC in this study involved mainly upper limb activity, like the arm ergometer cycling performed in a similar standing position. Both exercises were bimanual, so motor arousal was equally distributed on the two sides of the brain. Previous research has proposed that the right brain is responsible for sympathetic control of the heart, while the left side is related to parasympathetic control (Wittling et al. 1998). The results showing more activation of the left prefrontal cortex during TC than during EGO cycling may therefore be related to greater parasympathetic control of the heart during TC, as indicated also by the higher HF power and lower LF/HF ratio. However, any direct connection between increased pre-frontal oxygenation during TC

practice and dominant parasympathetic control of the heart could not be definitively established in the present investigation. Further study is warranted.

There was only one female subject participated in this study and she was at a master level of TC. Therefore, the findings cannot be generalized to male subjects and practitioners at the beginner level. Although the participants performed the exercises in a quiet environment, their mental state was not controlled.

6.6 Conclusion

The present study compared the effects of TC and EGO on heart rate variability and concurrent prefrontal lobe activities during the exercises. Our results showed that both exercises increased the parasympathetic modulation of the autonomic nervous system and prefrontal lobe activities with more activities observed in TC exercise. TC, a mind-body exercise may be a good choice to improve the cardiovascular health and cognitive function of the older adults. However, further research is warranted.

CHAPTER 7

SUMMARY AND CONCLUSIONS

7.1 The rationale of the study

Aging increases the risks of cardiovascular diseases and falls, and this is a growing social problem. Studies have shown that arterial compliance is an important predictor of cardiovascular diseases, making maintaining good arterial compliance important for older adults. Aerobic exercises are beneficial for arterial compliance. Improving and maintaining muscle strength is also important, but resistance exercises have been found to decrease arterial compliance. Therefore exercise modes which combine muscle strengthening with improving arterial compliance are needed.

Falls often occur when older adults are dual-tasking. Modern falls prevention programs focus on maintaining postural control while dual-tasking. Stepping down is a posturally demanding functional task, and the incidence of falls while negotiating stairs and simultaneously trying to deal with a second cognitive task is high for older adults. Therefore, exercises which can enhance older adults' ability to manage such functional activities while dual-tasking are required.

Tai Chi requires a combination of mind and body control during practice. Practicing it therefore trains both cognitive and physical capacity. Previous studies have explored only the postural or cognitive effects of Tai Chi training either, never both

together. Research on the interaction of Tai Chi's mind and body elements has been lacking.

Studies 1 and 3 were cross-sectional investigations while studies 2 and 4 were randomized clinical trials. Studies 1 and 2 explored Tai Chi's effects on arterial compliance and muscle strength. Studies 3 and 4 aimed to find out to what extent Tai Chi training might improve dual-tasking performance. Finally, study 5 was a pilot case study exploring the underlying mechanisms of Tai Chi's mind and body effects.

7.2 Summary of the findings

The studies presented in this thesis aimed to contribute to the knowledge about the mind-body interaction effects of Tai Chi on the cardiovascular, muscle strength and dual-tasking performance. The summary below outlines the findings in regard of the gains in arterial compliance, muscle strength, and the dual-tasking performance.

7.2.1 Arterial compliance and muscle strength

This has been the first research to demonstrate that older Tai Chi practitioners display significantly better arterial compliance than controls similar in age, gender and physical activity level. The results also show that experienced Tai Chi practitioners had better lower limb muscle strength without any decrease in arterial compliance (Chapter 2). These findings were corroborated by a randomized clinical trial conducted with elderly women (Chapter 3). After 16 weeks of Tai Chi training the women had improved arterial compliance as well as stronger lower limbs while matched controls showed no such improvements. A cause-effect relationship could therefore be established. Tai Chi training improved leg strength without decreasing arterial compliance.

The shifting of autonomic control to the parasympathetic system may contribute to this effect. Tai Chi is practiced with mindful relaxation, which may counteract the sympathetic activity resulting from the strengthening component of Tai Chi exercise during the semi-squatting position.

Based on these positive findings, Tai Chi may be an option for older adults to maintain and improve their cardiovascular health and muscle strength.

7.2.2 Dual-tasking performance

Previous studies have demonstrated that older adults suffer from insufficient attentional capacity during dual-tasking. The better performance during dual-tasking (a cognitive with a stepping down task) shown by the Tai Chi subjects in this study may be an indicator of their greater attentional resources (Chapter 4). In the subsequent randomized clinical trial, after 16 weeks of Tai Chi training, the elderly subjects improved their postural control in both single- and dual-task conditions, they also making fewer errors in the auditory Stroop test (Chapter 5). The achievements in Tai Chi groups compared with the control groups might be related to the training effects of Tai Chi's interacting mind and body aspects. Through repeated training, both cognitive and postural control capabilities can be enhanced in older adults.

7.2.3 Brain activity

The pilot study exploring the effects of Tai Chi on the autonomic control of heart rate and prefrontal lobe activation (Chapter 6) showed that an experienced Tai Chi practitioner had greater parasympathetic control of the heart and more prefrontal lobe activity during Tai Chi practice than during ergometer exercise. The parasympathetic

control of the heart maybe related to the relaxation response caused by Tai Chi's meditation element. The greater prefrontal lobe activity observed during Tai Chi practice than during cycling may have been caused by the higher mental involvement during Tai Chi practice exciting the prefrontal lobe.

7.3 Limitations and future studies

The target group of these experiments was healthy adults aged 60 years or above. Further studies of the effects of Tai Chi training on arterial compliance and muscle strength in older subjects with cardiovascular diseases or at risk of developing cardiovascular diseases are needed. Studies on the effects of Tai Chi training on subjects who are at risk of falling or subjects with balance impairments are also required to gain an understanding of to what extent Tai Chi might benefit such populations.

In the cross-sectional study on arterial compliance and muscle strength (Chapter 2), no measurements of autonomic nervous system activity were conducted. As a result, no contribution to better arterial compliance from decreasing in sympathetic control could be established. Further studies on the association between arterial compliance and

autonomic control are needed to support the proposed mechanism of Tai Chi's mind effects on vascular health. On the other hands, then female and male subjects were analysis together in this study, the lack of gender specific analyses made the results be generalized to male subjects more difficult.

Only women were recruited for the two randomized clinical trials (Chapters 3 and 5). Further studies with male subjects are needed. This is especially important for studying arterial compliance, since there is a known gender difference in arterial compliance as well as muscle strength. Men normally have better arterial compliance and greater muscle strength than women of the same age. Hence male subjects may behave differently in terms of arterial compliance and muscle strength after training. Besides, the small sample size in these two RCT studies also made some of the results did not show significant difference.

The mind-body effect of Tai Chi training was proposed to promote vascular health and muscle strength, but also to improve dual-tasking performance. The underlying association between the mind effects and the body effects needs to be further established. The results also show that demonstrating any relationship between

autonomic control and prefrontal activation will require a study with more subjects to establish any relationship.

7.4 Conclusion

Tai Chi could be a suitable exercise for improving the arterial compliance and muscle strength of older adults. Practicing Tai Chi can also enhance older adults' dual-tasking performance and may help to prevent falls.

REFERENCES

Acree LS, Montgomery PS, Gardner AW. The influence of obesity on arterial compliance in adult men and women. *Vasc Med* 2007; 12(3):183-188.

Akselrod S, Gordon D, Ubel FA, Shannon DC, Berger AC, Cohen RJ. Power spectrum analysis of heart rate fluctuations: a quantitative probe of beat to beat cardiovascular control. *Science* 1981; 213: 220-222.

Albaladejo P, Laurent P, Pannier B, Achimastos A, Safar M, Benetos A. Influence of sex on the relation between heart rate and aortic stiffness. *J Hypertens* 2003; 21(3): 555-562.

American Heart Association. *Heart Disease and Stroke Statistics—2008 Update*. Dallas, Texas: American Heart Association; 2008.

Anstey KJ, von Sanden C, Luszcz MA. An 8-year prospective study of the relationship between cognitive performance and falling in very old adults. *J Am Geriatr Soc* 2006; 54(8): 1169–1176.

Appels A, Mulder P. Fatigue and heart disease. The association between 'vital exhaustion' and past, present and future coronary heart disease. *J Psychosom Res* 1989; 33(6):727-738.

Arnett DK, Evans GW, Riley WA. Arterial stiffness: a new cardiovascular risk factor? *Am J Epidemiol* 1994; 140(8):669–682.

Audette, J F, Jin, YS, Newcomer, R. et al. Tai Chi versus brisk walking in elder woman. *Age Aging* 2006; 35(4): 388–393.

Barrow DE, Bedford A, Ives G, O'Toole L, Channer KS. An evaluation of the effects of Tai Chi Chuan and Chi Kung training in patients with symptomatic heart failure: A randomised controlled pilot study. *Postgrad Med J* 2007; 83(985):717–721.

Beauchet O, Annweiler C, Allali G, Berrut G, Herrmann FR, Dubost V. Recurrent falls and dual task-related decrease in walking speed: is there a relationship? *J Am Geriatr Soc* 2008; 56(7):1265-1269.

Beauchet O, Dubost V, Gonthier R, Kressig RW. Dual-task-related gait changes in transitionally frail older adults: the type of the walking-associated cognitive task matters. *Gerontology* 2005; 51(1):48-52.

Beauchet O, Dubost V, Nevers A, Stierlam F, A Blanchon M, Mourey F, Pfitzenmeyer P, Gonthier R. Development of a clinical test of gait in frail elderly by a cognitive approach of locomotion. *Ann Readapt Med Phys* 2002; 45(3): 123–230.

Benson H. Historical and clinical considerations of the relaxation response. *Am Sci* 1977; 65: 441–445.

Bergland A, Jarnlo GB, Laake K. Predictors of falls in the elderly by location. *Aging Clin Exp Res* 2003; 15(1): 43–50.

Bertelson P. Central intermittency twenty years later. *Q J Exp Psychol* 1966; 18(2):153-163.

