THE HONG KONG POLYTECHNIC UNIVERSITY

DEPARTMENT OF REHABILITATION SCIENCES

EFFECT OF TAI CHI ON EYE-HAND COORDINATION IN THE OLDER ADULTS

BY

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A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF PHILOSOPHY

May 2008

CERTIFICATE OF ORIGINALITY

I hereby declare that this thesis is my own work and that, to the best of my knowledge and belief, it produces no material previously published or written, nor material that has been accepted for the award of any other degree or diploma, except where due acknowledgement has been made in the next.

Kwok Chi Ying Jasmine

ABSTRACT

Eye-hand coordination is an important function required in many daily activities. However, motor control is known to decline with aging which could affect finger-pointing tasks. The requirement for coordinating eye and hand movements with movements of the trunk and lower extremities during repeated Tai Chi practice may have also improved the practitioners' eye-hand coordination. Moreover, eye-hand coordination demands temporal, spatial, and often cognitive processing in daily activities that require the registration of visual signals in finger-pointing tasks involving choice. Tai Chi is a mind-body exercise, previous studies have demonstrated that experienced Tai Chi practitioners showed better attention and memory than did the older controls.

University students, older subject controls and experienced Tai Chi practitioners participated in this cross-sectional study. The subjects performed rapid index finger-pointing using their dominant hand, from a fixed starting position on a desk to a 1.2cm circle that appeared on a visual display unit. The task was to touch the circle as quickly and as accurately as possible in 3 testing protocols: (1) A single visual signal appeared randomly. (2) A visual signal moved horizontally from left to right. (3) A choice test paradigm. Outcome measures included reaction time, movement time, accuracy and the number of wrong movements.

Static visual signal

The young university students achieved faster reaction and movement times, and greater accuracy significantly than the older control subjects. Tai Chi

practitioners showed significantly better accuracy than the older controls at the signal contra-laterally and centrally. Their accuracy was also similar to that of the young subjects.

Moving visual signal

The students achieved significantly better outcome measures than the older controls. Although the Tai Chi practitioners only tended to have faster but not statistically significant reaction time than the older control subjects, they showed significantly better accuracy than the older controls, which was comparable to that of the younger students.

Finger-pointing with a cognitive component

The students achieved significantly better outcome measures and fewer wrong movements than the older control subjects. The Tai Chi practitioners had significantly faster movement times than the control subjects, attained significantly better accuracy and made fewer wrong movements. Their accuracy and number of wrong movements were similar to those of the young students.

These results demonstrate that, with aging, a decline in eye-hand coordination occurs in finger-pointing tasks toward static and moving visual signals. This is also true of tasks that require cognitive processing in a choice paradigm. However, Tai Chi practitioners had achieved significantly better accuracy. Tai Chi emphasizes exact joint positioning and precise movement control. It may be that better joint proprioception and control of arm trajectory in Tai Chi practitioners have enhanced their accuracy in finger-pointing tasks - even to the level of healthy young subjects. The finding of fewer wrong movements in Tai Chi practitioners may be due to their

better attention in the signal encoding process and to their better registration of the visual signal in the memory retrieval process, both of which have been shown in our previous study.

Key Words: AGING, EYE-HAND COORDINATION, EXERCISE, SPEED, ACCURACY, ATTENTION, MEMORY

ACKNOWLEDGEMENT

I would like to express my heartfelt thanks to my supervisor, Dr. William Tsang, Assistant Professor of the Department of Rehabilitation Sciences, The Hong Kong Polytechnic University. Dr. Tsang had diligently guided me throughout the whole process, even when he had to face his personal challenge at the end of the study.

I would also like to deeply thank my co-supervisor, Prof. Christina W.Y. Hui-Chan, Chair Professor of the Department of Rehabilitation Sciences, The Hong Kong Polytechnic University, who originated the idea of this research study.

With their guidance, I have not just learnt how to do a research, but with all the accompanied skills such as an analytical and critical mind. It was such a fruitful experience for me during these two years.

I would also like to thank my family, friends and teammates for their love and support throughout my whole study period.

My deepest thanks would also like to express to these people:

- Mr. Siu Sik Cheung, Senior Technician, Department of Rehabilitation Sciences, The Hong Kong Polytechnic University, for his valuable skills and advice on my data capturing and analyzing program for my research study
- The elderly centers, the elderly Tai Chi practitioners, older adult controls and university students.

This project was supported by a grant from the Hong Kong Polytechnic University.

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LIST OF ABBREBIATIONS

α / *P*	:	Significance level
A/D card	:	National Instrument NI DAQCard-6024E
ACSM	:	American College of Sports Medicine
ANOVA	:	Analysis of variance
CI	:	confidence interval
cm	:	centimeter
$cm \cdot s^{-1}$	:	centimeter per second
DAQ	:	Data Acquisition
EMG	:	Electromyography
F	:	female
Hz	:	Hertz
ICC	:	Intraclass correlation coefficient
LCD	:	Clear Tek 3000 LCD screen, MicroTouch Systems Inc., Methuen,USA
m	:	meter
M	:	male
Mm	:	millimeter
MANOVA	:	Multivariate analysis of variance
METS	:	Metabolic equivalents
MMSE	:	Mini-Mental Status Examination
ms	:	millisecond
N	:	number
s	:	second
SD	:	standard deviation
SPSS	:	Statistical Package for the Social Sciences
yr	:	year

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CHAPTER 1

INTRODUCTION

1.1 Eye-hand coordination

1.1.1 Importance of eye-hand coordination in daily living

Eye-hand coordination may be defined as the skillful, integrated use of the eyes, arms, hands, and fingers in fine, precision movements (Williams, 1983).

Pressing a lift button, reaching for a cup, punching keys on a phone to make phone calls, all require good eye-hand coordination to execute the desired actions precisely. Obviously, we require fine motor skills in the upper limbs to perform our daily activities (Shumway-Cook & Woollacott, 2001). Sports and other leisure activities also involve precise visual and motor control to execute particular actions or manipulate tools (Williams, 1990). It is impossible to live independently without eye-hand coordination.

1.1.2 Neural mechanism of eye-hand coordination

Eye-hand coordination of course involves both the eyes (vision) and the hands. Executing volitional actions smoothly and sequentially requires coordinating these two components. To perform goal-directed movement, we must first target our object, then transport the arm while visual information helps us adjust a smooth and accurate movement (Bekkering & Sailer, 2002).We may try to understand the mechanism using the 3 stages of eye-hand coordination defined by previous researchers (Paillard & Beaubaton, 1975; Arrington & Logan, 2004).

(I) First Stage - perceptual

The first stage requires visual locating and focusing on the target (Paillard & Beaubaton, 1975; Arrington & Logan, 2004) and sensing the joints' positions through proprioception (Rösblad, 1995).

(a) Vision

The peripheral part of the retina helps to locate targets and encode this information into neural code for transmission to the brain to enable a perception of the target location. The position of our eyes also helps to encode the target (Gaveau et al., 2003). Bock (1986) found that when a subject reaches in the dark, the final location of the subject's hand was related with the position of their eyes. However, the final position was less related to eye position when subjects reached under well-lit conditions (Bock, 1986). Therefore, the position of the eyes helps to encode, but it is not the major component used to encode the target (Gaveau et al., 2003).

Moreover, vision will continue to provide sensory feedback for making corrective adjustments until the action is complete (Boisseau et al., 2002).

(b) Proprioception

Another important perceptual input for eye-hand coordination is proprioception. Proprioceptive information is detected by muscle spindles and receptors in the tendons and joints. This information helps to direct the arms and hands, making sure we reach the target accurately, and gives sensory feedback for adjustment of the motor planning (Sugden, 1990; Rösblad, 1995).

Previous researchers have shown that vision and proprioception are always interlinked, because vision, while providing information about the target and environment, also aids in providing information about body positions and movement. So vision also has a proprioceptive function (Sugden, 1990).

(II) Second Stage - cognitive

The second stage of coordination involves planning the action and triggering the arm to perform it, which is cognitive planning and execution (Gottsdanker, 1982; Inui, 1997; Walker et al., 1997; Bellgrove et al., 1998; Yan, 2000). These processes involve the frontal and parietal cortex in directional control, movement control and motor planning (Marconi et al., 2001).

After receiving the neural code from the vision and proprioception sensors, the brain will gather the entire extrinsic (environment), intrinsic (body position) and target information to make a motor plan, initiate the movement and execute it. When the action begins, the cognitive centers will go on to modify the motor plan according to newly received sensory and motor feedback, making any correction or adjustment to maintain eye-hand coordination.

(III) Third Stage - motor

The last stage of coordination includes steering the hand to the target and shaping the hands and fingers in order to reach for and/or grasp the target. This involves the ability to produce a movement which is at the same time controlled, accurate and rapid. In this last stage, the arm and hand adjust their movement speed and the shaping of the fingers according to the new sensory feedback and make new corrective adjustment (Paillard & Beaubaton, 1975; Desrosiers et al., 1995; Boisseau et al., 2002).

There are two phases to the movement: a transportation phase and a grasp phase. The transportation phase directs the proximal muscles and joints (shoulder and elbow), while the grasp phase mainly involves distal muscles and joints (the wrist and fingers). The phases are simultaneous, using visual feedback to control adjustment. The extrinsic condition of the target (especially its location) helps to modify the transportation phase, while intrinsic factors (e.g. its shape) help in shaping the fingers and wrist in the grasp phase.

Motor coordination is important for adequate upper-extremity performance, and it can be defined as the ability to produce a controlled, accurate and rapid movement (Desrosiers et al., 1995). Accurate arm movements depend not only on vision (sensory information), but also on muscular work and proprioceptive information about the current angles of the head and arm joints (Henriques & Crawford, 2002). Deterioration of motor coordination is a major cause of this age-related slowing behavior (Desrosiers et al., 1995) and will be discussed in the following section.

1.2 Aging

1.2.1 Aging and eye-hand coordination

Deterioration and slowing of the central nervous system during aging is well documented (William, 1990; Hortobágyi & DeVita, 2006). It is usually reflected in slower movement control among older adults.

Since poor vision and degeneration of the joints which affects joint sense are also common during aging, and because eye-hand coordination has such a complex neural mechanism, a decline in eye-hand coordination in older adults is only to be expected. Boisseau and his colleagues (2002) investigated the effect of aging on eye-hand coordination by comparing the movement time and accuracy of young subjects (mean age = 36.8±2.5 yr) and older subjects (mean age = 64.9±2.9 yr). Subjects were asked to pierce the centers of circular targets on a horizontal sheet with a stylus as fast as possible while sitting, and under two conditions: with and without a centre cue (a dot in the centre of each circular target). Their accuracy was measured by the distance from the pierced point to the target's centre, but how they recorded the movement time was not stated in their report. The investigators found that both groups had comparable movement time and accuracy when centre cues were not presented, and both groups had better accuracy when the cues were presented. However, older subjects had slower movement times than younger subjects when a centre cue was present. The investigators proposed that this was due to slowing of the feedback processing in eye-hand coordination. The centre cues served as helpful information for movement planning in order to achieve better accuracy, and the slower movement might reflect a slower performance in processing the visual feedback information. Other researchers have used grooved peg-board tests to demonstrate changes in eye-hand coordination during aging (Ruff & Parker, 1993), and found that their older group (age: 55-70 yr) needed more time to complete the task than a younger group (age: 16-25 yr).

Ketcham's group (2002) also found that older subjects (mean age = 68±6 yr) required longer movement time than younger subjects (mean age = 23±3 yr) when doing a finger-pointing task on a computer screen. Different sized circles were used as targets. When pointing to smaller targets, older subjects needed even longer times, but the accuracy of the two groups was not compared. There have also been investigators who asked older (age: 67-80 yr) and younger (age: 22-30 yr) subjects to reach for different sized targets with an electronic pen in the horizontal plane. The results of this research confirmed the observations of the prior studies. Older subjects were significantly slower than younger subjects in reaching all sizes of targets, and the movement time was longer when the targets were smaller. This research also found that older subjects had less error involving over-shooting targets than younger subjects due to their desire for better accuracy (Goggin & Meeuwsen, 1992). The slowing of movement in order to achieve a better accuracy conforms to Fitts' law, which states that movement time is indirectly proportional to target size (Fitts, 1992).

Apart from outcome measures like movement time and accuracy, decline in eye-hand coordination may also be reflected in slow reaction time (Birren & Botwinick, 1951; Chaput & Proteau, 1996). Reaction time also involves stages like receiving sensory information; planning action according to the information and executing the planned action (Birren et al., 1980), which resembles the mechanism of eye-hand coordination. Older subjects (age: 57-63 yr) record significantly slower reaction times than younger subjects (age: 19-22 yr) when asked to tap a switch when a light comes on (Inui, 1997). The results were the same when Yan and his colleagues(2000) asked young adults (mean age = 24.4±3.0 yr) and older adults (mean age = 73.5±3.3 yr) to touch targets on a horizontal digital tablet. They were required to touch the target with a stylus after hearing a signal in conformity with one of three different instructions. The instruction was either to move the stylus from the home position to the target once, or to and fro from the home position to the target three times, or six times. The reaction time and the time for each movement of the older adults increased as the number of motions increased.

In an aging population, more and more older adults suffer the effects of poor upper-extremity motor coordination caused by sensorimotor impairment. This can affect their upper limb performance and consequently make them more dependent in their activities of daily living (Desrosiers et al., 1995).

1.2.2 Limitations of previous studies

Previous studies have usually employed a stylus pen and required subjects to reach for static targets in a horizontal plane, which is only a two-dimensional task. The main exception has been the finger-pointing task on a computer screen used by Ketcham's group (2002). In real life, people rely on three-dimensional eye-hand coordination.

Investigators have tested subjects' reaction time and movement time by recording the time of beginning of hand movement and the time needed to move from a starting point to a target, respectively (Goggin et al., 1992; Bellgrove et al., 1998; Boisseau et al., 2002), but time is needed to initiate the movement of the arm, so these studies actually only looked at the last stage. The motor stage was poorer with aging, but whether onset time (time between the appearances of visual signal to onset of muscle activity) of the muscles is also longer remains unknown.

Another limitation of all past research has been that no matter whether using a stylus pen or pressing a button in response to a signal, all of the targets have been static. In daily life, people are often reaching for moving targets.

1.2.3 Eye-hand coordination with a moving visual signal

Target reaching often involves targets which are moving. For instance, reaching for the moving handrail of an escalator is a dynamic target situation, as is passing objects to or from another person whose hand is also moving. Indeed, for many people, passing keys or small items of clothing from one hand to the other commonly involves a brief flight phase.

Reaching for a moving object requires both spatial and temporal prediction. That is, a person must predict the position of the moving object in order to reach for it at the right time and location (Carnahan et al., 1998). Logically, according to the eye-hand coordination mechanism, any slowing of the central nervous system should slow spatial and temporal prediction performance, and this should be reflected in longer movement times, but observation does not bear out this expectation.

Carnahan and his colleagues (1998) compared the performance of young (mean age = 26.0 yr) and older (mean age = 70.1 yr) adults by asking them to reach for big and small blocks in 3 conditions: stationary, moving at 29.2 cm/s and moving at 40.3 cm/s. They found that no matter whether the target was large or small, stationary or moving, the older group had faster movement times than the younger group, and also less variability in movement time. The researchers tried to explain the effect by suggesting that the older group tended to anticipate the target instead of using feedback. However, this study did not reflect accuracy of performance, as the small block was quite big (6.5cm X 2.9cm X 2.5cm) and accuracy was reflected only in whether or not a subject could or could not grasp the target, which they did not report. Cooke and his colleagues (1989) also observed that older adults had faster moving times than younger adults, but only when the accuracy requirement was omitted. Previous studies have shown that older adults tend to strive for accuracy (Goggin & Meeuwsen, 1992), so what will be the performance of older adults when there is an accuracy requirement? Will their performance to comparable to that of younger adults?

1.2.4 Eye-hand coordination tasks with a cognitive component

In daily life, there are situations that require us to set priorities and choose responses to different signals. This is essential in dangerous situations, like receiving a sudden warning to withdraw from something unsafe before reaching it.

“The ability to suppress irrelevant or interfering stimuli is a fundamental cognitive function, but it deteriorates with aging” (Nielson et al., 2002).

Nielson and his colleagues (2002) employed functional magnetic resonance imaging (fMRI) to compare activated areas in the brains of older and young adults with interfering stimuli. Different alphabet letters were displayed one by one, and subjects were asked to press a button when they saw the letter X or Y alternately. That is, if they pressed the button in responses to X, they should not press the button again until they saw a Y. Random letters appeared between the targets. The investigators found that older adults activated more areas in the brain to compensate for their decline in neural changes (Nielson et al., 2002). Despite the using more activated areas, the reaction time of the older adults was still slower than that of the younger subjects. There was no significant difference in their error percentages, but there was a trend of poorer performance in older adults.

Van der Lubbe and Verleger (2002) conducted another study comparing the visual-spatial attention and inhibitory control (which is similar to the "ability to suppress irrelevant or interfering stimuli" of the above study) between older and young adults. They asked them to press a button with their left hand when a letter "A" was present on a computer screen, and press another button with their right hand when "B" appeared. The letters (yellow in color) randomly appeared in either one of two white frames (left and right) on the screen. When one frame was filled by a letter, the other frame would be filled with 3 horizontal yellow bars which had the same size and luminance as the letter. The result showed that older adults had much slower response times when the stimulus was not on the same side as the assigned button (e.g. when an A appeared in the right frame). The researchers concluded that the delay was due to slower internal processing in the brain (Van der Lubbe & Verleger, 2002).

1.3 Exercise

1.3.1 Exercise effects on eye-hand coordination

Exercise effects on eye-hand coordination have not yet been well investigated. There have been only few investigations of exercise, accuracy and reaction time.

Lobjois and his colleagues (2006) studied young (age = 20-30 yr), older (age = 60-69 yr) and elderly (age = 70-79 yr) tennis players and non-tennis players, asking them to press a button when a moving visual signal coincided with a target on a long track. They found that both of the older tennis playing groups achieved better accuracy than similar non-players, and that their results were even comparable with those of the young tennis players.

Another research study compared active (strenuous exercise at least 3 times a week for more than 30 minutes regularly for at least 10 yr) and inactive (no regular strenuous exercise) females in two different age groups by having them press a micro-switch when a light stimulus was on. The older active group (mean age = 68.7 yr) had better reaction times than old inactive group (mean age = 68.9 yr), and even achieved reaction times comparable with those of the young active subjects (mean age = 22.2 yr). The 2 older groups were then compared with women golfers (mean age = 69.5 yr, having golfing regularly for 10 yr, 2-3 times per week, without playing any strenuous sports). The golfers had significantly better results than the inactive women, but there were no significant differences in reaction time compared with the active older women (Rikli et al., 1986). So less vigorous exercise like golf may also benefit reaction time.

Exercise may compensate for aging effects on reaction time, movement time and accuracy as reflected in eye-hand coordination. However, racket sports and running are physically demanding, while golf is expensive to play. Both exercises also require equipment and a lot of space. These factors make these exercises less suitable for older adults who are not especially fit or lack financial support, whatever their benefits for eye-hand coordination.

1.4 Tai Chi

1.4.1 Benefits of Tai Chi

Tai Chi is a popular form of exercise among older Chinese adults. It consists of series of slow, smooth and graceful movements. It does not need expensive equipments or a large space. Recent studies have shown that Tai Chi benefits cardio-respiratory function, muscle strength, balance, flexibility and psychological well-being (Lan et al., 2002; Tsang & Hui-Chan, 2003; Tsang et al., 2004a). Tai Chi training emphasizes the integration of mind and body as well as movement coordination.

1.4.2 Ten principles of Tai Chi

According to Yu (2002), the 10 principles of Tai Chi suggested by Tai Chi master Yeng Siu Ching are:

1) **Straightening the head** (虛靈頂勁). The back and neck must be held in a natural upright position while practitioners concentrate on the vertex of the head.
2) **Correct positioning of the chest and back** (含胸拔背). To facilitate diaphragmatic breathing, practitioners are required to move their chest inward and breathe from their "lower belly" (丹田).
3) **Relaxation of the waist** (鬆腰). Tai Chi theory states that the four limbs are controlled by the trunk (Yu, 2002). Therefore, a relaxed waist is essential for the trunk to lead an accurate movement of the limbs. Relaxation of the waist also helps in maintaining lower limb support.
4) **Solid and empty stance** (分虛實). To achieve refined and smooth movement in Tai Chi, one must know how to shift their body weight in order to transfer from the solid (實) to the empty (虛) stance. A solid stance is on the side where the leg is supporting most of the body weight, and the empty stance is the opposite. Failing to transfer properly usually results in ungraceful and awkward movement.
5) **Sinking of the shoulders and elbows** (沈肩墜肘). Effortless movements require relaxation of the shoulders and elbows and maintaining a natural position.

6) **Using the mind instead of force** (用意不用力). The whole body should be led by the mind instead of forcing the limbs to move. Thus, the whole body should rest in a relaxed state without any stiffness.

7) **Coordination of the upper and lower parts of the body** (上下相隨). Movements of the head, arms, trunk and feet are meant to be coordinated. Force should be transmitted from the legs, to the waist and eventually to the fingers. Any abortive movement of a particular part may lead to disorder in the whole body movement.

8) **Harmony between the internal and external parts of the body** (內外相合). Tai Chi emphasizes the conscious mind controlling the body. A peaceful mind leads mild and refined movement, which expresses the harmony of the mind and body.

9) **The importance of continuity** (相連不斷). The flowing of the peaceful mind and movement in Tai Chi should be continuous and without end, like walking in a circle.

10) **Tranquility in movement** (動中求靜). Movement led by a tranquil mind should be effortless without any need of gasping.

From these 10 essential principles, it is clear that Yeng conceives of Tai Chi as coordinating the whole body, including the mind. The focus is on exact positions and movement control involving every body part, because any wrong movement or positioning of a single body part may disrupt the whole Tai Chi sequence.

1.4.3 Effects of Tai Chi on older adults' sensorimotor performance

Previous studies have shown that practicing Tai Chi can improve knee proprioception (Tsang and Hui-Chan, 2003, Xu et al., 2004, Fong and Ng, 2006). Older Tai Chi practitioners showed smaller knee angle errors in both active (Fong and Ng, 2006) and passive (Tsang and Hui-Chan, 2003) knee repositioning test when compared with control subjects of similar age, gender and physical activity level. Older adults who practiced Tai Chi also showed better joint (kinesthetic) sense in detecting knee flexion and ankle movement when their knee and ankle joints were passively moved (Xu et al., 2004).

Tsang & Hui-Chan (2003) used a dynamic standing balance assessment, and found that older Tai Chi practitioners had faster lower limb reaction times and better directional control than their elderly control subjects in a limits of stability test (Tsang & Hui-Chan, 2003) in which subjects were asked to move their centre of gravity by weight shifting without bending their waist. Fong & Ng (2006) also found faster reaction times in the lower limbs muscles (medial hamstrings and gastrocnemius) of Tai Chi practitioners when compared with control older adults. They used surface EMG to detect the onset of lower limb muscle activity when blindfolded and ear shielded subjects threw a ball behind their back.

1.4.4 Effects of Tai Chi on eye-hand coordination in older adults

Research has shown that when experienced Tai Chi practitioners perform a task which requires moving a stylus from target to target (a total of 10 targets) in a zigzag pattern, their time needed to complete the task is significantly shorter, there is less extra displacement and their pause time is less when compared with Tai Chi non-practitioners (Pei et al., 2008). Both groups were in their 60s, and these results indicate that Tai Chi may promote better upper limb motor control with faster movements and a smoother trajectory.

Yan (1998) also found that older adults (age = 78.8±2.1 yr) who practiced Tai Chi (24-form simplified Tai Chi) in an 8-week program (3 times a week, at least 45 minutes) could perform fine motor control tasks with their upper limbs better than matched groups which practiced walking or jogging in their 8-week program. These subjects were first assessed before the exercise program, after 4 weeks, and at the end of the program. They were asked to move a stylus with their dominant hand to reach a final target by crossing another intermediate target with a curved line. Movement time and movement jerks were recorded. Although the movement times were not significantly different, the Tai Chi group made smoother movements showing fewer jerks than the non-Tai Chi group.

Jacobson and his colleagues (1997) carried out a pre- and post-tests with or without a Tai Chi program with 2 groups of young adults aged between 20 and 45. They found that young adults who practiced Tai Chi three times a week for 12 weeks showed better glenohumeral joint proprioception afterward than the control group. The Tai Chi group made fewer errors in repositioning their shoulder joint angle when they were blindfolded and asked to reproduce the angle of motion a researcher had generated in moving their shoulder in medial rotation passively.

These results show that practicing Tai Chi may improve eye-hand coordination, because arm trajectory, faster movement and better kinesthetic sense all contribute to good eye-hand coordination.

The present thesis consists of 2 studies aimed at investigating the extent to which Tai Chi could improve eye-hand coordination in the older adults. It starts with a detailed description on methods and procedures (chapter 2). The rationale and objectives of each study will be presented here and in chapter 3 and chapter 4. Chapter 5 contains the summary and conclusion of the present study.

1.4.5 Rationale and objectives

Study 1: Practicing Tai Chi improves performance among the elderly in pointing toward static and moving targets

Rationale

Previous work has shown that practicing Tai Chi improves upper limb movement speed, smoothes movement control. This may be explained by the continuous movements in Tai Chi and its training effect on proprioception which helps in directing the upper limbs to execute better trajectories. The better directional control of Tai Chi practitioners could be due to their increased awareness of their joints, since Tai Chi puts much emphasis on exact joint positioning and movement control. Repeated practice of the same movement may also enhance the body's cortical representation, which should improve joint sense (Tsang & Hui-Chan, 2003, 2004a, 2004b).

It is reasonable, then, to believe that Tai Chi may improve eye-hand coordination. However, there has been too little research supporting this contention with comprehensive outcome measures.

Objective 1

To compare eye-hand coordination in a simple finger-pointing task with stationary targets among elderly Tai Chi practitioners, matched elderly controls and young control subjects. The outcome measures included reaction time, movement time, and accuracy.

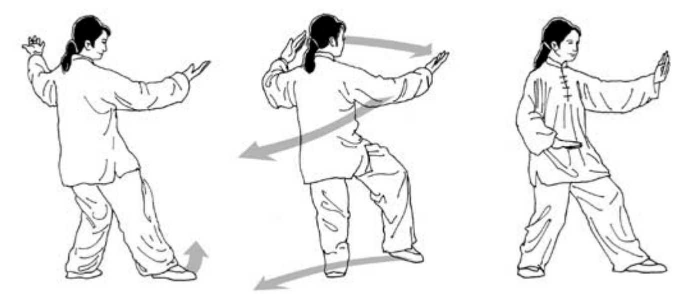


Figure. 1 A Tai Chi form "repulse the monkey"

Rationale

Tai Chi practice involves lots of continuous movement. For example, the "repulsing the monkey" maneuver (Figure. 1) requires the practitioner to move both hands continuously in different directions and accompany this with a rotation of the trunk and stepping back, focusing the eyes all the while on the hand. Practicing such drills may help in maintaining eye-hand coordination in responding to a moving visual target.