Bertovic DA, Waddell TK, Gatzka CD, Cameron JD, Dart AM, Kingwell BA. Muscular strength training is associated with low arterial compliance and high pulse pressure. *Hypertension* 1999; 33(6):1385–1391.

Blacher J, Asmar R, Djane S, London GM, Safar ME. Aortic pulse wave velocity as a marker of cardiovascular risk in hypertensive patients. *Hypertension* 1999; 33(5): 1111-1117.

Borchard U. The role of the Sympathetic Nervous System in Cardiovascular Disease. *J Clin Basic Cardiol* 2001; 4(3): 175-177.

Boutouyrie P, Tropeano AI, Asmar R, Gautier I, Benetos A, Lacolley P, Laurent S. Aortic stiffness is an independent predictor of primary coronary events in hypertensive patients: a longitudinal study. *Hypertension* 2002; 39(1):10–15.

Brauer SG, Woollacott M, Shumway-Cook A. The interacting effects of cognitive demand and recovery of postural stability in balance-impaired elderly persons. *J Gerontol A Biol Sci Med Sci* 2001; 56(8): M489-496.

Brauer SG, Woollacott M, Shumway-Cook A. The influence of a concurrent cognitive task on the compensatory stepping response to a perturbation in balance-impaired and healthy elders. *Gait Posture* 2002; 15(1):83-93.

Brown LA, Shumway-Cook A, Woollacott MH. Attentional demands and postural recovery: the effects of aging. *J Gerontol A Biol Sci Med Sci* 1999; 54(4): M165-171.

Brown LA, Sleik RJ, Polych MA, Gage WH. Is the prioritization of postural control altered in conditions of postural threat in younger and older adults? *J Gerontol A Biol Sci Med Sci* 2002; 57(12): M785–792.

Brown M, Holloszy JO. Effects of walking, jogging and cycling on strength, flexibility, speed and balance in 60- to 72-year olds. *Aging (Milano)* 1993; 5: 427–434.

Buch AN., Coote JN., Townend JN. Mortality, cardiac vagal control and physical training--what's the link? *Exp Physiol* 2002; 87(4): 423-435.

Bunker SJ, Colquhoun DM, Esler MD, Huickie IB, Hunt D, Jelinek VM et al. “Stress” and coronary heart disease: psychosocial risk factors. *Med J Aust* 2003; 178(6): 272–276.

Buracchio TJ, Mattek NC, Dodge HH, Hayes TL, Pavel M, Howieson DB, Kaye JA. Executive function predicts risk of falls in older adults without balance impairment. *BMC Geriatr* 2011; 11:74.

Cameron JD, Bulpitt CJ, Pinto ES, Rajkumar C. The aging of elastic and muscular arteries: a comparison of diabetic and nondiabetic subjects. *Diabetes Care* 2003; 26(7): 2133-2138.

Cameron JD, Cruickshank JK. Glucose, insulin, diabetes and mechanisms of arterial dysfunction. *Clin Exp Pharmacol Physiol* 2007; 34(7): 677-682.

Carspersen C, Powell K, Christenson G. Physical activity, exercise, and physical fitness: definition and distinctions for health-related research. *Public Health Rep* 1985; 100: 126-131.

Carter JB, Banister EW, Blaber AP. Effect of endurance exercise on autonomic control of heart rate. *Sports Med* 2003; 33 (1): 33-46.

Carter ND, Kannus P, Khan KM. Exercise in the prevention of falls in older people: A systematic literature review examining the rationale and the evidence. *Sports Med* 2001; 31:427-438.

Cernes N, Zimlichman R, Shargorodsky M. Arterial elasticity in cardiovascular disease: focus on hypertension, metabolic syndrome and diabetes. *Adv Cardiol* 2008; 45: 65-81.

Chan KM, Maffulli N, Korkia P, LI RCT. Principles and Practice of Isokinetics in Sports Medicine and Rehabilitation. Hong Kong: Williams & Wilkins, 1996, pp. 107–186.

Channer KS, Barrow D, Barrow R, Osborne M, Ives G. Changes in haemodynamic parameters following Tai Chi Chuan and aerobic exercise in patients recovering from acute myocardial infarction. *Postgrad Med J* 1996; 72(848):349–351.

Chen EW, Fu AS, Chan KM, Tsang WW. The effects of tai chi on the balance control of elderly persons with visual impairment: A randomised clinical trial. *Age Ageing* 2012; 41(2): 254–259.

Chiu, HFK, Lee HC, Chung WS, Kwong PK. Reliability and validity of the Cantonese version of Mini-Mental Status Examination: A preliminary study. *J Hong Kong Coll. Psychiatr* 1994; 4: 25–28.

China Sport. Simplified 'Taijiquan'. 2nd. Beijing: China Publications Center, 1983.

Chuckrow R. The tai chi book. Boston: YMAA Publication Center, 1998.

Chumaeva N, Hintsanen M, Ravaja N, Juonala M, Raitakari OT, Keltikangas-Järvinen L.

Chronic stress and the development of early atherosclerosis: moderating effect of

endothelial dysfunction and impaired arterial elasticity. *Int J Environ Res Public Health*

2009; 6(12): 2934-2949.

Chumaeva N, Hintsanen M, Juonala M, Raitakari OT, Keltikangas-Järvinen L. Sex

differences in the combined effect of chronic stress with impaired vascular endothelium

functioning and the development of early atherosclerosis: the Cardiovascular Risk in

Young Finns study. *BMC Cardiovasc Disord* 2010; 12: 10-34.

Cohen G, Martin M. Hemisphere differences in an auditory Stroop test. *Perception &*

Psychophysics 1975; 17(1): 79-83.

Cohn JN, Finkelstein S, McVeigh G, Morgan D, LeMay L, Robinson J et al.

Noninvasive pulse wave analysis for the early detection of vascular disease.

Hypertension 1995; 26(3): 503-508.

Condron JE, Hill KD. Reliability and validity of a dual-task force platform assessment of balance performance: Effect of age, balance impairment, and cognitive task. *J Am Geriatr Soc* 2002; 50(1): 157–162.

Cook JN, DeVan AE, Schleifer JL, Anton MM, Cortez-Cooper MY, Tanaka H. Arterial compliance of rowers: implications for combined aerobic and strength training on arterial elasticity. *Am J Physiol Heart Circ Physiol* 2006; 290(4):H1596–600.

Coppin AK, Shumway-Cook A, Saczynski JS, Patel KV, Ble A, Ferrucci L, Guralnik JM. Association of executive function and performance of dual-task physical tests among older adults: analyses from the InChianti study. *Age Ageing* 2006; 35(6):619-624.

Cortez-Cooper MY, Anton MM, Devan AE, Neidre DB, Cook JN, Tanaka H. The effects of strength training on central arterial compliance in middle-aged and older adults. *Eur J Cardiovasc Prev Rehabil* 2008; 15(2):149–155.

Cottin F, Papelier Y, Durbin F, Koralsztejn JP, Billat VL. Effect of fatigue on spontaneous velocity variations in human middle-distance running: use of short-term Fourier transformation. *Eur J Appl Physiol* 2002; 87(1): 17-27.

Cruickshank K, Riste L, Anderson SG, Wright JS, Dunn G, Gosling RG. Aortic pulse-wave velocity and its relationship to mortality in diabetes and glucose intolerance: an integrated index of vascular function? *Circulation* 2002; 106(16): 2085-2090.

Curiati JA, Bocchi E, Freire JO, Arantes AC, Braga M, Garcia Y, Guimaraes G, Fo WJ. Meditation reduces sympathetic activation and improves the quality of life in elderly patients with optimally treated heart failure: a prospective randomized study. *J Altern Complement Med* 2005; 11(3): 465-472.

de Hoon EW, Allum JH, Carpenter MG, Salis C, Bloem BR, Conzelmann M, Bischoff HA. Quantitative assessment of the stops walking while talking test in the elderly. *Arch Phys Med Rehabil* 2003; 84(6):838-842.

De Meersman RE. Heart rate variability and aerobic fitness. *Am Heart J* 1993; 125(3): 726-731.

De Meersman RE, Stein P K. Vagal modulation and aging. *Biol Psychol* 2007; 74(2): 165-173.

de Vegt F, Dekker JM, Ruhé HG, Stehouwer CD, Nijpels G, Bouter LM, Heine RJ.

Hyperglycaemia is associated with all-cause and cardiovascular mortality in the Hoorn population: the Hoorn Study. *Diabetologia* 1999; 42(8): 926-931.

Dekker JM, Crow RS, Folsom AR, Hannan PJ, Liao D, Swenne CA, et al. Low heart rate variability in a 2-minute rhythm strip predicts risk of coronary heart disease and mortality from several causes: the ARIC Study. *Atherosclerosis Risk In Communities. Circulation* 2000; 102(11): 1239-1244.

Dernellis J, Panaretou M. Aortic stiffness is an independent predictor of progression to hypertension in nonhypertensive subjects. *Hypertension* 2005; 45(3):426-431.

DeSouza CA, Shapiro LF, Clevenger CM, Dinunno FA, Monahan KD, Tanaka H, Seals DR. Regular aerobic exercise prevents and restores age-related declines in endothelium-dependent vasodilation in healthy men. *Circulation* 2000; 102:1351–1357.

Deviterne D, Gauchard GC, Jamet M, Vançon G, Perrin PP. Added cognitive load through rotary auditory stimulation can improve the quality of postural control in the elderly. *Brain Res Bull* 2005; 64(6): 487-492.

Dimsdale JE, Mills PJ. An unanticipated effect of meditation on cardiovascular pharmacology and physiology. *Am J Cardiol* 2002; 90(8): 908-909.

Ditto B, Eclache M, Goldman N. Short-term autonomic and cardiovascular effects of mindfulness body scan meditation. *Ann Behav Med* 2006; 32(3): 227–234.

Dobrin PB. Mechanical factors associated with the development of intimal and medial thickening in vein grafts subjected to arterial pressure: A model of arteries exposed to hypertension. *Hypertension* 1995; 26(1):38–43.