Objective 2

To investigate the performance of eye-hand coordination when pointing to a moving target among the three subject groups.

The study on “Practicing Tai Chi improves performance among the elderly in pointing toward static and moving targets” will be presented in Chapter 3.

Study 2: Finger-pointing task with a cognitive component in older Tai Chi practitioners

Rationale

Tai Chi’s emphasis on attention to the exact positions of joints and memorizing a long series of movements might increase the strength of synaptic connections and promote structural changes in the organization and number of connections among neurons due to repeated firing of nerves along the gamma route from muscle spindles. This might induce plastic change in the central nervous system (Fong and Ng, 2006, Tsang & Hui-Chan, 2003, 2004a, 2004b).

Since the suppressing ability during eye-hand coordination has a cognitive component which deteriorates with age (Nielson et al., 2002), it would be useful to know whether or not Tai Chi’s mind-focusing predicts effects on the central nervous system. It might also improve cognitive function.

Objective 3

To investigate the effect of Tai Chi practice on performance in a finger-pointing task with a cognitive component among the three groups.

The study on “Finger-pointing task with a cognitive component in older Tai Chi practitioners” will be presented in Chapter 4.

CHAPTER 2

METHODS AND PROCEDURES

2.1 Methods

2.1.1 Subjects

All 91 subjects were recruited through convenience sampling. They were divided into 3 groups, the young adults (aged from 18 to 32 yr), older control adults (aged $\geq$ 60 yr), and older Tai Chi practitioners (aged $\geq$ 60 yr). The older subjects were either from elderly centers or community Tai Chi classes, whereas the younger subjects were recruited at universities in Hong Kong. Each group contained 15 male and 15 female participants except in the Tai Chi group (15 male and 16 female).

2.1.2 Inclusion Criteria

For inclusion in the Tai Chi group, subjects had to have experience of practicing Tai Chi (either Wu or Yang style) more than one and a half hours per week for 3 years or more. There were two reasons for these criteria. First, the ACSM (American College of Sports Medicine) suggests that an exercise frequency of three to five days per week, with duration of 30 minutes or more is recommended in order to maintain fitness (Armstrong et al., 2006). Thus, the minimum time of exercise per week should be one and a half hours, which was one of the inclusion criteria. Second, according to Tsang and Hui-Chan (2003), Tai Chi practitioners with more than 3 years of experience showed significantly better reaction times than those with less experience during a balance control test. A training effect on eye-hand coordination may be expected after 3 years of practice.

The elderly and young adult control subjects recruited did not have any Tai Chi experience. All the subjects underwent four screening tests, in which they had to

(1) score of at least 24 in the Mini-Mental Status Examination (MMSE) to show no cognitive impairment (Folstein et al., 1975). Chiu and colleagues had validated the Chinese version which was applied in this study (Chiu et al., 1994); (2) attain 20/20 or above in Snellen's visual acuity test (Elkington et al., 1999), with eye-glasses if necessary; (3) demonstrate sufficient active range of motion in their upper limbs in performing the eye-hand coordination tests in which the subjects were asked to flex and extend the shoulder, elbow, wrist and fingers; and (4) complete a modified Minnesota Leisure Time Physical Activity Questionnaire (Van Heuvelen et al., 1998). This latter questionnaire categorized older subjects' daily activities (household chores, hobbies and sports) into 3 different physical levels according to metabolic index units (METs), namely light (<4 METs), moderate (4-5.5 METs), and heavy (> 5.5 METs) in order to rate the energy expenditure. It was used to compare the physical level among older subject groups (Tsang & Hui-Chan 2003, 2004a, 2005, 2006; Tsang et al., 2004).

2.1.3 Exclusion Criteria

Subjects who could not fulfill the inclusion criteria included those with any eye pathology such as glaucoma or cataract (unless it had been corrected and they were able to score at least 20/20 in Snellen's acuity test). Cognitive impairments were screened for by the MMSE and were grounds for exclusion. Cardiovascular pathologies, such as symptomatic cardiovascular diseases or uncontrolled hypertension were also a basis for exclusion. Subjects suffering from any pathology affecting their upper limb function such as stroke, Parkinson's disease, or any disabling neurological or musculoskeletal disorder were also excluded. Peripheral neuropathies of the upper extremities or metastatic cancer were also grounds for exclusion.

2.1.4 Ethical Considerations

Subjects were given an explanation of the objectives and procedure of the study, and signed a consent form in order to participate in the study. They were also informed that they could withdraw from the study at any time without any punishment or penalty.

The study's assessments and measurement were all non-invasive, and all were approved by the ethics committee of The Hong Kong Polytechnic University.

2.2 Procedures

The setup of the visual display unit was shown in fig. 1a. The equipment included a visual display unit (Clear Tek 3000 LCD screen, MicroTouch Systems Inc., Methuen, USA), 3 surface electrodes (B&L Engineering Division of Pinsco Inc., USA), and an Data Acquisition (DAQ) card (type 6024E, National Instruments, , Hungary). The data was collected using a tailored LabView (version 7.0, National Instruments, Hungary) software program.

The surface electrodes were used to record EMG activities in the subjects' anterior deltoid, biceps and extensor carpi radialis longus muscles during testing. The monitor was fixed on a table with the upper edge of the screen at each subject's eye level (fig. 2a). The subject was strapped into a chair at the table facing the screen with both hands on the table. The angle of the visual display unit and the distance between the mid-point of the LCD and the starting position of the subject's dominant hand (the side major for writing and holding chopsticks) were fixed. At the starting point, the subject's index finger was 10cm from the screen (fig. 2b).

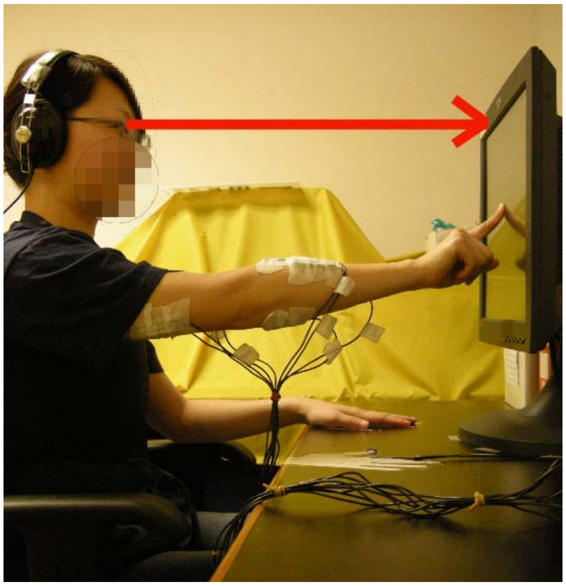


Figure. 2a

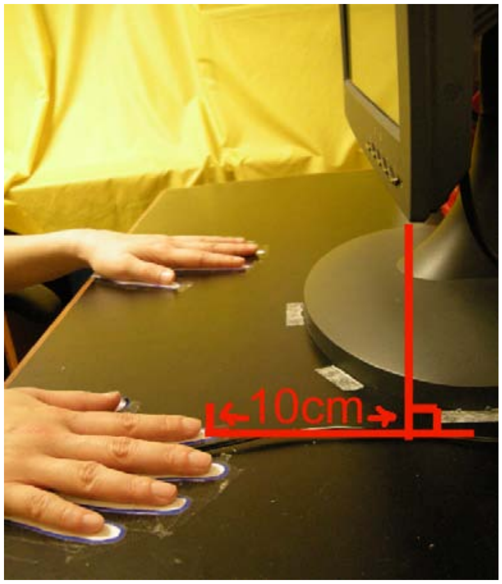


Figure. 2b

Figure. 2c

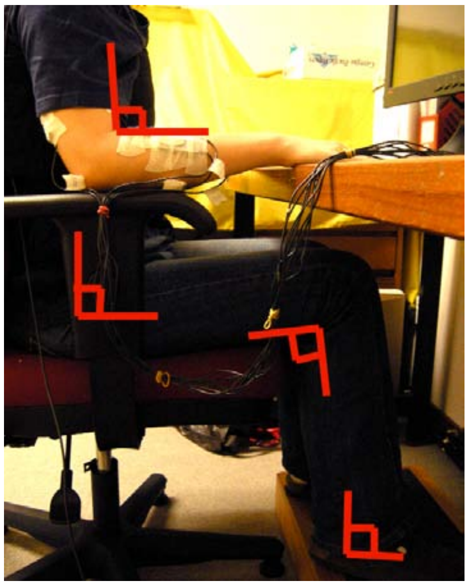


Figure. 2d

The subject's upper trunk was strapped to the chair with a Velcro belt (fig. 2c) to prevent trunk movement, because finger pointing can involve either trunk and arm movement or arm joint movement alone (Pigeon et al., 2000). Since the objective was to record EMG responses of arm muscles only, it was necessary to inhibit the trunk movement so that the subjects reached for the targets with only arm joint movement.

Subjects sat on a height-adjustable, non-rotating chair with arm-rests. The angles of their elbow, hip, knee, and ankle joints were all approximately 90 degrees (fig. 2d). Foot and arm-rests, where necessary, allowed the subjects to assume the posture explained above (as shown in fig. 2d).

According to the EMG electrodes manufacturer, the electrodes did not need any skin preparation or gel but the skin of each subject's arm was nevertheless cleaned with a wet tissue, then abraded and cleaned with alcohol to remove any excess dead skin and skin oil, and gel was also used, because Roy and his colleagues have shown that skin preparation can improve conduction for subjects with dry skin by facilitating the flow of ions between and electrode and the skin (Roy et al., 2007). The electrodes were positioned over the anterior deltoid, biceps and extensor carpi radialis longus with an elastic adhesive fabric tape and electrolyte gel, and placed in line with the muscles as recommended by Cram and Kasman (1997). However, we only presented the results on anterior deltoid as it is the prime mover for arm reaching component (Schmid et al., 2006), while other muscles' data served as ground-work for further studies.

A headphone (Panasonic- RP-HTX7) was used to deliver a preparatory signal to alert the subjects before the appearance of a target ball in each test. A “Ding” sound was generated by the computer and delivered via the headphone. The time between the auditory signal and appearance of target was 2 seconds, but there were tests in which no visual signal appeared after the auditory signal to deter subjects’ anticipation.

At the beginning of each task, subjects were first asked to relax and looked at the center of the LCD. When the test started, the first second of each test was used to record the relaxed muscles’ EMGs as the resting threshold. After finishing each task, the hand was returned to the starting position and relaxed. The next target would not appear until the EMGs of the arm muscles had returned to their original resting thresholds.

After a warning “ding”, a visual signal (a black ball 1.2cm in diameter) appeared at an arbitrary position on the screen. Subjects were instructed to point to the visual signal as fast and as accurately as possible. Spoken encouragement “fast and accurate” was delivered (in Cantonese) in the middle of each set of tests to counter any decrease in attention span. Familiarization trial runs were given for each protocol.

2.2.1 Protocol A (Finger-pointing task to a static visual signal)

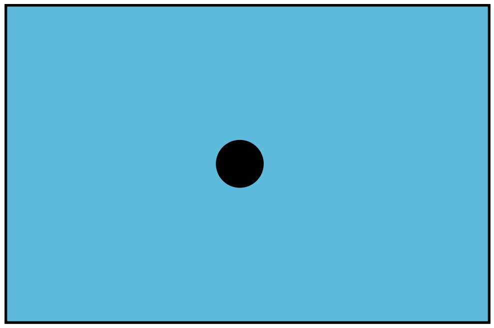
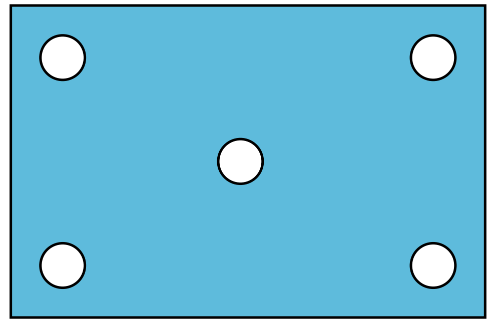


Figure. 3a

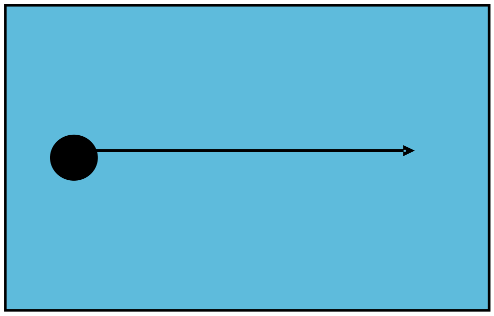


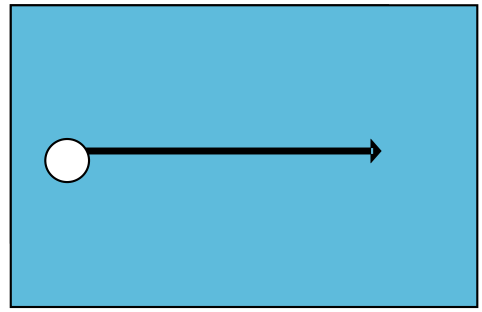
Visual signals' location on touch screen

Figure. 3b

Subjects used their index finger to point at the visual signal as fast and as accurately as possible when it appeared on the LCD screen. After touching the visual signal (indicated by the disappearance of the visual signal), subjects returned their hand to the starting position at once and relaxed before the next trial. Each subjects had 2 trial runs before the assessment. The LCD monitor was 34cm wide and 27cm tall. It was divided into 1000 sections from left to right, and top to bottom. The target of each trial appeared at one of only 5 locations: 100,100 (upper left), 100,900 (upper right), 500,500 (center), 900,100 (lower left) and 900,900 (lower right) (Figure. 3b). Its initial appearance was randomized across trials for each subject, but the sequence of appearances was the same for all subjects. Each subject's reaction time, movement time and accuracy when performing this task were recorded.