Donato AJ, Gano LB, Eskurza I, Silver AE, Gates PE, Jablonski K, Seals DR. Vascular endothelial dysfunction with aging: endothelin-1 and endothelial nitric oxide synthase. *Am J Physiol Heart Circ Physiol* 2009; 297(1): H425-432.

Doonan RJ, Hausvater A, Scallan C, Mikhailidis DP, Pilote L, Daskalopoulou SS. The effect of smoking on arterial stiffness. *Hypertens Res* 2010; 33(5): 398-410.

Dubost V, Kressig RW, Gonthier R, Herrmann FR, Aminian K, Najafi B, Beauchet O. Relationships between dual-task related changes in stride velocity and stride time variability in healthy older adults. *Hum Mov Sci* 2006; 25(3): 372-382.

Durrant JR, Seals DR, Connell ML, Russell MJ, Lawson BR, Folian BJ, Donato AJ, Lesniewski LA. Voluntary wheel running restores endothelial function in conduit arteries of old mice: Direct evidence for reduced oxidative stress, increased superoxide dismutase activity and down-regulation of NADPH oxidase. *J Physiol* 2009; 587: 3271–3285.

Esler M, Kaye D. Sympathetic nervous system activation in essential hypertension, cardiac failure and psychosomatic heart disease. *J Cardiovasc Pharmacol* 2000; 35(7 Suppl 4): S1-7.

Everson-Rose SA, Lewis TT. Psychosocial factors and cardiovascular diseases. *Annu Rev Public Health* 2005; 26: 469-500.

Fallgatter AJ, Strik WK. Right frontal activation during the continuous performance test assessed with near-infrared spectroscopy in healthy subjects. *Neurosci Lett* 1997; 212(2): 89-92.

Fallgatter AJ, Strik WK. Frontal brain activation during the Wisconsin Card Sorting Test assessed with two-channel near-infrared spectroscopy. *Eur Arch Psy Clin N* 1998; 248(5): 245-249.

Faulkner KA, Redfern MS, Rosano C, Landsittel DP, Studenski SA, Cauley JA, Zmuda JM, Simonsick EM, Kritchevsky SB, Newman AB; Health ABC Study. Reciprocal influence of concurrent walking and cognitive testing on performance in older adults. *Gait Posture* 2006; 24(2):182-189.

Faulkner KA, Redfern MS, Cauley JA, Landsittel DP, Studenski SA, Rosano C, Simonsick EM, Harris TB, Shorr RI, Ayonayon HN, Newman AB. Multitasking: Association between poorer performance and a history of recurrent falls. *J Am Geriatr Soc* 2007; 55(4): 570–576.

Field T, Diego M, Hernandez-Reif M. Tai chi/yoga effects on anxiety, heartrate, EEG and math computations. *Complement Ther Clin Pract* 2010; 16(4): 235-8.

Field T. Tai Chi research review. *Complement Ther Clin Pract* 2011; 17(3): 141-146.

Fjeldstad AS, Bemben MG, Bemben DA. Resistance training effects on arterial compliance in premenopausal women. *Angiology* 2009; 60(6):750-756.

Francis K. Physical activity in the prevention of cardiovascular disease. *Phys Ther* 1996; 76(5): 456-468.

Franklin SS. Arterial stiffness and hypertension: a two-way street? *Hypertension* 2005; 45(3):349-351.

Fujimoto N, Prasad A, Hastings JL, Arbab-Zadeh A, Bhella PS, Shibata S, Palmer D, Levine BD. Cardiovascular effects of 1 year of progressive and vigorous exercise training in previously sedentary individuals older than 65 years of age. *Circulation* 2010; 122(18):1797–1805.

Gates PE, Seals DR. Decline in large elastic artery compliance with age: a therapeutic target for habitual exercise. *Br J Sports Med* 2006; 40(11):897–899.

Gazzaniga MA. *The Cognitive Neurosciences*. 3rd ed. Cambridge, Mass.; MIT Press. 2004.

Gehlsen GM, Whaley MH. Falls in the elderly: Part II, Balance, strength, and flexibility. *Arch Phys Med Rehabil* 1990; 71: 739–741.

Gemmell C, Leatham JM. A study investigating the effects of Tai Chi Chuan: individuals with traumatic brain injury compared to controls. *Brain Inj* 2006; 20(2):151-156.

Gerstenblith G, Frederiksen J, Yin FC, Fortuin NJ, Lakatta EG, Weisfeldt ML.

Echocardiographic assessment of a normal adult aging population. *Circulation* 1977;
56(2):273-278.

Goldsmith RL, Bloomfeld DM, Rosenwinkel ET. Exercise and autonomic function.
Coron Artery Dis 2000; 11: 129-135.

Grey E, Bratteli C, Glasser SP, Alinder C, Finkelstein SM, Lindgren BR, Cohn JN.
Reduced small artery but not large artery elasticity is an independent risk marker for
cardiovascular events. *Am J Hypertens* 2003; 16(4): 265-269.

Gyllensten AL, Hui-Chan CW, Tsang WW. Stability limits, single-leg jump, and body
awareness in older tai chi practitioners. *Arch Phys Med Rehabil* 2010; 91(2):215-220.

Haidet GC, Wennberg PW, Finkelstein SM, Morgan DJ. Effects of aging per se on
arterial stiffness: systemic and regional compliance in beagles. *Am Heart J* 1996; 132(2
Pt 1): 319-327.

Hall CD, Miszko T, Wolf SL. Effects of tai chi intervention on dual-task ability in older
adults: A pilot study. *Arch Phys Med Rehabil* 2009; 90(3): 525–529.

Harley C, Wilkie RM, Wann JP. Stepping over obstacles: attention demands and aging.

Gait Posture 2009; 29(3): 428-432.

Hartman CA, Manos TM, Winter C, Hartman DM, Li B, Smith JC. Effects of T'ai Chi training on function and quality of life indicators in older adults with osteoarthritis. J

Am Geriatr Soc 2000; 48(12):1553-1559.

Harwood RH. Visual problems and falls. Age Ageing 2001; 30 (Suppl 4):13-18.

Hauer K, Pfisterer M, Weber C, Wezler N, Kliegel M, Oster P. Cognitive impairment decreases postural control during dual tasks in geriatric patients with a history of severe falls. J Am Geriatr Soc 2003; 51(11): 1638–1644.

Hausdorff JM, Schweiger A, Herman T, Yogev-Seligmann G, Giladi N. Dual-task decrements in gait: contributing factors among healthy older adults. J Gerontol A Biol Sci Med Sci 2008; 63(12):1335-43.

Hawkes TD, Siu KC, Silsupadol P, Woollacott MH. Why does older adults' balance become less stable when walking and performing a secondary task? Examination of attentional switching abilities. Gait Posture 2012; 35(1):159-163.

Hay L, Bard C, Fleury M, Teasdale N. Availability of visual and proprioceptive afferent messages and postural control in elderly adults. *Exp Brain Res* 1996; 108(1):129-139.

HDI/PulseWave™ CR-2000 Research CardioVascular Profiling System Manual. HDI Hypertension Diagnostics Inc. 2005.

Henry RM, Kostense PJ, Spijkerman AM, Dekker JM, Nijpels G, Heine RJ, Kamp O, Westerhof N, Bouter LM, Stehouwer CD; Hoorn Study. Arterial stiffness increases with deteriorating glucose tolerance status: the Hoorn Study. *Circulation* 2003; 107(16):2089-2095.

Herdman SJ, Blatt P, Schubert MC, Tusa RJ. Falls in patients with vestibular deficits. *Am J Otol* 2000; 21(6):847-851.

Herrington DM, Kesler K, Reiber JC, Davis W, Brown WV, Helms R, Mallon SM, Raines J. Arterial compliance adds to conventional risk factors for prediction of angiographic coronary artery disease. *Am Heart J* 2003; 146(4):662-667.

Hittmair-Delazer M, Semenza C, Denes G. Concepts and facts in calculation. *Brain* 1994; 117 (Pt 4):715-728.

Hong Y, Li JX, Robinson PD. Balance control, flexibility, and cardiorespiratory fitness among older Tai Chi practitioners. *Br J Sports Med* 2000; 34(1):29–34.

Hortobágyi T, DeVita P. Muscle pre- and coactivity during downward stepping are associated with leg stiffness in aging. *J Electromyogr Kinesiol* 2000; 10(2): 117–126.

Hung C, Daub B, Black B, Welsh R, Quinney A, Haykowsky M. Exercise training improves overall physical fitness and quality of life in older women with coronary artery disease. *Chest* 2004; 126(4): 1026-1031.

Hurley BF. Age, gender, and muscular strength. *J Gerontol A Biol Sci Med Sci* 1995; 50 Spec No: 41-44.

Huxhold O, Li SC, Schmiedek F, Lindenberger U. Dual-tasking postural control: Aging and the effects of cognitive demand in conjunction with focus of attention. *Brain Res Bull* 2006; 69(3): 294–305.

Jackson ZS, Gotlieb AI, Langille BL. Wall tissue remodeling regulates longitudinal tension in arteries. *Circ Res* 2002; 90: 918–925.

Jamet M, Deviterne D, Gauchard GC, Vançon G, Perrin PP. Age-related part taken by attentional cognitive processes in standing postural control in a dual-task context. *Gait Posture* 2007; 25(2): 179–184.

Jamet M, Deviterne D, Gauchard GC, Vançon G, Perrin PP. Higher visual dependency increases balance control perturbation during cognitive task fulfilment in elderly people. *Neurosci Lett* 2004; 359(1-2):61-64.

Jani B, Rajkumar C. Ageing and vascular ageing. *Postgrad Med J* 2006; 82(968):357-362.

Jin P. Changes in heart rate, noradrenaline, cortisol and mood during Tai Chi. *J Psychosom Res* 1989; 33(2):197-206.

Jin P. Efficacy of Tai Chi, brisk walking, meditation, and reading in reducing mental and emotional stress. *J Psychosom Res* 1992; 36(4):361-70.

Joyner MJ. Effect of exercise on arterial compliance. *Circulation* 2000; 102(11):1214-1215.

Kahneman D. *Attention and effort*, Prentice-Hall, Englewood Cliffs, N.J. 1973.

Kannel WB. Coronary heart disease risk factors in the elderly. *Am J Geriatr Cardiol* 2002; 11(2): 101-107.

Kawano H, Tanaka H, Miyachi M. Resistance training and arterial compliance: keeping the benefits while minimizing the stiffening. *J Hypertens* 2006; 24(9):1753–1759.

Kaye DM, Esler MD. Autonomic Control of the Aging Heart. *Neuromolecular Med* 2008; 10(3): 179-186.

Kelly VE, Schragger MA, Price R, Ferrucci L, Shumway-Cook A. Age-associated effects of a concurrent cognitive task on gait speed and stability during narrow-base walking. *J Gerontol A Biol Sci Med Sci* 2008; 63(12): 1329–1334.

Khot UN, Khot MB, Bajzer CT, Sapp SK, Ohman EM, Brener SJ, Ellis SG, Lincoff AM, Topol EJ. Prevalence of conventional risk factors in patients with coronary heart disease. *JAMA* 2003; 290(7): 898-904.

Kivimäki M, Leino-Arjas P, Luukkonen R, Riihimäki H, Vahtera J, Kirjonen J. Work stress and risk of cardiovascular mortality: prospective cohort study of industrial employees. *BMJ* 2002; 325(7369): 857.

Kutner NG, Barnhart H, Wolf SL, McNeely E, Xu T. Self-report benefits of Tai Chi practice by older adults. *J Gerontol A Biol Sci Med Sci* 1997; 52B: 242–246.

Lachin JM. Statistical considerations in the intent-to-treat principle. *Control Clin Trials* 2000; 21: 167-189.

Lacour M, Bernard-Demanze L, Dumitrescu M. Posture control, aging, and attention resources: models and posture-analysis methods. *Neurophysiol Clin* 2008; 38(6):411-421.

La Forge R. Mind-body fitness: Encouraging prospects for primary and secondary prevention. *J Cardiovasc Nurs* 1997; 11(3): 53-65.

La Forge R. Aligning mind and body: Exploring the discipline of mindful exercise. *ACSM Health & Fitness J* 2005; 9(5): 7-14.

Lai JS, Lan C, Wong MK, Teng SH. Two-year trends in cardiorespiratory function among older Tai Chi Chuan practitioners and sedentary subjects. *J Am Geriatr Soc* 1995; 43(11):1222–1227.

Lakatta EG. Deficient neuroendocrine regulation of the cardiovascular system with advancing age in healthy humans. *Circulation* 1993; 87(2):631-636.

Lakatta EG, Levy D. Arterial and cardiac aging: major shareholders in cardiovascular disease enterprises: Part I: aging arteries: a "set up" for vascular disease. *Circulation* 2003; 107(1):139-146.

Lam LC, Chau RC, Wong BM, Fung AW, Lui VW, Tam CC, Leung GT, Kwok TC, Chiu HF, Ng S, Chan WM. Interim follow-up of a randomized controlled trial comparing Chinese style mind body (Tai Chi) and stretching exercises on cognitive function in subjects at risk of progressive cognitive decline. *Int J Geriatr Psychiatry* 2011; 26(7): 733–740.

Lam LC, Chau RC, Wong BM, Fung AW, Tam CW, Leung GT, Kwok TC, Leung TY, Ng SP, Chan WM. A 1-year randomized controlled trial comparing mind body exercise (tai chi) with stretching and toning exercise on cognitive function in older Chinese adults at risk of cognitive decline. *J Am Med Dir Assoc* 2012; 13(6):568.e15-20.

Lan C, Chen SY, Lai JS, Wong MK. The effect of Tai Chi on cardiorespiratory function in patients with coronary artery bypass surgery. *Med Sci Sports Exerc* 1999; 31(5): 634-638.

Lan C, Chen SY, Lai JS. Relative exercise intensity of Tai Chi Chuan is similar in different ages and gender. *Am J Chin Med* 2004; 32(1):151-160.

Lan C, Chen SY, Lai JS, Wong MK. Heart rate responses and oxygen consumption during Tai Chi Chuan practice. *Am J Chin Med* 2001; 29(3-4):403-410.

Lan C, Lai JS, Chen SY. Tai Chi Chuan: An ancient wisdom on exercise and health promotion. *Sports Med* 2002; 32(4):217-224.

Lan C, Lai JS, Chen SY, Wong MK. 12-month Tai Chi training in the elderly: its effect on health fitness. *Med Sci Sports Exerc* 1998; 30(3):345-351.

Larson EB, Wang L, Bowen, JD, McCormick WC, Teri L, Crane P, Kukull W. Exercise associated with reduced risk for incident dementia among persons 65 years of age and older. *Annals Intern Med* 2006; 144: 73-81.

Lauer MS, Francis GS, Okin PM, Pashkow FJ, Snader CE, Marwick, T. H. Impaired chronotropic response to exercise stress testing as a predictor of mortality. *JAMA* 1999; 281(6): 524-529.

Laurent S, Boutouyrie P, Asmar R, Gautier I, Laloux B, Guize L, Ducimetiere P, Benetos A. Aortic stiffness is an independent predictor of all-cause and cardiovascular mortality in hypertensive patients. *Hypertension* 2001; 37(5):1236-1241.

Laurent S, Katsahian S, Fassot C, Tropeano AI, Gautier I, Laloux B, Boutouyrie P. Aortic stiffness is an independent predictor of fatal stroke in essential hypertension. *Stroke* 2003; 34(5):1203–1206.

Lavie CJ, Milani RV. Benefits of cardiac rehabilitation and Prevention of heart failure exercise training programs in elderly coronary patients. *Am J Geriatric Cardiol* 2001; 10: 323-327.

Lazar SW, George B, Gollub RL, Fricchione GL, Khalsa G, Benson H. Functional brain mapping of relaxation response and meditation. *NeuroReport* 2000; 11:1581-1585.

Lee K YT, Jones AYM, Hui-Chan, CWY, Tsang, WWN. Kinematics and energy expenditure of sitting t'ai chi. *J Altern Com Med* 2011; 17: 1–4.

Lee MS, Lee EN, Kim JI, Ernst E. Tai chi for lowering resting blood pressure in the elderly: a systematic review. *J Eval Clin Pract* 2010; 16(4):818–824.

Lezak MD, Howieson DB, Loring DW. *Neuropsychological assessment*. Oxford University Press; 2004.

Li B, Zhang W. Trend of population aging in China and the strategy. *China Popul Today*. 1998; 15(1-2):2-4.

Li F, Harmer P, Fisher, McAuley E, Chaumeton N, Eckstrom E, Wilson NL. Tai chi and fall reduction in older adults: A randomized controlled trial. *J Gerontol A Biol Sci Med Sci* 2005; 60(2): 187–194.

Li JX, Xu DQ, Hong Y. Effects of 16-week tai chi intervention on postural stability and proprioception of knee and ankle in older people. *Age Ageing* 2008; 37(5): 575–578.

Li JX, Hong Y, Chan, KM. Tai chi: Physiological characteristics and beneficial effects on health. *Br J Sports Med* 2001; 35(3): 148–156.

Liao D, Arnett DK, Tyroler HA, Riley WA, Chambless LE, Szklo M, Heiss G. Arterial stiffness and the development of hypertension: The ARIC study. *Hypertension* 1999; 34(2):201–206.

Lim MA, Townsend RR. Arterial compliance in the elderly: its effect on blood pressure measurement and cardiovascular outcomes. *Clin Geriatr Med* 2009; 25(2):191-205.

Lipsitz L, Mietus J, Moody G, Goldberger A. Spectral characteristics of heart rate variability before and during postural tilt. Relations to aging and risk of syncope. *Circulation* 1990; 81(6): 1803-1810.

Litscher G, Wenzel G, Niederwieser G, Schwarz G. Effects of Qigong on brain function. *Neurol Res* 2001; 23(5): 501-505.

Liu Y, Mimura K, Wang L, Ikuta K. Psychological and physiological effects of 24-style taijiquan. *Neuropsychobiology* 2005; 52(4):212-218.

Liu Z, Brin KP, Yin FC. Estimation of total arterial compliance: an improved method and evaluation of current methods. *Am J Physiol* 1986; 251(3 Pt 2): H588-600.

Lord SR, McLean D, Stathers G. Physiological factors associated with injurious falls in older people living in the community. *Gerontology* 1992; 38: 338-346.

Lord SR, Ward JA, Williams P, Anstey KJ. Physiological factors associated with falls in older community-dwelling women. *J Am Geriatr Soc* 1994; 42(10):1110-1117.

Lu RX, Jones AYM, Tsang WWN. Changes of prefrontal oxygenation and heart rate variability during Tai Chi practice and ergometer cycling. In *The Seventh Pan-Pacific Conference on Rehabilitation, Hong Kong, October 23–24, 2010*, p. 67.

Lu WA, Kuo CD. The effect of Tai Chi Chuan on the autonomic nervous modulation in older persons. *Med Sci Sports Exerc* 2003; 35(12):1972–1976.

Lu X, Hui-Chan CW, Tsang WW. Effects of Tai Chi training on arterial compliance and muscle strength in female older seniors: a randomized clinical trial . *Eur J Cardiovasc Prev Rehabil* 2012a; Mar 12. Epub ahead of print.

Lu X, Hui-Chan CW, Tsang WW. Tai Chi, arterial compliance and muscle strength in older adults. *Eur J Cardiovasc Prev Rehabil* 2012b; Apr 4. Epub ahead of print.

Lu X, Siu KC, Fu SN, Hui-Chan CW, Tsang WW. Tai Chi practitioners have better postural control and cognitive performance in stepping down with and without a concurrent auditory response task. *Eur J Appl Physio* 2012c; (under review).

Lu X, Siu Ka-Chun, Hui-Chan, C. W. Y. and Tsang, W. W.N. A dual task paradigm for assessing older adults' stepping down performance - a test-retest reliability study. Joint World Congress of ISPGR and Gait & Mental Function, 24-28 June 2012d, Norway, p. 310, P1-H-164.