2.2.2 Protocol B (Finger-pointing task with a moving visual signal)





Visual signals’ locations on touch screen

Figure. 4a **Figure. 4b**

Protocol B was a finger-pointing task with moving visual signal. A moving visual signal (in the form of a black ball) appeared from the left side of the LCD screen and moved to the right along the same Y coordinate (500) at 12 cm/s (Figure. 4a) for 10 times. Brouwer and colleagues (2002) used target speeds of 6, 12 and 18 cm/s and found that 6 and 12 cm/s gave similar success rates (81%) with normal adults, while the success rate at 18 cm/s was only 73%. The speed of 12 cm/s was chosen in the present investigation, since this speed was not as difficult as 18 cm/s for the older subjects, but might provide a more challenging condition to differentiate the performance between the 2 older adult groups. Also, such speed was found to produce a repeatable testing protocol to the older adults as shown in our present findings.

When the visual signal appeared on the screen, the subjects used their index finger to touch the ball as fast and as accurately as possible. After successfully touching the target (indicated by the disappearance of the visual signal), the subjects returned the hand to the starting position at once and relaxed before the next trial. Again, there were tests in which no visual signal appeared after the auditory signal to deter subjects' anticipation.

2.2.3 Protocol C (Finger-pointing task with a cognitive component)

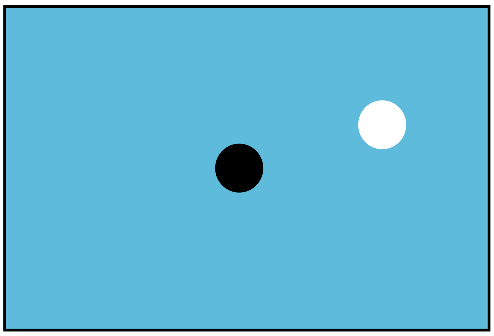
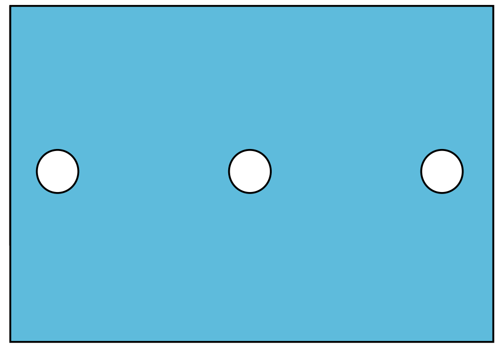


Figure. 5a



Visual signals' locations on touch screen

Figure. 5b

Subjects were tested under 3 different conditions in this protocol. The coordinates of the targets that required touching were at 100, 500 (middle-left), 500,500 (centre) and 900,500 (middle-right) (Figure. 5b). The sequence of appearance of the three conditions was random, and subjects did not know which condition would popup next, but the order was programmed to be the same for every subject. In condition 1, 1 black ball appeared, and the subjects were required to touch it as fast and as accurately as possible. In condition 2, 1 white ball appeared, and the participants were told not to touch it. In condition 3, both a black and a white visual signal appeared on the screen, and the subjects were required to touch only the white ball. Condition 1 and 3 appeared for 15 times each, and 10 times for condition 2. Thus, there were a total of 40 runs. Each coordinate had a total 10 times of touch. As in protocol A, they were instructed to return their hand to the starting position and relaxed it until the next target appeared. Familiarization trials of each protocol were given. Outcome measures included the number of *wrong movements*, either touching the white ball in condition 2, or the black ball in condition 3. The reaction time, movement time and accuracy were also measured for comparison.

2.2.4 Variables

Each subject's total time, reaction time, movement time and accuracy in each trial were collected and served as the dependent variables. *Total time* was the time from the beginning of EMG activity in any muscle until contact with the target. *Reaction time* was from the appearance of the ball on the screen to the onset of the EMG response. Reaction time reflected the transmission time and the cognitive processing speed involved in response preparation (Schmidt & Lee, 1999). *Movement time* was the time from the onset of the EMG response to touching of the ball. A shorter movement time indicated faster hand speed. As for *accuracy*, it is the absolute deviation of the subject's finger-pointing location from the center of the ball (Schmidt & Lee, 1999).

2.3 Statistical Analysis

The data were analyzed with the Statistical Package for the Social Sciences (SPSS) 14.0 software (SPSS Inc., USA). The test-retest reliability of outcome measures of older adults was assessed by calculating the intraclass correlation coefficient (3, x), as suggested by Shrout & Fleiss (1979), where x represents the number of trials. This procedure is suitable for assessing intra-tester reliability with more than one dependent variable.

The subjects' mean age, height, and arm-length (distance between acromion and tip of middle finger measured by measuring tape) among the three groups were calculated using one-way analysis of variance (ANOVA) and gender was compared through a chi-square test.

Arm-length was treated as co-variate in the statistical analysis if a significant difference was found. This is because the starting position of hand and the visual display unit was fixed for all participants, and the differences in arm-length might constitute a co-variate in the finger-pointing tasks. Arm-length was defined as the distance between subjects' acromion and tip of middle finger.

The MMSE scores of the two subject groups were compared using independent t-tests to assure that eye-hand coordination performance was not affected by cognitive differences.

The activity levels measured with the modified physical activity level questionnaire were compared using the chi-squared statistic to ensure that the elderly controls and the Tai Chi group had similar physical activity levels. Any difference in the eye-hand coordination performance will not be due to such factor.

Multi-variate analysis of variance (MANOVA) was used to compare each of the outcome measures—reaction time, movement time and accuracy—among the three groups and the five locations in finger-pointing task with static visual signal and the three locations in finger-pointing task with a cognitive component. If statistically significant differences were found in the multivariate tests, univariate tests were conducted for each of the locations. And when a significant difference was found in the univariate test, post hoc analysis using Bonferroni's adjustment was conducted.

One-way ANOVA and Bonferroni's post-hoc test were used to analyze the three outcome measures in finger-pointing task with a moving signal and the number of wrong movement in finger-pointing task with a cognitive component. The latter analysis was carried out only when a statistically significant difference was found in the one-way ANOVA. For statistical comparison, 0.05 was chosen as the significance level (α).

CHAPTER 3

PRACTICING TAI CHI IMPROVES PERFORMANCE AMONG THE ELDERLY IN POINTING TOWARD STATIC AND MOVING TARGETS

3.1 Abstract

Purpose: A cross-sectional study examined the aging effect on speed and accuracy in pointing toward static and moving visual targets, and attempted to determine whether or not Tai Chi practitioners performed better than healthy older control subjects in these tasks.

Methods: The pointing abilities of 30 young university students (24.2±3.1 yr) were compared with those of 30 healthy older control subjects (72.3±7.2 yr), and 31 experienced (mean yr of practice = 7.1 yr) older Tai Chi practitioners (70.3±5.9 yr). The subjects pointed with the index finger of their dominant hand, from a fixed starting position on a desk to a visual signal appearing on a display unit, as quickly and as accurately as possible. Reaction times, movement times and accuracy were recorded.

Results: The students achieved significantly faster reaction and movement times, with significantly better accuracy than the older control subjects in all finger-pointing tasks. The Tai Chi practitioners attained significantly better accuracy than the older controls with static visual signals appearing contra-laterally and centrally to their pointing hand. They also demonstrated significantly better accuracy when the target was moving. Of special interest is that their accuracy was similar to that of the young controls.

Conclusion: These results confirmed that eye-hand coordination in finger-pointing declines with age. However, Tai Chi practitioners attained significantly better accuracy than control subjects similar in age, gender and physical activity level.

Key Words: EYE-HAND COORDINATION, EXERCISE, SPEED, ACCURACY

3.2 Introduction

Eye-hand coordination is an important perceptual-motor function facilitating goal-directed movements in daily life, for example reaching for and manipulating objects (Bekkering and Sailer 2002). Decline in eye-hand coordination is a major problem among older adults (Chaput and Proteau 1996). Previous studies have demonstrated that slower initiation of limb movement and task execution are the major contributing factors (Yan et al. 2000).

Motor coordination can be defined as the ability to produce a controlled, accurate and rapid movement. Its deterioration is a major factor in much age-related slowing (Desrosiers et al. 1995). In particular, it is an important prerequisite for adequate upper-extremity performance. Accurate arm movements depend not only on visual input, but also on proprioceptive information about the current angles of the head, neck, trunk and arm joints, and their respective muscular work (Henriques and Crawford 2002). In an aging population, more and more older adults suffer from poor upper-extremity motor coordination following sensori-motor impairment. This can influence their upper limb performance and consequently make them more dependent in their activities of daily living (Desrosiers et al. 1995).

The more complicated the stimulus presented and the decisions to be made, the slower will be the reaction time of persons of any age, but studies have shown that reaction time slows with advancing age, and this retardation becomes pronounced as task difficulty increases (Ketcham et al. 2002). This age-complexity effect is probably because of age-induced changes in processing resources. Investigators have suggested that increases in task complexity lead to increased demands on processing resources, and as older adults have smaller available resources, their performance is affected more than that of young adults (Inui 1997).

Although aging inevitably involves physiological changes, some of the declines in mental and physical fitness can be retarded through exercise. Research findings have shown that older adults can benefit from exercise through faster reaction times, better accuracy, and increased muscle strength (Baylor and Spirduso 1988; Lobjois et al. 2006; Spirduso and Clifford 1978). Tai Chi is a popular form of exercise among older adults. It involves a series of slow, smooth and graceful movements. Its training emphasizes the integration of mind and body, as well as movement coordination. Many Tai Chi forms require practitioners to focus their eyes on their hand movement through head and/or trunk rotation (Tsang et al. 2004). The improved knee joint proprioception and balance control in stance observed among Tai Chi practitioners (Tsang and Hui-Chan 2003) suggests that repeated Tai Chi practice might also improve the eye-hand coordination of older adults.

Tsang and Hui-Chan (2003) have demonstrated that older Tai Chi practitioners show significantly more acute knee proprioception than untrained, matched controls. They showed smaller knee angle errors in a passive knee repositioning test than control subjects similar in age, gender and physical activity level. Indeed, their performance was comparable to that of young university students (Tsang and Hui-Chan 2004a). As limb proprioceptive sense contributes to motor coordination, better proprioception might enhance performance in eye-hand coordination. In a dynamic standing balance assessment, older Tai Chi practitioners had faster reaction times, leaned further without losing stability, and showed better control of leaning trajectory than did matched control subjects in a limits of stability test (Tsang and Hui-Chan 2003). The latter 2 outcome measures were also comparable to those of young subjects (Tsang and Hui-Chan 2004a). Faster reaction time and better control of leaning trajectory as found in balance control could reflect the better motor coordination which might also be reflected in better eye-hand coordination. Therefore, the objectives of the present study were (1) to examine the effect of aging on performance in a finger-pointing task involving static and moving visual signals, and (2) to compare the performance of experienced older Tai Chi practitioners and healthy older control subjects in these tasks.

3.3 Methods

3.3.1 Subjects and Study Design

Thirty young university students (aged 24.2±3.1 yr) were compared with 31 healthy older control subjects (aged 72.3±7.2 yr), and 31 experienced (mean = 7.1±6.5 yr of practice) Tai Chi practitioners (aged 70.3±5.9 yr) in this cross-sectional study. All the university students claimed to exercise for at least 2 $h \cdot wk^{-1}$. The control subjects were recruited from several community centers for older adults. They had no previous experience in Tai Chi, though some took morning walks or did stretching exercises. For inclusion in the Tai Chi group, subjects had to have recent experience of practicing Tai Chi more than 1.5 $h \cdot wk^{-1}$ for 3 yr or more. All the subjects underwent 4 screening tests. They had to (1) score at least 24 in the

Mini-Mental Status Examination (MMSE) to show they had no cognitive impairment (Folstein et al. 1975). Chiu and his colleagues had validated the Chinese version which was applied in this study (Chiu et al. 1994); (2) attain 20/20 or above in Snellen's visual acuity test (Elkington et al. 1999), with eye-glasses if necessary; (3) demonstrate sufficient active range of motion in their upper limbs to perform finger-pointing tasks in which the subjects were asked to flex and extend the shoulder, elbow, wrist and fingers; and (4) complete a modified Minnesota Leisure Time Physical Activity Questionnaire (Van Heuvelen et al. 1998). This latter questionnaire categorized the subjects' daily activities (household chores, hobbies and sports) into 3 different physical activity levels according to metabolic index units (METs), namely light (<4 METs), moderate (4-5.5 METs), and heavy (> 5.5 METs) reflecting energy expenditure. The Minnesota questionnaire has often been used to compare the physical activity levels of older subjects (Tsang and Hui-Chan 2003; Tsang and Hui-Chan 2004b; Tsang and Hui-Chan 2005).

Subjects who could not fulfill the inclusion criteria included those with any eye pathology such as glaucoma or cataract (unless it had been corrected and they were able to score at least 20/20 in Snellen's acuity test). Cognitive impairments revealed by the MMSE and were also grounds for exclusion. Cardiovascular pathologies, such as symptomatic cardiovascular diseases or uncontrolled hypertension were also a basis for exclusion. Subjects suffering from any pathology affecting their upper limb function such as stroke, Parkinson's disease, or any disabling neurological or musculoskeletal disorder were also excluded. Peripheral neuropathies of the upper extremities or metastatic cancer were also grounds for exclusion. The project was approved by the Ethics Committee of The Hong Kong Polytechnic University, and written informed consent was obtained from all subjects.