Lundy-Ekman L . Cerebrum. In *Neuroscience Fundamentals for Rehabilitation*. 2nd ed. Philadelphia; Elsevier Science, 2002, pp395-396.

Maki BE, McIlroy WE. Cognitive demands and cortical control of human balance-recovery reactions. *J Neural Transm* 2007; 114(10):1279-1296.

Maki BE, Zecevic A, Bateni H, Kirshenbaum N, McIlroy WE. Cognitive demands of executing postural reactions: Does aging impede attention switching? *Neuroreport* 2001; 12(16): 3583–3587.

Man DW, Tsang WW, Hui-Chan CW. Do older t'ai chi practitioners have better attention and memory function? *J Altern Complement Med* 2011; 16(12): 1259–1264.

Marsh AP, Geel SE. The effect of age on the attentional demands of postural control.

Gait Posture 2000; 12(2):105-113.

Martinmäki K, Rusko H. Time-frequency analysis of heart rate variability during

immediate recovery from low and high intensity exercise. Eur J Appl Physiol 2008;

102(3): 353-360.

Mattace-Raso FU, van der Cammen TJ, Hofman A, van Popele NM, Bos ML,

Schalekamp MA, Asmar R, Renman RS, Hoeks AP, Breteler MM, Wittteman JC.

Arterial stiffness and risk of coronary heart disease and stroke: the Rotterdam Study.

Circulation 2006; 113(5):657-663.

Matthews MM, Williams HG. Can Tai chi enhance cognitive vitality? A preliminary

study of cognitive executive control in older adults after A Tai chi intervention. J S C

Med Assoc 2008; 104(8):255-257.

Maylor EA, Allison S, Wing AM. Effects of spatial and nonspatial cognitive activity on

postural stability. Br J Psychol 2001; 92 Part 2:319-338.

Maylor EA, Wing AM. Age differences in postural stability are increased by additional cognitive demands. *J Gerontol B Psychol Sci Soc Sci* 1996; 51(3):P143-154.

McDowd JM, Craik IM. Effects of aging and task difficulty on divided attention performance. *J Exp Psychol Hum Percept Perform* 1988; 14(2): 267-280.

McEniery CM, Wallace S, Mackenzie IS, McDonnell B, Yasmin, Newby DE, Cockcroft JR, Wilkinson IB. Endothelial function is associated with pulse pressure, pulse wave velocity, and augmentation index in healthy humans. *Hypertension* 2006; 48(4): 602-608.

McVeigh GE, Lemay L, Morgan D, Cohn JN. Effects of long-term cigarette smoking on endothelium-dependent responses in humans. *Am J Cardiol* 1996; 78(6): 668-672.

Meaume S, Benetos A, Henry OF, Rudnichi A, Safar ME. Aortic pulse wave velocity predicts cardiovascular mortality in subjects >70 years of age. *Arterioscler Thromb Vasc Biol* 2001; 21(12):2046–2050.

McEniery CM, Wilkinson IB, Avolio AP. Age, hypertension and arterial function. *Clin Exp Pharmacol Physiol* 2007; 34(7): 665-671.

McVeigh GE, Burns DE, Finkelstein SM, McDonald KM, Mock JE, Feske W, Carlyle PF, Grimm R, Cohn JN. Reduced vascular compliance as a marker for essential hypertension. *Am J Hypertens* 1991; 4: 245-251.

McVeigh GE, Lemay L, Morgan D, Cohn JN. Effects of long-term cigarette smoking on endothelium-dependent responses in humans. *Am J Cardiol* 1996; 78(6):668-672.

Meaume S, Benetos A, Henry OF, Rudnichi A, Safar ME. Aortic pulse wave velocity predicts cardiovascular mortality in subjects >70 years of age. *Arterioscler Thromb Vasc Biol* 2001; 21(12): 2046-50.

Megnien JL, Simon A, Valensi P, Flaud P, Merli I, Levenson J. Comparative effects of diabetes mellitus and hypertension on physical properties of human large arteries. *J Am Coll Cardiol* 1992; 20(7): 1562-1568.

Melzer I, Benjuya N, Kaplanski J. Age-related changes of postural control: Effect of cognitive tasks. *Gerontology* 2001; 47(4): 189-194.

Melzer I, Liebermann DG, Krasovsky T, Oddsson LI. Cognitive load affects lower limb force-time relations during voluntary rapid stepping in healthy old and young adults. *J Gerontol A Biol Sci Med Sci* 2010; 65(4):400-406.

Mitchell GF, Hwang SJ, Vasan RS, Larson MG, Pencina MJ, Hamburg NM, Vita JA, Levy D, Benjamin EJ. Arterial stiffness and cardiovascular events: the Framingham Heart Study. *Circulation* 2010; 121(4):505-511.

Miyachi M, Donato AJ, Yamamoto K, Takahashi K, Gates PE, Moreau KL, Tanaka H. Greater age-related reductions in central arterial compliance in resistance-trained men. *Hypertension* 2003; 41(1):130–135.

Miyachi M, Kawano H, Sugawara J, Takahashi K, Hayashi K, Yamazaki K, Tabata I, Tanaka H. Unfavorable effects of resistance training on central arterial compliance: A randomized intervention study. *Circulation* 2004; 110(18):2858–2863.

Moreau KL, Donato AJ, Seals DR, DeSouza CA, Tanaka H. Regular exercise, hormone replacement therapy and the age-related decline in carotid arterial compliance in healthy women. *Cardiovasc Res* 2003; 57(3): 861–868.

Mustian KM, Katula JA, Gill DL, Roscoe JA, Lang D, Murphy K. Tai Chi Chuan, health-related quality of life and self-esteem: a randomized trial with breast cancer survivors. *Support Care Cancer* 2004; 12(12): 871-876.

Nashner LM Evaluation of postural stability, movement and control. In: *Clinical Exercise Physiology*. Hasson S.M. (Eds.). St. Louis: Mosby, 1994.

Navon D, Miller J. Role of outcome conflict in dual-task interference. *J Exp Psychol Hum Percept Perform* 1987; 13(3): 435-448.

Nualnim N, Barnes JN, Tarumi T, Renzi CP, Tanaka H. Comparison of central artery elasticity in swimmers, runners, and the sedentary. *Am J CardioL* 2011; 107(5):783-787.

Ockene IS, Miller NH. Cigarette smoking, cardiovascular disease, and stroke: a statement for healthcare professionals from the American Heart Association. American Heart Association Task Force on Risk Reduction. *Circulation* 1997; 96(9): 3243-3247.

Oda A, Taniguchi T, Yokoyama M. Leptin stimulates rat aortic smooth muscle cell proliferation and migration. *Kobe J Med Sci* 2001; 47(3): 141-150.

Oren S, Isakov I, Golzman B, Kogan J, Turkot S, Peled R, Yosefy C. The influence of smoking cessation on hemodynamics and arterial compliance. *Angiology* 2006; 57(5): 564-568.

Ojha HA, Kern RW, Lin CH, Winstein CJ. Age affects the attentional demands of stair ambulation: Evidence from a dual-task approach. *Phys Ther* 2009; 89(10): 1080–1088.

Pashler HE. *The psychology of attention*. MIT press, Cambridge, MA. 1998.

Perrey S. Non-invasive NIR spectroscopy of human brain function during exercise. *Methods* 2008; 45(4): 289-299.

Peterson RC. Conceptual overview. In RC Peterson (Ed.), *Mild Cognitive Impairment*. New York: Oxford University Press. 2003, pp. 1-14.

Peterson RC, Smith GE, Waring SC, Ivnik RJ, Kokmen E, Tangelos EG. Aging, memory, and mild cognitive impairment. *Int Psycho geriatri* 1997; 9: 65-69.

Poelkens F, Rakobowchuk M, Burgomaster KA, Hopman MT, Phillips SM, MacDonald MJ. Effect of unilateral resistance training on arterial compliance in elderly men. *Appl Physiol Nutr Metab* 2007; 32(4): 670-676.

Porter MM, Myint A, Kramer JF, Vandervoort AA. Concentric and eccentric knee extension strength in older and younger men and women. *Can J Appl Physiol* 1995; 20(4):429-439.

Portney LG, Watkins MP, Foundation of clinical research. Application to practice. 3rd ed. New Jersey; Pearson Education International, 2009, pp262-263.

Powell KE, Thompson PD, Caspersen CJ, Kenderick JS. Physical activity and the incidence of coronary artery disease. *Annu Rev Public Health* 1987; 8: 253-287.

Prado JM, Stoffregen TA, Duarte M. Postural sway during dual tasks in young and elderly adults. *Gerontology* 2007; 53(5):274-281.

Priebe H. The aged cardiovascular risk patient. *Br J Anesth* 2000; 85(5): 763-778.

Priest AW, Salamon KB, Hollman JH. Age-related differences in dual task walking: a cross sectional study. *J Neuroeng Rehabil* 2008; 5: 29.

Prisant LM, Resnick LM, Hollenberg SM. Arterial elasticity among normotensive subjects and treated and untreated hypertensive subjects. *Blood Press Monit* 2001; 6(5): 233-237.

Rankin JK, Woollacott MH, Shumway-Cook A, Brown LA. Cognitive influence on postural stability: A neuromuscular analysis in young and older adults. *J Gerontol A Biol Sci Med Sci* 2000; 55(3): M112–119.

Rauch SD, Velazquez-Villaseñor L, Dimitri PS, Merchant SN. Decreasing hair cell counts in aging humans. *Ann N Y Acad Sci* 2001; 942: 220-227.

Redfern MS, Jennings JR, Martin C, Furman JM. Attention influences sensory integration for postural control in older adults. *Gait Posture* 2001; 14(3): 211–216.

Redfern MS, Müller ML, Jennings JR, Furman JM. Attentional dynamics in postural control during perturbations in young and older adults. *J Gerontol A Biol Sci Med Sci* 2002; 57(8): B298–303.