3.3.2 Test Procedures

The subjects were instructed to perform pointing with the index finger of their dominant hand (the hand used for writing or holding chopsticks) as quickly and as accurately as possible, from a fixed starting position on a desk to a visual signal appearing on a display unit (Clear Tek 3000 LCD screen, MicroTouch Systems Inc., Methuen, USA). The visual display unit was fixed on and perpendicular to the supporting surface, with its upper edge at each subject's eye level and 36 cm from the supporting surface. At the starting point, the subject's index finger was motionless on the desktop 10 cm from the screen. The visual signal was a black spot 1.2 cm in diameter. There were 2 testing protocols involving a static or a moving visual signal.

The subjects sat stably on a height-adjustable, non-rotating chair with arm-rests in front of a computer-controlled LCD touch screen, with their hands resting on a desk and their elbows, hips, knees and ankles at approximately 90º. Their upper trunks were strapped to the chair with a Velcro belt to prevent trunk movement, because finger-pointing can involve either trunk and arm movement or arm movement alone (Pigeon et al. 2000). Since the electromyographic responses of the arm muscles only were being recorded, it was necessary to inhibit trunk movement so that the subjects reached for the visual signal only with their arm joints. A headphone (Panasonic – RP-HTX7) was used to deliver a preparatory signal to alert the subjects before the appearance of a visual signal in each test. A “Ding” sound was generated by the computer and delivered via the headphone. The time between the auditory signal and the target’s appearance was 2 s, but there were tests in which no visual signal appeared after the auditory signal to deter anticipation. At the beginning of each test, the subjects were first asked to relax and look at the center of the LCD display unit. When the test started, the first second of each test was used to record the relaxed muscles’ EMG signal as the resting threshold. After finishing each task, the hand was returned to the starting position and relaxed. The next target would not appear until the EMG signals of the arm muscles had returned to their original resting thresholds. After a warning “ding”, a visual signal appeared on the screen. The subjects were instructed to point to the dot as quickly and as accurately as possible. Spoken encouragements, “fast and accurate” were delivered at the middle of each set of tests by the same tester (regardless of the subject’s actual performance) to counter any decrease in attention span.

3.3.2.1 Pointing toward a static visual signal

Subjects used their index finger to point at a static visual signal as quickly and as accurately as possible when it appeared on the LCD screen. The LCD monitor was 34 cm wide and 27 cm tall. It was divided into 1000 sections from left to right, and from top to bottom. The visual signal of each trial appeared at one of only five locations: 100,100 (upper left), 100,900 (upper right), 500,500 (center), 900,100 (lower left) and 900,900 (lower right). Its initial appearance was randomized across trials for each subject, but the sequence of appearances was the same for all subjects. There were 10 trials for each location and the average of each location was used to compare the eye-hand coordination performance among the three groups. Each subject had familiarization trials before the assessment. Subjects' reaction time, movement time and accuracy when performing this task were recorded.

3.3.2.2 Pointing toward a moving visual signal

A moving visual signal (the same black spot) appeared from the left side of the LCD screen and moved to the right along the same Y coordinate (500) at 12 $cm\cdot s^{-1}$. Brouwer's group (2002) has previously used visual signal speeds of 6, 12 and 18 $cm\cdot s^{-1}$ and found that 6 and 12 $cm\cdot s^{-1}$ gave similar success rates (81%) with normal adults, while the success rate at 18 $cm\cdot s^{-1}$ was only 73%. The speed of 12 $cm\cdot s^{-1}$ was chosen in the present investigation, since this speed was not as difficult as 18 $cm\cdot s^{-1}$ for the older subjects, but might provide a more challenging condition to better differentiate the performance of the 2 older adult groups. A set of 10 trials with each subject was found to generate repeatable results.

3.3.3 Data Recording and Analysis

A surface electrode was used to record EMG activity in the anterior deltoid muscle of each subject's dominant hand. The electrode was positioned with electrolyte gel and adhesive tape and placed in line with the muscle as recommended by Cram and Kasman (1998). The EMG signals were recorded using surface electrodes (B&L Engineering Division of Pinsco Inc., California, USA) at a total gain of 320 times, a total input impedance of >100megaOhms, and over a bandwidth of 12Hz to 3000Hz. The signals were sampled at 1000Hz and digitized using an analog/digital converter card (National Instrument NI DAQCard-6024E), then stored for off-line analysis. The EMG data were processed using the LabView software suite (National Instrument, Texas, USA). The signals were full-wave rectified and smoothed using a second-order Butterworth low pass filter with a cut off frequency of 10Hz. The onset of muscle activity was identified as the point where the EMG signal fired and deviated more than 3 standard deviations from the baseline. The point was determined by using a tailor-made LabView software program, but visually checked (Figure. 6). Onset of visual signals, EMG signals, and positions/timings of touching the visual display unit were recorded and time marked for synchronization using the LabView program.

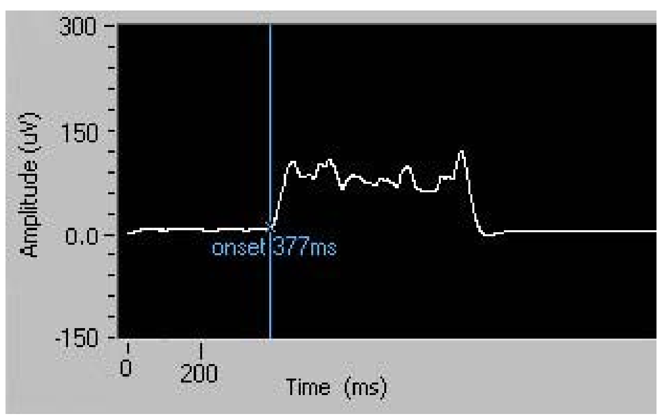


Figure. 6 A full-wave rectified and smoothed EMG signal

Reaction time, movement time and accuracy were used to compare among the three groups. Reaction time was the time from the appearance of the spot on the screen to the onset of the anterior deltoid EMG response. Movement time was the time from the onset of the EMG response to touching the spot. Accuracy in locating the spot on the LCD screen was defined as the absolute deviation of the subject's finger-pointing location from the center of the spot.

3.3.4 Statistical Analysis

To ensure data reliability, an intraclass correlation coefficient (ICC) was used to assess the test-retest reliability of the outcome measures in the older adults. One-way analysis of variance (ANOVA) was used to compare the age, height, and arm-length among the three groups, and gender was compared through a chi-square test. Since the starting position of the hand with respect to the visual display unit was fixed for all participants, the differences in arm-length might constitute a co-variate in the finger-pointing task. Arm-length was thus treated as a co-variate in the statistical analysis if a significant difference was found. Arm-length was defined as the distance between a subject's acromion and the tip of the middle finger. For the comparison between the two older adult groups, independent-t tests were conducted with the MMSE scores, and a chi-square test was used to compare their physical activity levels. With the static visual signal, multi-variate analysis of variance (MANOVA) was used to compare each of the outcome measures—reaction time, movement time and accuracy—among the three groups and the five locations. If statistically significant differences were found in the multivariate tests, univariate tests were conducted for each of the locations. Post hoc analysis using Bonferroni's adjustment was conducted if a significant difference was found in the univariate test. One-way ANOVA was used to compare reaction time, movement time and accuracy among the three groups in the task with a moving signal. If a statistically significant difference was found in the one-way ANOVA, post hoc analysis using Bonferroni's adjustment was performed. A significance level (α) of 0.05 was chosen for the statistical comparisons.

3.4 Results

3.4.1 Subjects

Eighty older subjects volunteered to participate in this study. Two Tai Chi practitioners were excluded because they had less than three years of Tai Chi practice. Among the control subjects, three were excluded because of their previous Tai Chi experience, eight due to MMSE scores lower than 24, and a further 6 subjects were excluded because they were unable to score 20/20 or more in Snellen's acuity test.

Table 1 shows a comparison of age, height, and arm-length among the three groups. One-way ANOVA showed statistically significant differences between the young subjects and the older adults in age, height and arm-length, with no significant difference between the two older adult groups in the post hoc analysis. Since the arm-lengths were significantly different, this was treated as a co-variate in the MANOVA and one-way ANOVA procedures. Chi-square tests showed no significant difference in gender distribution among the three groups. All the older adults had scored at least 24 on the Mini-Mental Status Examination, which indicated no cognitive dysfunction (Chiu et al. 1994). A chi-square test found no statistically significant difference between the two older adult groups in terms of their physical activity level (Table 1). The Tai Chi practitioners and control subjects were thus similar with respect to age, height, arm-length, gender, MMSE scores and physical activity levels.

Table 1: Comparisons of age, height and arm-length among young control, older Tai Chi, and older control subjects; Mini-Mental Status Examination and physical activity levels between the two older adult groups.

	Young Control Subjects (*N* = 30)	Tai Chi Subjects (*N* = 31)	Older Control Subjects (*N* = 30)	*P*
Age (yr)	24.2±3.1	70.3±5.9†	72.3±7.2†	0.000*
Height (m)	1.67±0.08	1.59±0.07†	1.58±0.08†	0.000*
Arm-length (cm)	70.5±4.3	67.2±4.3†	65.3±5.8†	0.000*
Gender (M/F)	15/15	15/16	15/15	0.989
MMSE score	-	26.6±1.9	26.7±2.0	0.966
Physical activity level				0.364
Light < 4 METs	-	*N* = 10	*N* = 15	
Moderate 4-5.5 METs	-	*N* = 16	*N* = 11	
Heavy > 5.5 METs	-	*N* = 5	*N* = 4	

NOTE. Values are mean ± SD for this and all subsequent tables.
- Denotes “not tested.”
Abbreviations: F, female; M, male; MMSE, Mini Mental Status Examination; MET, metabolic equivalent.
* Denotes a significant difference at the $P<0.05$ level using one-way ANOVA.
† Denotes a difference from the young controls significant at the $P<0.05$ level by means of *post hoc* analysis using Bonferroni’s adjustment.

3.4.2 Test-retest reliability

Among the 61 older adult participants, 6 males (3 Tai Chi subjects) and 14 females (9 Tai Chi subjects) with a mean age = 69.2±7.1 yr, returned to the laboratory one week after the first finger-pointing trials for a second assessment. Table 2 shows their ICC values for reaction time, movement time, and accuracy, which ranged from 0.68 to 0.97, thus showing moderate to very good data repeatability.

Table 2. Interclass correlation coefficients (ICC) for each response in replicate tests (*N* = 20).

	Finger-pointing toward a static visual signal		Finger-pointing toward a moving visual signal	
	ICC#	95% CI	ICC	95% CI
Anterior deltoid muscle				
- reaction time	0.70	0.55-0.80	0.85	0.63-0.94
- movement time	0.68	0.52-0.78	0.89	0.73-0.96
Accuracy	0.71	0.57-0.81	0.97	0.93-0.99

Abbreviations: ICC, intraclass correlation coefficient; CI, confidence interval.

The ICC values shown in the table were a combination of 5 locations.

3.4.3 Static visual signal

The young university students achieved significantly faster reaction and movement times, with significantly greater accuracy than the older controls (Figure. 7.1, 7.2, 7.3). The Tai Chi practitioners tended to have faster reaction and movement times than the older controls, but the difference was not statistically significant (Figure. 7.1, 7.2). The Tai Chi practitioners did, however, show significantly better accuracy than the older controls when the signal appeared contra-laterally and centrally in their visual field: the upper left, center, and lower left locations (Figure. 7.3). Of special interest is that their accuracy was similar to that of the young subjects (Figure. 7.3).

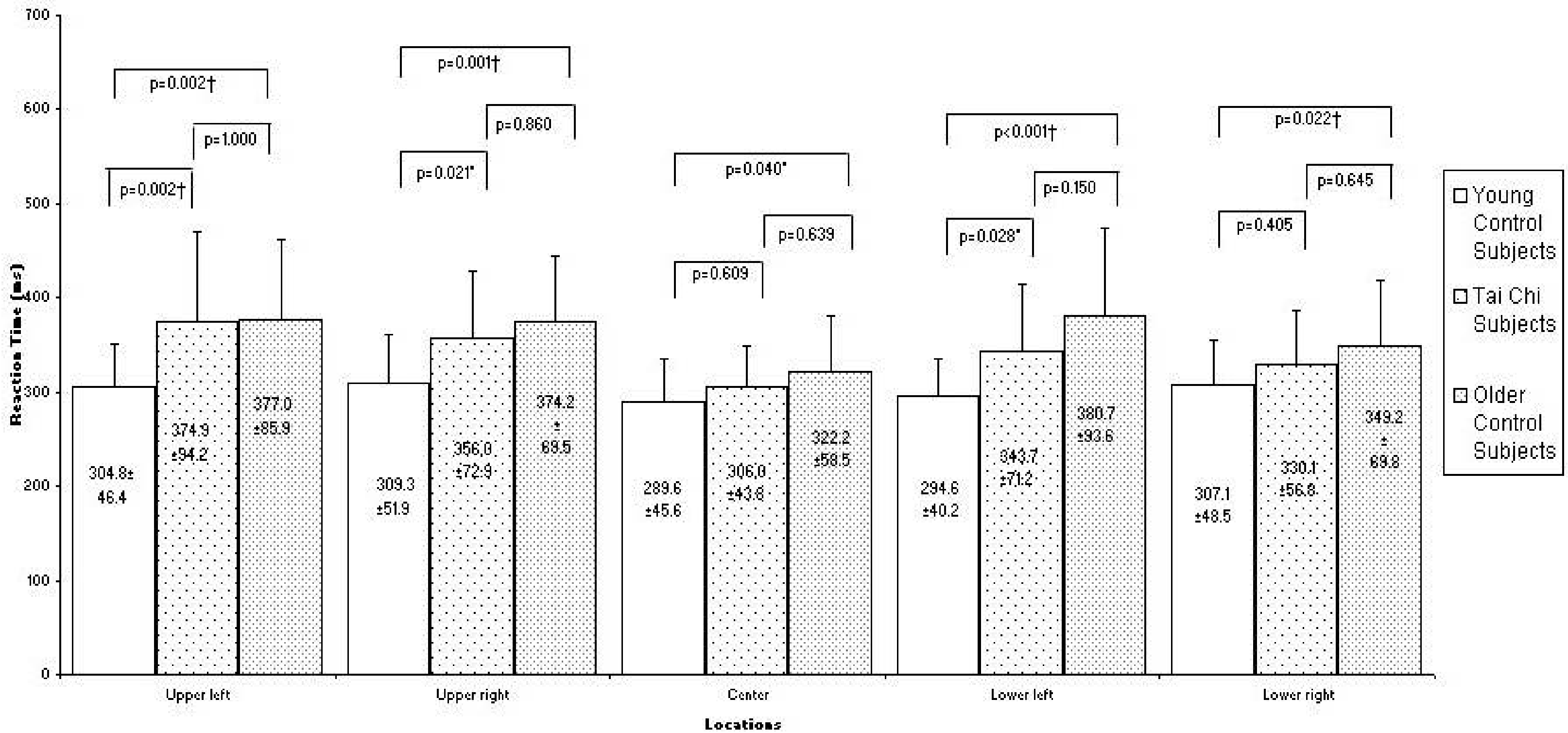


Figure. 7.1 Comparison of reaction time among young control, older Tai Chi and older control subjects in the finger-pointing performance with a static target at 5 locations.