Remsberg KE, Siervogel RM. A life span approach to cardiovascular disease risk and aging: The Fels longitudinal study. *Mech Ageing Dev* 2003; 124: 249–257.

Resnick LM, Militianu D, Cunnings AJ, Pipe JG, Evelhoch JL, Soulen RL, Lester MA. Pulse waveform analysis of arterial compliance: relation to other techniques, age, and metabolic variables. *Am J Hypertens* 2000; 13(12):1243–1249.

Rogers RL, Meyer JS, Mortel KF. After reaching retirement age physical-activity sustains cerebral perfusion and cognition. *J Am Geriatr Soc* 1990; 38: 123–128.

Rosengren A, Wilhelmsen L. Physical activity protects against coronary death and deaths from all causes in middle-aged men: evidence from a 20-year follow-up of the primary prevention study in Goteborg. *Ann Epidemiol* 1997; 7(1): 69-75.

Royall DR, Lauterbach EC, Cummings JL, Reeve A, Rummans TA, Kaufer DI, LaFrance WC Jr, Coffey CE. Executive control function: a review of its promise and challenges for clinical research. A report from the Committee on Research of the American Neuropsychiatric Association. *J Neuropsychiatry Clin Neurosci* 2002; 14(4):377-405.

Rubenstein LZ. Falls in older people: epidemiology, risk factors and strategies for prevention. *Age Ageing* 2006; 35 Suppl 2: ii37-ii41.

Safar ME, Czernichow S, Blacher J. Obesity, arterial stiffness, and cardiovascular risk. *J Am Soc Nephrol* 2006; 17(4 Suppl 2): S109-111.

Sakakibara M, Takeuchi S, Hayano J. Effect of relaxation training on cardiac parasympathetic tone. *Psychophysiology* 1994; 31: 223–228.

Salthouse TA, Fristoe NM, Linewaeber TT, Coon VE. Aging of attention: Does the ability to divide decline? *Mem Cognit* 1995; 23: 59–71.

Sattin RW, Easley KA, Wolf SL, Chen Y, Kutner MH. Reduction in fear of falling through intense tai chi exercise training in older, transitionally frail adults. *J Am Geriatr Soc* 2005; 53(7):1168-78.

Schaller KJ. Tai Chi Chih: An exercise option for older adults. *J Gerontol Nurs* 1996; 22(10): 12–17.

Schuit AJ, van Amelsvoort LG, Verheij TC, Rijnke RD, Maan AC, Swenne CA, Schouten EG. Exercise training and heart rate variability in older people. *Med Sci Sports Exerc* 1999; 31(6):816-821.

Schultz AB, Ashton-Miller JA, Alexander NB. What leads to age and gender differences in balance maintenance and recovery? *Muscle Nerve Suppl* 1997; 5:S60-64.

Scuffham P, Chaplin S, Legood R. Incidence and costs of unintentional falls in older people in the United Kingdom. *J Epidemiology Community Health* 2003; 57(9): 740–744.

Seals DR, Taylor JA, Ng AV, Esler MD. Exercise and aging: autonomic control of the circulation. *Med Sci Sports Exe* 1994; 26(5): 568-576.

Seals DR, Walker AE, Pierce GL, Lesniewski LA. Habitual exercise and vascular ageing. *J Physiol* 2009; 587(Pt 23):5541-5549.

Shi X, Stevens G, Foresman B, Stern SA, Raven PB. Autonomic nervous system control of the heart: endurance exercise training. *Med Sci Sports Exe* 1995; 27 (10): 1406-1413.

Shumway-Cook A, Woollacott M. Attentional demands and postural control: The effect of sensory context. *J Gerontol A Biol Sci Med Sci* 2000; 55(1): M10–16.

Shumway-Cook A, Woollacott M, Kerns KA, Baldwin M. The effects of two types of cognitive tasks on postural stability in older adults with and without a history of falls. *J Gerontol A Biol Sci Med Sci* 1997; 52(4):M232-240.

Shumway-Cook, A. and Woollacott MH. Motor Control: Theory and Practical Applications. Baltimore MD: Williams & Wilkins, 2001.

Sierra-Honigmann MR, Nath AK, Murakami C, García-Cardena G, Papapetropoulos A, Sessa WC, Madge LA, Schechner JS, Schwabb MB, Polverini PJ, Flores-Riveros JR.

Biological action of leptin as an angiogenic factor. *Science* 1998; 281(5383): 1683-1686.

Silsupadol P, Lugade V, Shumway-Cook A, van Donkelaar P, Chou LS, Mayr U, Woollacott MH Training-related changes in dual-task walking performance of elderly persons with balance impairment: A double-blind, randomized controlled trial. *Gait Posture* 2009; 29(4): 634–639.

Silsupadol P, Shumway-Cook A, Lugade V, van Donkelaar P, Chou LS, Mayr U, Woollacott MH. Effects of single-task versus dual-task training on balance performance in older adults: A double-blind, randomized controlled trial. *Arch Phys Med Rehabil* 2009; 90(3): 381–387.

Sinnreich R, Kark JD, Friedlander Y, Sapoznikov D, Luria MH. Five minute recordings of heart rate variability for population studies: Repeatability and age-sex characteristics. *Heart* 1998; 80(2): 156-162.

Siu KC, Catena RD, Chou LS, van Donkelaar P, Woollacott MH. Effects of a secondary task on obstacle avoidance in healthy young adults. *Exp Brain Res*. 2008; 184(1):115-120.

Siu KC, Chou LS, Mayr U, Donkelaar P, Woollacott MH. Does inability to allocate attention contribute to balance constraints during gait in older adults? *J Gerontol A Biol Sci Med Sci* 2008; 63(12): 1364–1369.

Siu KC, Chou LS, Mayr U, van Donkelaar P, Woollacott MH. Attentional mechanisms contributing to balance constraints during gait: The effects of balance impairments. *Brain Res* 2009; 1248: 59–67.

Smith ML, Hudson D, Graitzer H, Raven PB. Exercise training bradycardia: the role of autonomic balance. *Med Sci Sports Exe* 1989; 21 (1): 40-44.

Song HG, Kim EJ, Hong SS, Kim SH, Park CG, Han SW, Ryu KH. Relative contributions of different cardiovascular risk factors to significant arterial stiffness. *Int J Cardiol* 2010; 139(3):263-268.

Song R, Lee EO, Lam P, Bae SC. Effects of tai chi exercise on pain, balance, muscle strength, and perceived difficulties in physical functioning in older women with osteoarthritis: A randomized clinical trial. *J Rheumatol* 2003; 30(9): 2039–2044.

Spencer MP, Denison AB Jr. Pulsatile blood flow in the vascular system. *Handbook of Physiology. Circulation.* II 1963 Am. Physiol. Soc Washington, DC, chapt. 25, p. 842.

Spier SA, Delp MD, Stallone JN, Dominguez JM, Muller-Delp JM. Exercise training enhances flow-induced vasodilation in skeletal muscle resistance arteries of aged rats: Role of PGI₂ and nitric oxide. *Am J Physiol Heart Circ Physiol* 2007; 292: H3119–3127.

Sports Department and Sports Committee of the People's Republic of China: Taijiquan Exercise. Beijing, People's Physical Education Publishing House, 1983.

Springer S, Giladi N, Peretz C, Yogev G, Simon ES, Hausdorff JM. Dual-tasking effects on gait variability: the role of aging, falls, and executive function. *Mov Disord* 2006; 21(7): 950-957.

Startzell JK, Owens DA, Mulfinger LM, Cavanagh PR. Stair negotiation in older people: A review. *J Am Geriatr Soc* 2000; 48(5): 567–580.

Stroop JR. Studies of interference in serial verbal reactions. *J Exp Psychol* 1935; **18** (6): 643–662.

Sturnieks DL, St George R, Lord SR. Balance disorders in the elderly. *Neurophysiol Clin* 2008; 38(6):467-478.

Sutton-Tyrrell K, Najjar SS, Boudreau RM, Venkitachalam L, Kupelian V, Simonsick EM et al. Health ABC Study: Elevated aortic pulse wave velocity, a marker of arterial stiffness, predicts cardiovascular events in well-functioning older adults. *Circulation* 2005; 111(25):3384–3390.

Sutton-Tyrrell K, Newman A, Simonsick EM, Havlik R, Pahor M, Lakatta E, Spurgeon H, Vaitkevicius P. Aortic stiffness is associated with visceral adiposity in older adults enrolled in the study of health, aging, and body composition. *Hypertension* 2001; 38(3): 429-433.

Swain RA, Harris AB, Wiener EC, Dutka MV, Morris HD, Theien BE, Konda S, Engberg K, Lauterbur PC, Greenough WT: Prolonged exercise induces angiogenesis and increases cerebral blood volume in primary motor cortex of the rat. *Neuroscience* 2003; 117: 1037–1046.

Swan L, Otani H, Loubert PV, Sheffert SM, Dunbar GL. Improving balance by performing a secondary cognitive task. *Br J Psychol* 2004; 95(Pt 1):31-40.

Swanenburg J, de Bruin ED, Uebelhart D, Mulder T. Compromising postural balance in the elderly. *Gerontology* 2009; 55(3):353-360.

Syeda B, Gottsauner-Wolf M, Denk S, Pichler P, Khorsand A, Glogar D. Arterial compliance: a diagnostic marker for atherosclerotic plaque burden? *Am J Hypertens* 2003; 16(5 Pt 1): 356-362.

Taddei S, Virdis A, Ghiadoni L, Salvetti G, Bernini G, Magagna A, Salvetti A. Age-related reduction of NO availability and oxidative stress in humans. *Hypertension* 2001; 38(2): 274-279.

Takami T, Saito Y. Effects of smoking cessation on central blood pressure and arterial stiffness. *Vasc Health Risk Manag* 2011; 7:633-638.

Tanaka H, DeSouza CA, Seals DR. Absence of age-related increase in central arterial stiffness in physically active women. *Arterioscler Thromb Vasc Biol* 1998; 8(1):127-132.

Tanaka H, Dinunno FA, Monahan KD, Clewenger CM, DeSouza CA, Seals DR. Aging, habitual exercise, and dynamic arterial compliance. *Circulation* 2000; 102(11):1270–1275.

Task Force of the European Society of Cardiology, the North American Society of Pacing, and Electrophysiology. Heart rate variability: standards of measurement, physiological interpretation, and clinical use. *Circulation* 1996; 93: 1043–1065.

Taylor-Piliae RE, Tai Chi as an adjunct to cardiac rehabilitation exercise training. *J Cardiopulm Rehabil* 2003, 23: 90-96.

Teasdale N, Bard C, LaRue J, Fleury M. On the cognitive penetrability of posture control. *Exp Aging Res* 1993; 19(1):1-13.

Teasdale N, Simoneau M. Attentional demands of postural control: the effects of aging and sensory reintegration. *Gait Posture* 2001; 14: 203-210.

Timinkul A, Kato M, Omori T, Deocaris CC, Ito A, Kizuka T, Sakairi Y, Nishijima T, Asada T, Soya H. Enhancing effect of cerebral blood volume by mild exercise in

healthy young men: a near-infrared spectroscopy study. *Neuros Res* 2008; 61(3): 242-248.

Tinetti ME, Speechley M, Ginter SF. Risk factors for falls among elderly persons living in the community. *N Engl J Med* 1988; 319(26): 1701–1707.

Tinetti ME. Clinical practice. Preventing falls in elderly persons *The New England Journal of Medicine* 2003; 348(1): 42-49.

Tomiyama H, Yamashina A. Arterial stiffness in prehypertension: a possible vicious cycle. *J Cardiovasc Transl Res* 2012; 5(3): 280-286.

Tsai JC, Wang WH, Chan P, Lin LJ, Wang CH, Tomlinson B, Hsieh MH, Yang HY, Liu JC. The beneficial effects of Tai Chi Chuan on blood pressure and lipid profile and anxiety status in a randomized controlled trial. *J Altern Complement Med* 2003; 9(5):747-754.

Tsai PS, Yucha CB, Nichols WW, Yarandi H. Hemodynamics and arterial properties in response to mental stress in individuals with mild hypertension. *Psychosom Med* 2003; 65(4): 613-619.

Tsang WWN, Fu ASN, Lui F, Hui-Chan CWY. Trunk position sense in older tai chi sword practitioners. *Hong Kong Physio J* 2009; 27: 55–60.

Tsang WW, Hui-Chan CW. Comparison of muscle torque, balance, and confidence in older Tai Chi and healthy adults. *Med Sci Sports Exerc* 2005; 37(2):280–289.

Tsang WW, Hui-Chan CW. Effects of tai chi on joint proprioception and stability limits in elderly subjects. *Med Sci Sports Exerc* 2003; 35(12): 1962–1971.

Tsang WW, Hui-Chan CW, Fu SN. Effects of Tai Chi on pre-landing muscle response latency during stepping down while performing a concurrent mental task in older adults. *Eur J Appl Physiol* 2011; 112(7): 2663–2669.

Tsang WW, Hui-Chan CW. Sensorimotor control of balance: A tai chi solution for balance disorders in older subjects. *Med Sport Sci* 2008; 52: 104–14.

Tsang WW, Hui-Chan CW. Standing balance after vestibular stimulation in Tai Chi-practicing and nonpracticing healthy older adults. *Arch Phys Med Rehabil* 2006; 87(4):546–553.

Tsang WW, Wong VS, Fu SN, Hui-Chan CW. Tai chi improves standing balance control under reduced or conflicting sensory conditions. *Arch Phys Med Rehabil* 2004; 85(1): 129–137.

Tsao SW. An in-depth analysis of taijiquan. Hong Kong: The Chinese University Press, 1995.

Tse SK, Bailey DM. T'ai chi and postural control in the well elderly. *Am J Occup Ther* 1992; 46(4):295-300.

Väänänen J, Xusheng S, Wang S, Laitinen T, Pekkarinen H, Länsimies E. Taichiquan acutely increases heart rate variability. *Clin Physiol Funct Imaging* 2002; 22(1):2–3.

Vaitkevicius PV, Fleg JL, Engel JH, O'Connor FC, Wright JG, Lakatta LE, Yin FC, Lakatta EG. Effects of age and aerobic capacity on arterial stiffness in healthy adults. *Circulation*. 1993; 88(4 Pt 1):1456-1462.

Vandervoort AA. Aging of the human neuromuscular system. *Muscle Nerve* 2002; 25(1):17-25.

Van Heuvelen MJ, Kempen GI, Ormel J, Rispens P. Physical fitness related to age and physical activity in older persons. *Med Sci Sports Exerc* 1998; 30(3):434–441.

van Iersel MB, Olde Rikkert MG, Mulley GP. Is stair negotiation measured appropriately in functional assessment scales? *Clin Rehabil* 2003; 17(3): 325–333.

van Iersel MB, Ribbers H, Munneke M, Borm GF, Rikkert MG. The effect of cognitive dual tasks on balance during walking in physically fit elderly people. *Arch Phys Med Rehabil* 2007; 88(2):187-191.

van Schoor NM, Smit JH, Pluijm SM, Jonker C, Lips P. Different cognitive functions in relation to falls among older persons: Immediate memory as an independent risk factor for falls. *J Clin Epidemiol* 2002; 55(9): 855–862.

Verghese J, Buschke H, Viola L, Katz M, Hall C, Kuslansky G, Lipton R. Validity of divided attention tasks in predicting falls in older individuals: a preliminary study. *J Am Geriatr Soc* 2002; 50(9):1572-1576.

Wallmann HW. Comparison of elderly nonfallers and fallers on performance measures of functional reach, sensory organization, and limits of stability. *J Gerontol A Biol Sci Med Sci* 2001; 56(9): M580-583.

Wang J, Lan C, Wong M. Tai chi chuan training to enhance microcirculatory function in healthy elderly men. *Arch Phys Med Rehab* 2001; 82(9): 1176-1180.

Wayne PM, Krebs DE, Wolf SL, Gill-Body KM, Scarborough DM, McGibbon CA, Kaptchuk TJ, Parker SW. Can Tai Chi improve vestibulopathic postural control? *Arch Phys Med Rehabil* 2004; 85(1):142-152.

Wayne PM, Kaptchuk TJ. Challenges inherent to t'ai chi research Part I: t'ai vhi as a complex multicomponent intervention. *J Altern Complement Med* 2008; 14(1):95-102.

Wenger NK, Froelicher ES, Smith LK, Ades PA, Berra K, Blumenthal JA, Certo CM, Dattilo AM, Davis D, DeBusk RF, et al. Cardiac rehabilitation as secondary prevention. Agency for Health Care Policy and Research and National Heart, Lung, and Blood Institute. *Clin Pract Guidel Quick Ref Guide Clin* 1995; (17): 1-23.

Westhoff TH, Schmidt S, Gross V, Joppke M, Zidek W, van der Giet M, Dimeo F. The cardiovascular effects of upper-limb aerobic exercise in hypertensive patients. *J Hypertens* 2008; 26(7): 1336-1342.

Weyer C, Yudkin JS, Stehouwer CD, Schalkwijk CG, Pratley RE, Tataranni PA. Humoral markers of inflammation and endothelial dysfunction in relation to adiposity and in vivo insulin action in Pima Indians. *Atherosclerosis* 2002;161(1): 233-242.

Wildman RP, Mackey RH, Bostom A, Thompson T, Sutton-Tyrrell K. Measures of obesity are associated with vascular stiffness in young and older adults. *Hypertension* 2003; 42(4): 468-473.

Wittling W, Block A, Genzel S, Schweiger E. Hemisphere asymmetry in parasympathetic control of the heart. *Neuropsychologia* 1998; 36(5): 461-468.

Wolf SL, Barnhart HX, Ellison GL, Coogler CE. The effect of Tai Chi Quan and computerized balance training on postural stability in older subjects. *Atlanta FICSIT Group. Frailty and Injuries: Cooperative Studies on Intervention Techniques. Phys Ther* 1997; 77(4):371-381.

Wolf, SL, Coogler CE, Xu T. Exploring the basis for Tai Chi Chuan as a therapeutic exercise approach. *Arch Phys Med Rehabil* 1997; 78: 886–892.

Wolfson L, Whipple R, Derby C, Judge J, King M, Amerman P, Schmidt J, Smyers D. Balance and strength training in older adults: Intervention gains and Tai Chi maintenance. *J Am Geriatr Soc* 1996; 44: 498 –506.

Wong AM, Lin YC, Chou SW, Tang FT, Wong PY. Coordination exercise and postural stability in elderly people: Effect of tai chi chuan. *Arch Phys Med Rehabil* 2001; 82(5): 608–612.

World Health Organization. Population ageing: A public health challenge. *World Health Organization Information N°135*; 1998.

World Health Organization. Prevention of cardiovascular disease: guidelines for assessment and management of total cardiovascular risk. 2007.

World Health Organization. Falls. *World Health Organization Information N°344*; 2010.

World Health Organization. Cardiovascular diseases (CVDs). N°217. 2011.

World Health Organization. 10 facts on ageing and the life course. 2012.

Yang Y, Verkuilen JV, Rosengren KS, Grubisich SA, Reed MR, Hsiao-Wecksler ET.

Effect of combined Taiji and Qigong training on balance mechanisms: a randomized controlled trial of older adults. *Med Sci Monit* 2007; 13(8): 339-48.

Yamamoto K, Miyachi M, Saitoh T, Yoshika A, Onodera S. Effects of endurance training on resting and post-exercise cardiac autonomic control. *Med Sci Sports Exerc* 2001; 33: 1496-1502.

Yeh GY, Wood MJ, Lorell BH, Stevenson LW, Eisenberg DM, Wayne PM et al. Effects of tai chi mind-body movement therapy on functional status and exercise capacity in patients with chronic heart failure: a randomized controlled trial. *Am J Med* 2004; 117(8):541–548.

Yeh GY, Wang C, Wayne PM, Phillips RS. The effect of tai chi exercise on blood pressure: A systematic review. *Prev Cardiol* 2008; 11(2):82–89.