† Denotes significant difference at $P<0.01$

* Denotes significant difference at $P<0.05$

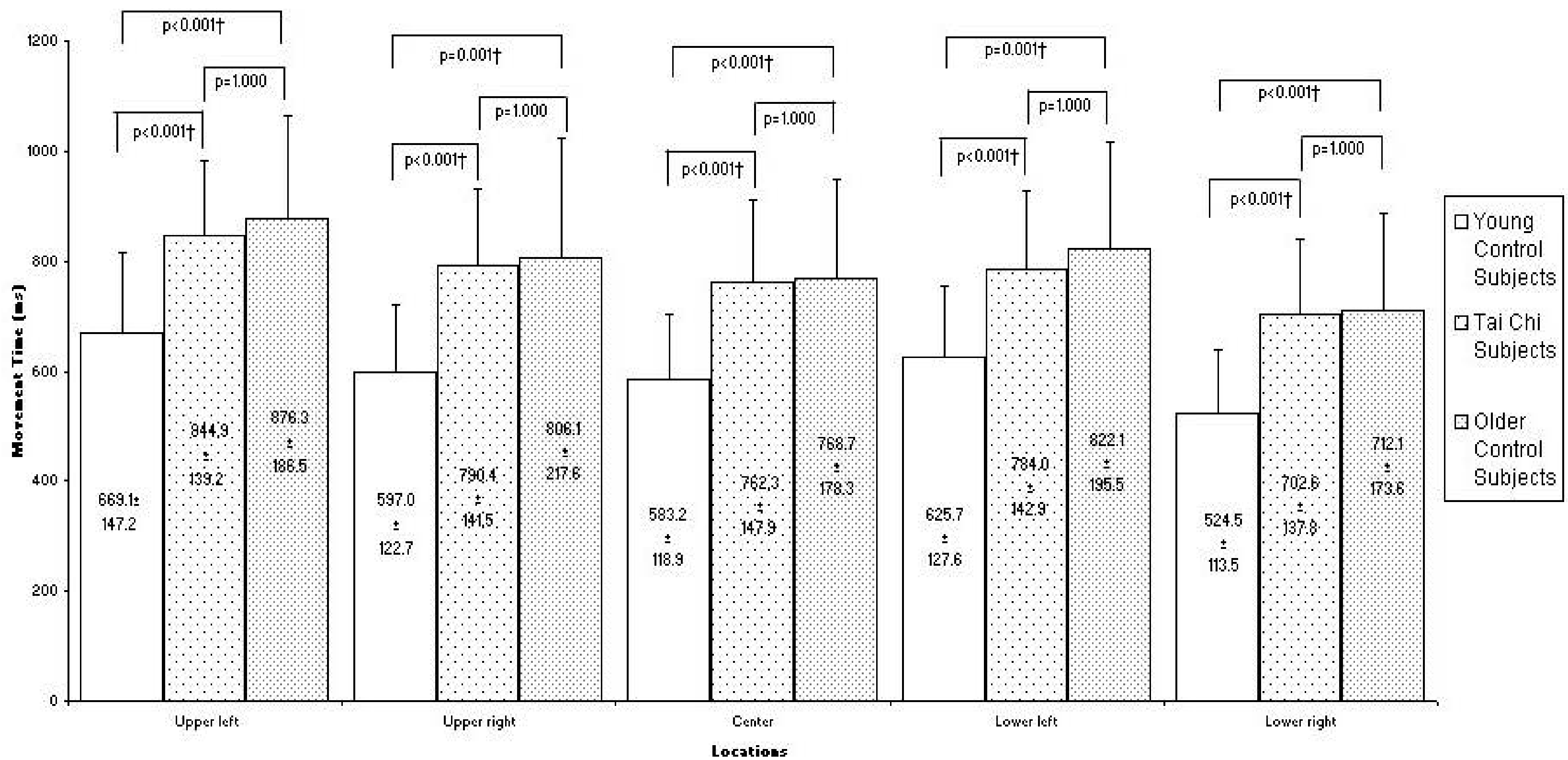


Figure. 7.2 Comparison of movement time among young control, older Tai Chi and older control subjects in the finger-pointing performance with a static target at 5 locations.

† Denotes significant difference at P<0.01

* Denotes significant difference at P<0.05

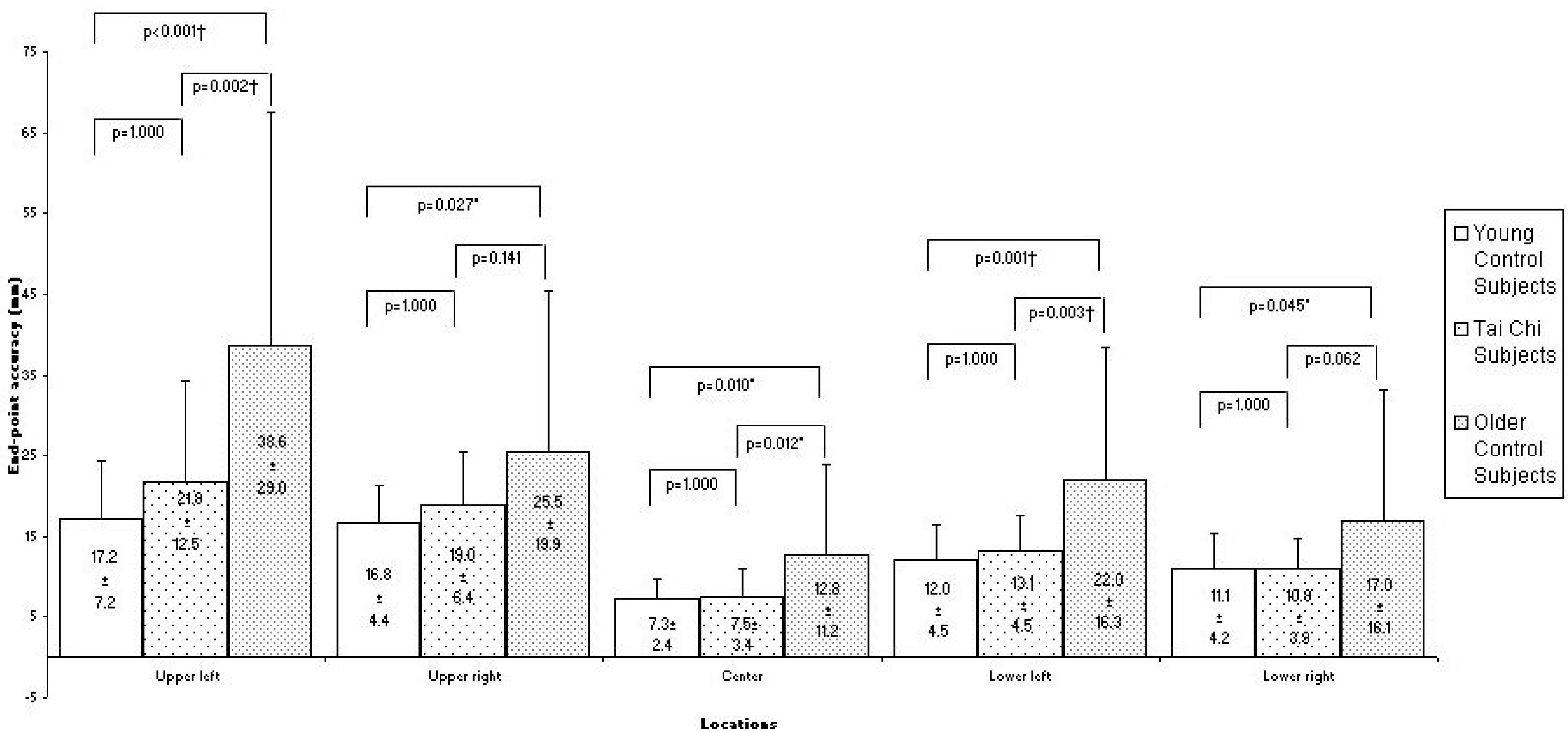


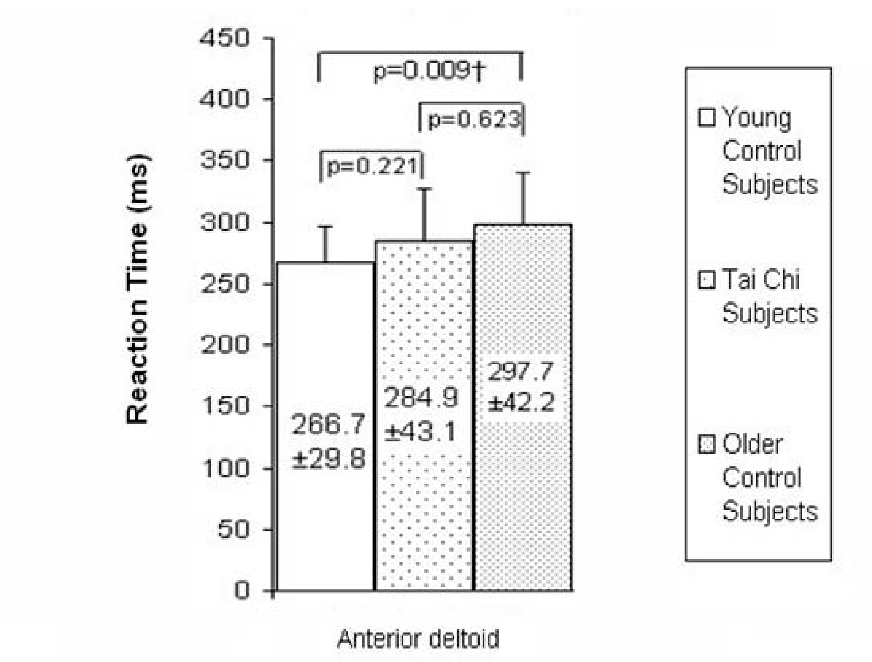
Figure. 7.3 Comparison of end-point accuracy among young control, older Tai Chi and older control subjects in the finger-pointing performance with a static target at 5 locations.

† Denotes significant difference at P<0.01

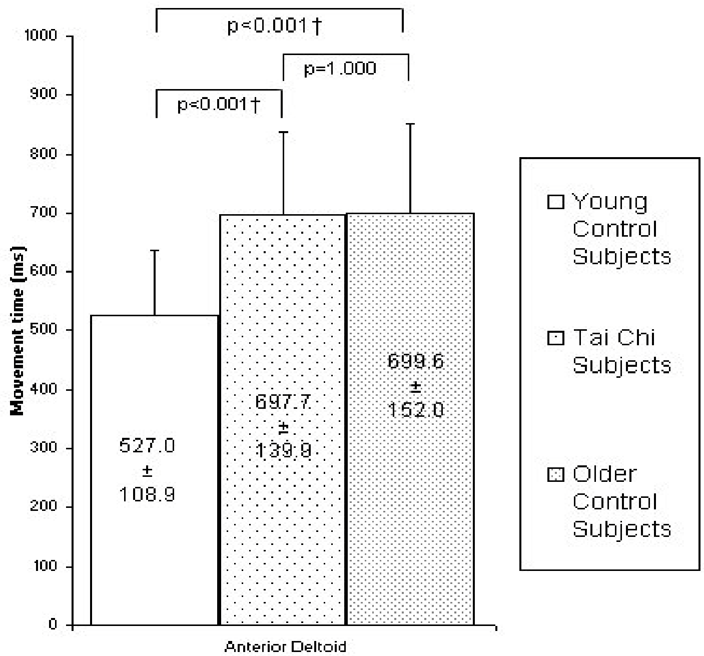
* Denotes significant difference at P<0.05

3.4.4 Moving visual signal

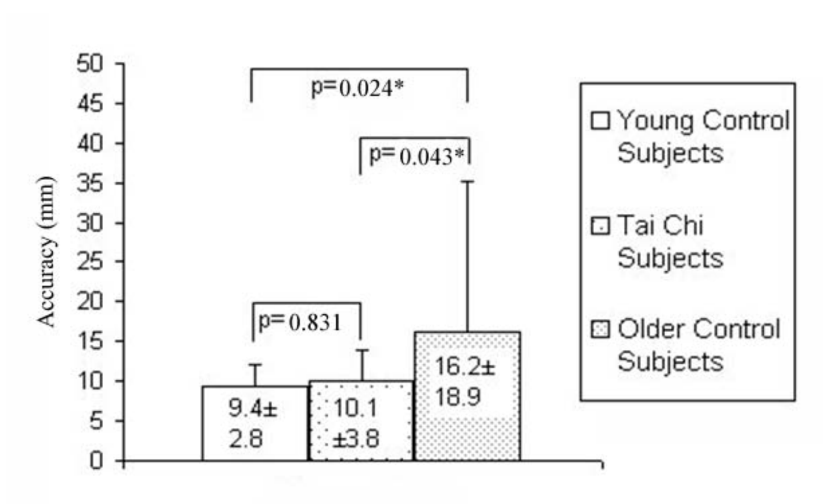
Similarly, the young students achieved significantly faster reaction and movement times, and also significantly greater accuracy than the older controls (Figure. 8). Although the Tai Chi practitioners did not have significantly faster reaction times than the control subjects, they showed significantly better accuracy. Indeed, their accuracy was not significantly different from that of the young students (Figure. 8).