Yogev-Seligmann G, Hausdorff JM, Giladi N. The role of executive function and attention in gait. *Mov Disord.* 2008; 23(3):329-42.

Young DR, Appel LJ, Jee S, Miller ER 3rd. The effects of aerobic exercise and T'ai chi on blood pressure in older people: Results of a randomized trial. *J Am Geriatr Soc* 1999; 47(3): 277-284.

Yu-Jie W, Hui-Liang L, Bing L, Lu Z, Zhi-Geng J. Impact of Smoking and Smoking Cessation on Arterial Stiffness in Healthy Participants. *Angiology* 2012 May 30. [Epub ahead of print].

Yusuf S, Reddy S, Ounpuu S, Anand S. Global burden of cardiovascular diseases: Part I: General considerations, the epidemiologic transition, risk factors, and impact of urbanization. *Circulation* 2001a; 104(22): 2746-2753.

Yusuf S, Reddy S, Ounpuu S, Anand S. Global burden of cardiovascular diseases: Part II: Variations in cardiovascular disease by specific ethnic groups and geographic regions and prevention strategies. *Circulation* 2001b; 104(23): 2855-2864.

Zettel JL, McIlroy WE, Maki BE. Effect of competing attentional demands on perturbation-evoked stepping reactions and associated gaze behavior in young and older adults. *J Gerontol A Biol Sci Med Sci* 2008; 63(12): 1370–1379.

Zhou RH, Vendrov AE, Tchivilev I, Niu XL, Molnar KC, Rojas M, Carter JD, Tong H, Stouffer GA, Madamanchi NR, Runge MS. Mitochondrial oxidative stress in aortic stiffening with age: the role of smooth muscle cell function. *Arterioscler Thromb Vasc Biol* 2012; 32(3):745-755.

Zieman SJ, Melenovsky V, Kass DA. Mechanisms, pathophysiology, and therapy of arterial stiffness. *Arterioscler Thromb Vasc Biol* 2005; 25(5):932-943.

Zijlstra A, Ufkes T, Skelton DA, Lundin-Olsson L, Zijlstra W. Do dual tasks have an added value over single tasks for balance assessment in fall prevention programs? A mini-review. *Gerontology* 2008; 54(1): 40–49.

Zimlichman R, Shargorodsky M, Boaz M, Duprez D, Rahn KH, Rizzoni D, Payeras AC, Hamm C, McVeigh G. Determination of arterial compliance using blood pressure waveform analysis with the CR-2000 system: Reliability, repeatability, and establishment of normal values for healthy European population, the seven European sites study (SESS). *Am J Hypertens* 2005; 18(1):65–71.

Zoungas S, Asmar RP. Arterial stiffness and cardiovascular outcome. *Clin Exp Pharmacol Physiol* 2007; 34(7): 647-651.

香港理工大學
康復治療科學系
同意書

研究題目：太極拳練習對老年人心血管功能和平衡控制力的影響

研究者： 曾偉男博士

許雲影教授

盧茜小姐

研究資料：

隨著世界 60 歲以上人口的增多，老齡化已經是一個世界性的問題。老化過程中心血管功能和平衡控制力都會隨之降低。這樣的退化過程會導致心肺疾病，心血管疾病的發生率及摔倒危險的增加、生活質量的降低和死亡率的上升。太極拳是一項注重思想的控制，呼吸調節及準確的關節活動方向、位置和身體姿勢的身心運動。所以，本研究的目的就是為了觀察太極拳的練習對老年人血管功能及平衡功能究竟有怎樣的效果。

入選標準：

- 年齡 60 歲或以上的長者
- 進行太極鍛煉 3 年以上或完全未接受過太極訓練
- 不需要任何輔助器具獨立行走者
- 可以聽從指令和要求

排除標準：

- 認知障礙者
- 心肺疾病患者
- 從事中等強度體力活動時有心血管疾病症狀者

- 高血壓控制不良者或有症狀的直立性低血壓者
- 神經系統疾病患者
- 在過去 12 個月內有骨科手術史或有骨折的病人

測試的內容：

1. 簡單問卷
2. 血壓及血管彈性測試：被測者平臥下測試其血壓及血管彈性
3. 肌肉力量測試
4. 平衡控制力測試— 走落梯級測試：被測者從一個梯級走落到單腳站立于壓力板，并保持平衡。

每次評定約需一小時三十至兩小時分。所有評定對於參與者無任何不良影響。

資料保密：

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參加者簽署：_____

日期：_____

見證人簽署：_____

日期：_____

The physical activity questionnaire

體能活動問卷

Question: what type of the leisure time activities most often performed in the recent one year?

問：在最近一年內，閒暇時經常進行的活動是什麼？

Answer 答：

Category 級別	Intensity 程度	Physical activities 活動類別 (Examples 例子)	Metabolic Index 新陳代謝指標 (MET)
I	Light 輕 (<4 METs)	Walking for pleasure 散步	3.5
		Fishing 釣魚	3.5
		Light house task 一般輕巧家務	3.5
		Yoga 瑜伽	3.5
II	Moderate 中 (4-4.5METs)	Music playing 彈奏音樂	4.5
		Table tennis 乒乓球	4
		House cleaning task 家居清潔	5.5
		Health club exercise 健身室	5.5
III	Heavy 重 (>5.5 METs)	Running 跑步	6
		Swimming 游泳	6
		Carpentry 木工	6.5
		Tennis 網球	7

MINI – MENTAL STATE EXAMINATION (MMSE)

簡短智能測驗

姓名: _____ 性別/年齡: _____ 評估日期: _____ 評估員: _____

最高分數 分數

5 () 依家係乜野日子(年份)、(季節)、(月份)、(幾號)、(星期幾)?

5 () 我地依家係邊度?

(九龍/新界/香港)(九龍/新界/香港既邊區)(邊條街/邊個屋村)(中心名字)(邊層樓)

3 () 依家我會講三樣野既名，講完之後，請你重複一次。

請記住佢地，因為幾分鐘後，我會叫你再講番俾我聽。

[蘋果]、[報紙]、[火車]。依家請你講番呢三樣野俾我聽。

(以第一次講的計分，一個一分；然後重複物件，直至全部

三樣)

5 () 請你用一百減七，然後再減七，一路減落去，直至我叫你停為

止。

(減五次後便停) () () () () ()

或:依家我讀幾個數目俾你聽，請你倒轉頭講番出黎。

[42731] ()

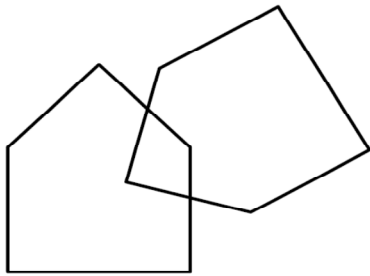
3 () 我頭先叫你記住既三樣野係乜野呀?

9 () a. 哩樣係乜野? (鉛筆)(手錶) (2)

b. 請你跟我講呢句話。(姨丈買魚腸) (1)

- 將
- c. 依家檯上面有一張紙，用你既右手拿起張紙，用兩隻手一齊張紙摺成一半，然後放番張紙係檯上面。(3)
 - d. 請讀出哩張紙上面既字，然後照住去做。(1)
 - e. 請你講任何一句完整既句子俾我聽。(1)
如: [我係一個人]、[今日天氣好好]
 - f. 哩處有幅圖，請你照住呢畫啦。(1)

拍手



總分： _____/30

香港理工大學

康復治療科學系

同意書

研究題目：太極拳練習對老年人心血管功能和平衡控制力的影響

研究者： 曾偉男博士

許雲影教授

盧茜小姐

研究資料：

隨著世界 60 歲以上人口的增多，老齡化已經是一個世界性的問題。老化過程中心血管功能和平衡控制力都會隨之降低。這樣的退化過程會導致心肺疾病，心血管疾病的發生率及摔倒危險的增加、生活質量的降低和死亡率的上升。太極拳是一項注重思想的控制，呼吸調節及準確的關節活動方向、位置和身體姿勢的身心運動。所以，本研究的目的就是為了觀察太極拳的練習對老年人血管功能及平衡功能究竟有怎樣的效果。

次研究的測試部分將在香港理工大學實驗室進行。這項研究包括 2 次測試，16 週、每週三次的太極或興趣班訓練。測試分為兩個階段，訓練前及訓練後。

入選標準：

- 年齡 60 歲或以上的長者
- 不需要任何輔助器具獨立行走者
- 可以聽從指令和要求
- 未曾接受過系統太極訓練

排除標準：

- 認知障礙者
- 心肺疾病患者

- 從事中等強度體力活動時有心血管疾病症狀者
- 高血壓控制不良者或有症狀的直立性低血壓者
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參加者簽署：_____ 日期：_____

見證人簽署：_____ 日期：_____

香港理工大學

康復治療科學系

同意書

研究題目：老年人心肺功能和腦含氧量的研究

研究者： 曾偉男博士

許雲影教授

盧茜小姐

研究資料：

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太極拳是一項注重思想的控制，呼吸調節及身體姿勢的身心運動。所以，本研究的目的就是為了觀察長期進行太極訓練的老年人心肺及腦含氧量在進行太極以及另一項身體運動時的表現。

入選標準：

- 年齡 60 歲或以上的長者
- 進行太極鍛煉 3 年以上
- 不需要任何輔助器具獨立行走者
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- 神經系統疾病患者
- 在過去 12 個月內有骨科手術史或有骨折的病人

評定方法：

測試者將會進行兩次評定：每次評定約需兩小時。所有評定對於參與者無任何不良影響。

主要評定項目包括：

- 心肺功能測試：測試過程中被測者將會佩帶一個心率檢測器，一個肺功能檢測儀，過程為被測者坐下休息 10 分鐘，舒適單車運動或打太極（分別兩天進行）10 到 12 分鐘，坐下休息 10 分鐘。
- 腦含氧量測試：被測者將於額前粘貼兩個遠紅外探測貼，以量度腦含氧量

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