Reaction time (ms)
† Denotes significant difference at $P<0.01$



Movement time (ms)
† Denotes significant difference at $P<0.01$



Accuracy (mm)
*Denotes significant difference at $P<0.05$

Figure. 8. Comparison of reaction time, movement time, and accuracy among young control, older Tai Chi and older control subjects in the finger-pointing performance with a moving target.

3.5 Discussion

These results demonstrate a decline in eye-hand coordination with age in finger-pointing toward a static or moving target. Deterioration and slowing of the central nervous system during aging is well documented (Hortobágyi and DeVita 2006; William 1990). It is usually reflected in slower movement control among older adults. Since poor vision and degeneration of the joints which affects joint sense are also common during aging, and because eye-hand coordination has such a complex neural mechanism, a decline in eye-hand coordination in older adults is only to be expected.

3.5.1 Pointing toward a static visual signal: Effects of aging

These finger-pointing results agree with previous findings that older subjects show significantly slower reaction times than those who are younger. Inui (1997) asked subjects to tap a switch when a light came on, and his younger subjects (age range, 19-22 yr) achieved faster reaction times than the older subjects (age range, 57-63 yr). The results were the same when Yan and his colleagues (2000) asked young adults (mean age = 24.4 ± 3.0 yr) and older adults (mean age = 73.5 ± 3.3 yr) to touch targets on a horizontal table. They were required to touch the target with a stylus after hearing a signal.

Previous studies have usually employed a stylus pen and required subjects to reach for targets in a horizontal plane. However, in real life, people rely on three-dimensional eye-hand coordination. Pressing a lift button, reaching for a cup, punching keys on a phone to make phone calls are a few examples. This finger-pointing task involved a vertical display unit. Nevertheless, the phenomenon of slower reaction times observed in older adults was consistent with earlier work. Reaction time involves stages like receiving sensory information, planning action according to the information and executing the planned action, and all these processes deteriorate with age (William 1990). Also, the older controls in this study had comparatively slower reaction times when indicating targets contra-lateral in their visual field when compared to younger subjects (23.7% and 29.2% more in the upper left and lower left locations, 11.3%, 21.0% and 13.7% more in the upper right, center and lower right locations).

The older adults showed significantly slower movement times. Ketcham's group (2002) found that older subjects (mean age = 68 ± 6 yr) displayed longer movement times than younger subjects (mean age = 23 ± 3 yr) when pointing at a computer screen. Different sized circles were used as targets. When pointing to smaller targets, older subjects needed even longer times, but the accuracy of the two groups was not compared. There have also been investigators who asked older (age range, 67-80 yr) and younger (age range, 22-30 yr) subjects to reach for different sized targets with an electronic pen in the horizontal plane. The results of this research confirmed the observations of the prior study. Older subjects were significantly slower than younger subjects in reaching for targets of all sizes, and the movement time was longer when the targets were smaller (Goggin and Meeuwsen 1992). This research also found that older subjects had less error involving over-shooting the targets than younger subjects due to their desire for better accuracy. This moving slowly in order to achieve a better accuracy conforms to Fitts' law, which states that movement time is indirectly proportional to target size (Fitts 1992). In our present testing protocol, the participants were required to touch the visual target as quickly and as accurately as possible. That demands movement with an accurate stop, which implies participants must decelerate using the antagonist muscles when hand approaches the target. It may explain why the older adults showed significantly slower movement times and significantly less accuracy with all five target locations.

3.5.2 Pointing toward a static target: Effects of Tai Chi practice

With this testing protocol, the Tai Chi practitioners had reaction times not significantly different from those of healthy older control subjects in all five locations of the visual signal (Figure. 7.1). These results differ from those of a previous study (Tsang and Hui-Chan 2004a) where subjects were asked to voluntarily weight shift to eight different spatial positions at their limits of stability within their base of support. Tai Chi practitioners had significantly faster reaction times (0.8 ± 0.1 s) than matched controls (1 ± 0.3 s) in that task. The difference between the two studies might be that the reaction time in weight shifting involves both neuromuscular control and cognitive factors. When notified with a visual signal, the subjects had to lean to one of the eight target positions as quickly and as smoothly as possible. Better balance control in advance of potentially destabilizing movements might explain why the Tai Chi practitioners had shorter reaction times than control subjects. This study, however, used EMG responses to define the onset of muscle activity in order to determine reaction time. This will certainly involve less neuromuscular control and fewer cognitive factors, which might explain the difference between the two studies.

In the present study, the Tai Chi practitioners did not achieve significantly faster movement times than those of the healthy older controls. Previous research has shown that when experienced Tai Chi practitioners perform a task which requires moving a stylus from target to target (a total of 10 targets) in a zigzag pattern in the horizontal plane, the time they need to complete the task is significantly shorter than that of matched controls who are not Tai Chi practitioners (Pei et al. 2008). There seems to be a discrepancy between Pei's findings and those observed here. The difference might be explained by the different protocols adopted in the two studies. Pei's protocol required subjects to reach eleven target locations, and the total time might have reflected better eye-hand coordination among the Tai Chi practitioners. However, in this study, subjects were required to touch one target only. Though there was a trend of faster movement when the Tai Chi practitioners reached for contralateral targets (3.9% and 4.6% on upper left and lower left), they did not display significantly faster movement times than the controls.

The Tai Chi practitioners showed significantly better accuracy than the older controls, who were similar in age, gender mix and physical activity level. Joint proprioception is essential for accurate finger-pointing, and research has shown that subjects with poor proprioception make extensive directional errors in pointing to visual targets (Gordon et al. 1995). Tai Chi puts great emphasis on both exact joint positioning and the direction of movement. The better joint proprioception of Tai Chi practitioners found in previous studies might enhance their accuracy in finger-pointing. Jacobson and colleagues (1997) conducted a Tai Chi intervention program with 24 subjects aged 20 to 45 and found a significant improvement in the accuracy of repositioning of the shoulder joint at 60° of shoulder rotation after 12-wk of Tai Chi training. Cross-sectional studies also show that older Tai Chi practitioners have better leg proprioception (Fong and Ng 2006; Tsang and Hui-Chan 2003; Xu et al. 2004). They demonstrated smaller knee angle errors in both active (Fong and Ng 2006) and passive (Tsang and Hui-Chan 2003; Tsang and Hui-Chan 2004a) knee repositioning compared with matched control subjects. Older adults who practice Tai Chi also show better joint kinesthetic sense in detecting knee flexion and ankle movement when their knee and ankle joints were passively moved (Xu et al. 2004).

3.5.3 Pointing toward a moving target: Effects of aging

Target reaching often involves targets which are moving, for instance, passing an object to or from another person whose hand is also moving. Indeed, for many people, passing keys or small items of clothing from one hand to the other commonly involves a brief flight phase. Reaching for a moving object requires both spatial and temporal prediction. That is, a person must predict the position of the moving object in order to reach for it at the right time and location (Carnahan et al. 1998). Logically, according to the eye-hand coordination mechanism, any slowing of the central nervous system should slow spatial and temporal prediction performance, and this should be reflected in longer movement times, but observation does not bear out this expectation. Carnahan and his colleagues (1998) compared the performance of young (average age = 26 yr) and older adults (average age = 70.1 yr) by asking them to reach for big and small blocks in three conditions: stationary, moving at 29.2 $cm \cdot s^{-1}$ and moving at 40.3 $cm \cdot s^{-1}$. They found that no matter whether the target was large or small, stationary or moving, the older group had faster movement times than the younger group. The researchers tried to explain the effect by suggesting that the older group tended to anticipate the target instead of using feedback. However, this study did not properly consider accuracy of performance, as the small block was actually quite large (6.5 cm x 2.9 cm x 2.5 cm), and accuracy was reflected only in whether or not a subject could or could not grasp the target, which was not reported. Cooke and his colleagues (1989) also observed that older adults had faster movement times than younger adults, but only when there was no accuracy requirement. In our present study, both the reaction time and movement time of the older adults were significantly slower than those of the young university students. This may have resulted from the requirement that the subjects had to touch the visual target as quickly and as accurately as possible. With these constraints the older control subjects had poorer accuracy than the young students in pointing to the moving visual signal.

3.5.4 Pointing toward a moving visual signal: Effects of Tai Chi practice

The Tai Chi practitioners showed significantly better accuracy than the older control subjects in pointing toward a moving visual signal (37.7% difference), and their accuracy was not significantly different from that of the young students (7.4% difference; Figure. 8). Tai Chi practice demands dynamic movement coordination. Tai Chi forms like “repulse the monkey” and “cloud hand” (Yu 2002) maneuvers, which require the practitioner to move both hands simultaneously in different directions and accompany this with a rotation of the trunk while stepping either back or sideways, focusing the eyes all the while on one hand. Practicing such drills may help in maintaining eye-hand coordination in responding to a moving visual signal. Any improved control of arm trajectory might lead to better end-point accuracy in the finger-pointing task. Yan (1998) found that older adults (average age = 78.8 yr) who practiced Tai Chi for 8 wks (three times a wk, at least 45 minutes) could perform fine motor control tasks with their upper limbs better than similar groups which practiced walking or jogging in their 8-week program. They were asked to move a stylus with their dominant hand to reach a final target by crossing another intermediate target with a curved line. Movement time and movement jerks were recorded. Although the movement times were not significantly different, the Tai Chi group made smoother movements, showing fewer jerks than the walkers and joggers. This finding was consistent with the better directional control Tai Chi practitioners demonstrate in voluntary weight shifting during a limits of stability test (Tsang and Hui-Chan 2003; Tsang and Hui-Chan 2004a). The better control of arm trajectory together with better joint proprioception might enhance end-point accuracy in a finger-pointing task with a moving target. These factors may explain why experienced Tai Chi practitioners attained a level of accuracy similar to that of young healthy students.

Since this study used a cross-sectional design, a causal relation between Tai Chi practices and better finger-pointing could not be established. A longitudinal study would be required to establish the causal relation. Because only healthy older adults were examined, the findings cannot be extended to frail older individuals or those who have a history of eye problems. Limitations aside, the findings from this cross-sectional study demonstrate that experienced Tai Chi practitioners are significantly more accurate in pointing to static and moving visual signals than older controls similar in age, gender and physical activity level, and their performance was similar to that of young university students.

CHAPTER 4

FINGER-POINTING TASK WITH A COGNITIVE COMPONENT IN OLDER TAI CHI PRACTITIONERS

4.1 Abstract

Purpose: The objectives of this cross-sectional study were to examine (1) the effect of aging on finger-pointing tasks that involved cognitive processing in a choice paradigm, and (2) whether experienced older Tai Chi practitioners had better performance than healthy older control subjects in such a task.

Methods: We compared 30 young university students (aged 24.2±3.1 yr), 30 healthy older control subjects (aged 72.3±7.2 yr), and with 31 experienced Tai Chi practitioners (aged 70.3±5.9 yr). Subjects were instructed to perform a rapid index finger-pointing task using their dominant hand, from a fixed starting position on a desk to a visual signal appearing on a display unit with a choice paradigm. The visual signal was a 1.2-cm diameter ball and subjects had to touch it as quickly and as accurately as possible. Reaction time, movement time, accuracy and number of wrong movements were recorded.

Results: The students achieved significantly faster reaction and movement times, with significantly greater accuracy, and less wrong movements than the older control subjects. The Tai Chi practitioners had significantly faster movement times than older control subjects. They also attained significantly better accuracy with visual targets appearing contra-laterally to their pointing hand and made less wrong movements. Of special interest is that the improvements in the latter two outcomes were even similar to those of the young subjects.

Conclusion: These results demonstrate that eye-hand coordination in finger-pointing task with a cognitive component declines with age. However, Tai Chi

practitioners attained significantly faster movement times, better accuracy and less wrong movements than the control subjects similar in age, gender and physical activity level.

Key Words: AGING, EYE-HAND COORDINATION, EXERCISE, ATTENTION, MEMORY

4.2 Introduction

Eye-hand coordination is defined as the skillful, integrated use of the eyes, arms, hands, and fingers in fine, precision movements (Williams 1983). Pressing a lift button, reaching for a cup, punching keys on a phone to make phone calls, all require good eye-hand coordination to execute the desired actions precisely. Obviously, we require fine motor skills in the upper limbs to perform our daily activities (Shumway-Cook and Woollacott 2001).

The mechanism of eye-hand coordination can be understood using three stages as defined by previous researchers. The first stage – *perceptual* stage requires visual locating and focusing on the target (Paillard and Beaubaton 1975; Arrington and Logan 2004) and sensing the joints' positions through proprioception (Rosblad 1995). The second stage – *cognitive* stage involves planning the action and triggering the arm to perform it, which is cognitive planning and execution (Bellgrove et al. 1998; Inui 1997). These processes involve the frontal and parietal cortex in directional control, movement control and motor planning (Marconi et al. 2001). After receiving the neural code from the vision and proprioception sensors, the brain will gather the entire extrinsic (environment), intrinsic (body position) and target information to make a motor plan, initiate the movement and execute it. When the action begins, the cognitive centers will go on to modify the motor plan according to newly received sensory and motor feedback, making any correction or adjustment to maintain eye-hand coordination (William 1990). The third stage – *motor* stage includes steering the hand to the target and shaping the hands and fingers in order to reach for and/or grasp the target.

In an aging population, increasing older adults suffer from upper-extremity motor in-coordination following sensori-motor impairment. Our previous study has shown that eye-hand coordination in finger-pointing declines with age. The older subjects (72.3±7.2 yr) showed significantly slower reaction and movement times, with significantly poorer accuracy than those who are younger (24.2±3.1 yr), when they were instructed to point with the index finger toward static and moving visual targets appearing on a display unit, as quickly and as accurate as possible (Kwok et al. 2008). The poorer eye-hand coordination can influence older adults' upper limb performance and consequently make them more dependent in their activities of daily living (Desrosiers et al. 1995).

The more complicated the stimulus presented and the decisions to be made, the slower will be the reaction time of persons of any age, but studies have shown that reaction time slows with advancing age, and this retardation becomes pronounced as task difficulty increases (Ketcham et al. 2002). This age-complexity effect is probably because of the age-induced changes in processing resources. Investigators have suggested that increases in task complexity lead to increased demands on processing resources, and as older adults have smaller quantities of available resources, and their performance is affected more than young adults (Inui 1997).

Eye-hand coordination demands temporal, spatial, and often cognitive processing in performing daily activities. The addition of a cognitive task might lead to the competition of central processing capacity. In this connection, recent studies have demonstrated that higher brain functions such as attention and consciousness influence balance control (Yardley et al. 2001). Our previous study has shown that older subjects with a history of falls exhibit greater disruption of co-contraction of ankle muscles when stepping down stairs if a concurrent cognitive task was added, when compared with controls without history of falls (Tsang et al. 2007). The competition for central processing capacity with physical and cognitive tasks alters the motor coordination of ankle which leads to higher incidence of falls is suggested. However, the effect of cognitive demands on finger-pointing performance remains unknown.

Tai Chi, a mind-body exercise, had a long history and is now practiced by millions of older adults both in the East and the West. Its original 108 forms are comparable to complex motor skill training (Wolf et al. 1997), and require a great deal of eye-hand coordination and balance control. Pei and colleagues (Pei et al. 2008) has shown that when experienced Tai Chi practitioners perform a task which requires moving a stylus from target to target (a total of 10 targets) in a zigzag pattern in the horizontal plane, the time they need to complete the task is significantly shorter than that of matched controls who are not Tai Chi practitioners. Our previous findings also show that the experienced Tai Chi practitioners attained significantly better accuracy than the older controls with finger-pointing tasks toward static signals appearing contra-laterally and centrally to their pointing hand. They also demonstrated significantly better accuracy when the visual target was moving. Of special interest is that their accuracy was similar to that of the young controls (Kwok et al. 2008).

Previous studies have shown that exercises not only improve the physical perspective, but also on the cognitive function which is of particular interest owing to the increased prevalence of cognitive deficits in the aging population (Craik and Jennings 1992). In Tai Chi practice, it requires the practitioners to incorporate deep and rhythmic breathing as well as concentration (Yu 2002; Wolf et al. 1997). Its practice has been demonstrated to improve relaxation, emotional and psychological status (Jin 1992; Chen et al. 2001). Our previous investigation had demonstrated that Tai Chi practitioners attained significantly better attention and memory functions than the non-cognitive demanding aerobic and non-exercise healthy control subjects similar in age, gender and educational level (Man et al. 2006). Therefore, the objectives of the present study were to examine (1) the effect of aging on finger-pointing tasks that involved cognitive processing in a choice paradigm, and (2) whether experienced Tai Chi practitioners had better performance than healthy older control subjects in such a task.

4.3 Methods

4.3.1 Subjects and Study Design

We compared 30 young university students (aged 24.2±3.1 yr), with 30 healthy older control subjects (aged 72.3±7.2 yr), and 31 experienced (mean = 7.1±6.5 yr of practice) Tai Chi practitioners (aged 70.3±5.9 yr) in this cross-sectional study. All university students had regular exercise for at least 2 $h \cdot wk^{-1}$. The control subjects were recruited from several community older adult centers. They had no previous experience in Tai Chi, though some took morning walks or did stretching exercises. For inclusion in the Tai Chi group, subjects had to have experience of practicing Tai Chi more than 1.5 $h \cdot wk^{-1}$ for 3 yr or more. All the subjects underwent 4 screening tests, in which they had to (1) score of at least 24 in the Mini-Mental Status Examination (MMSE) to show no cognitive impairment (Folstein et al. 1975). Chiu and colleagues had validated the Chinese version which was applied in this study (Chiu et al. 1994); (2) attain 20/20 or above in Snellen's visual acuity test (Elkington et al. 1999), with eye-glasses if necessary; (3) demonstrate sufficient active range of motion in their upper limbs in performing the finger-pointing tasks in which the subjects were asked to flex and extend the shoulder, elbow, wrist and fingers; and (4) complete a modified Minnesota Leisure Time Physical Activity Questionnaire (Van Heuvelen et al. 1998). This latter questionnaire categorized older subjects' daily activities (household chores, hobbies and sports) into 3 different physical levels according to metabolic index units (METs), namely light (<4 METs), moderate (4-5.5 METs), and heavy (> 5.5 METs) in order to rate the energy expenditure. It had been used to compare the physical level among older subject groups (Tsang and Hui-Chan 2004b; Tsang and Hui-Chan 2005; Tsang and Hui-Chan 2003).

Subjects who could not fulfill the inclusion criteria included those with any eye pathology such as glaucoma or cataract (unless it had been corrected and they were able to score at least 20/20 in Snellen's acuity test). Cognitive impairments were screened for by the MMSE and were grounds for exclusion. Cardiovascular pathologies, such as symptomatic cardiovascular diseases or uncontrolled hypertension were also a basis for exclusion. Subjects suffering from any pathology affecting their upper limb function such as stroke, Parkinson's disease, or any disabling neurological or musculoskeletal disorder were also excluded. Peripheral neuropathies of the upper extremities or metastatic cancer were also grounds for exclusion. The project was approved by the Ethics Committee of The Hong Kong Polytechnic University, and written informed consent was obtained from all subjects.

4.3.2 Test Procedures

Subjects were instructed to perform eye-hand coordination test with rapid index finger-pointing task using their dominant hand (the side major for writing or holding chopsticks) as quickly and as accurately as possible, from a fixed starting position on a desk to a visual signal appearing on a display unit (MicroTouch, ClearTek II, Capacitive Touch screen, 3M Touch Systems Inc. Methuen, USA). The visual display unit was fixed on and perpendicular to the supporting surface, with its upper edge at each subject's eye level and 36 cm from the supporting surface. At the starting point, the subject's index finger was motionless on the desktop 10 cm from the screen. The visual signal was a black spot with a 1.2 cm diameter. The details of finger-pointing tasks with a choice paradigm are described below.

Subjects sat stably on a height-adjustable, non-rotating chair with arm-rests in front of a computer-controlled LCD touch screen, with their hands resting on a table and their elbows, hips, knees and ankle joints positioned at approximately 90º. Their upper trunks was strapped to the chair with a Velcro belt to prevent trunk movement, because finger-pointing task can involve either trunk and arm movement or arm joint movement alone (Pigeon et al. 2000). Since the objective was to record EMG responses of arm muscles only, it was necessary to inhibit the trunk movement so that the subjects reached for the visual signal with only arm joints movement. A headphone (Panasonic – RP-HTX7) was used to deliver a preparatory signal to alert the subjects before the appearance of a visual signal in each test. A “Ding” sound was generated by the computer and delivered via the headphone. The time between the auditory signal and appearance of target was 2 s. The visual signal appeared randomly under 3 conditions: (1) A black ball required the subjects to touch it as quickly and as accurately as possible. (2) A white ball required the subjects not to touch it. (3) Both a black and a white ball required the subjects to touch only the white but not the black ball. The LCD panel sized 34 cm wide and 27 cm tall was divided into 1000 sections from left to right, and top to bottom. The visual signals that required touching were at 100,500 (middle-left), 500,500 (centre) and 900,500 (middle-right) of the LCD monitor. Condition 1 and 3 appeared for 15 times each, and 10 times for condition 2. Thus, there were a total of 40 runs. Each coordinate had a total 10 times of touch.

At the beginning of each task, subjects were first asked to relax and look at the center of the LCD display unit. When the test started, the first second of each test was used to record the relaxed muscles' EMGs as the resting threshold. After finishing each task, the hand was returned to the starting position and relaxed. The next target would not appear until the EMGs of the arm muscles had returned to their original resting thresholds. After a warning "ding", a visual signal appeared on the screen. Subjects were instructed to point to the visual signal as quickly and as accurately as possible. Recorded encouragements, fast and accurate, were delivered by the computer through the headphones at the middle of each set of tests to counter any decrease in attention span. There were familiarization trials to each condition before data recording to ensure that subjects understood how to perform the finger-pointing task.

4.3.3 Data Recording and Analysis

Surface electrode was used to record EMG activities of anterior deltoid of subjects' dominant hand. The electrode was positioned with electrolyte gel and adhesive tape and placed in line with the muscle as recommended by Cram and Kasman (Cram and Kasman 1998). EMG signals were recorded using surface electrodes (B&L Engineering Division of Pinsco Inc., California, USA) with a total gain of 320 times, total input impedance of >100Megohms, and with a bandwidth of 12Hz to 3000Hz. The signals were sampled at 1000Hz and stored for off-line analysis using an A/D card (National Instrument NI DAQCard-6024E). The EMG signals were processed using the LabView software suite (National Instrument, Texas, USA). The signals were full-wave rectified and smoothed using a second-order Butterworth low pass filter with a cut off frequency of 10Hz. The onset of muscle activity was identified as the point where the EMG signal fired and deviated more than 3 standard deviations from the baseline. The point was determined by using a tailored-made LabView software program, but visually checked.

Reaction time, movement time, accuracy and number of wrong movements were used to compare among the three groups. Reaction time was the time from the appearance of the visual target on the screen to the onset of the anterior deltoid EMG response. Movement time was the time from the onset of the EMG response to touching the visual target. Accuracy in locating the spot on the LCD screen was defined as the absolute deviation of the subject's finger-pointing location from the center of the spot. The number of wrong movements was defined as either touching the white ball in condition 2 or the black ball in condition 3.

4.3.4 Statistical Analysis

To ensure data reliability, an intraclass correlation coefficient (ICC) was used to assess the test-retest reliability of the outcome measures, combined with the three locations in the older adults. One-way analysis of variance (ANOVA) was used to compare the age, height, and arm-length among the three groups, and gender was compared by using chi-square test. Since the starting position of hand and the visual display unit was fixed for all participants, the differences in arm-length might constitute a co-variate in the finger-pointing task that involved cognitive processing in a choice paradigm. Therefore, the arm-length of subjects was treated as co-variate in the statistical analysis if a significant difference was found. Arm-length was defined as the distance between subjects' acromion and tip of middle finger. For the comparison between the two older adult groups, independent t-tests were conducted for the MMSE, and chi-square test was used for the comparisons of physical activity level. Multi-variate analysis of variance (MANOVA) was used to compare each of the outcome measures, namely reaction time, movement time and accuracy among the three groups of the three locations. If statistically significant differences were found in the multivariate tests, univariate tests were conducted for each of the locations. Post hoc analysis using Bonferroni's adjustment was conducted, if a significant difference was found in the univariate test. One-way ANOVA was used to compare the number of wrong movements among the three groups. If statistically significant difference in the one-way ANOVA test, post hoc analysis using Bonferroni's adjustment was conducted. A significance level (α) of 0.05 was chosen for the statistical comparisons.

4.4 Results

4.4.1 Subjects

Eighty older subjects volunteered to participate in this study. Two Tai Chi practitioners were excluded because they had less than three years of Tai Chi practice. Among the control subjects, three were excluded because of their previous Tai Chi experience, eight due to MMSE scores lower than 24, and a further 6 subjects were excluded because they were unable to score 20/20 or more in Snellen's acuity test.

Table 3 shows a comparison of age, height, and arm-length among the three groups. One-way ANOVA showed statistically significant differences between the young subjects and the older adults in age, height and arm-length, with no significant difference between the 2 older adult groups in the post hoc analysis. Since the arm-length was found to be significant difference, it was treated as co-variate in the MANOVA statistical analysis. Chi-square showed no significant difference in the gender distribution among the three groups. All the older adults had scored at least 24 on the Mini-Mental Status Examination, which indicated no cognitive dysfunction (Chiu et al. 1994). A chi-square test found no statistically significant difference between the two older adult groups in physical activity level (P = 0.364; Table 3). The Tai Chi practitioners and control subjects were thus similar with respect to age, height, arm-length, gender, MMSE scores and physical activity levels.

Table 3: Comparison of age, height and arm-length among young control, older Tai Chi, and older control subjects; Mini-Mental Status Examination and physical activity levels between the 2 older adult groups.

	Young Control Subjects (*N* = 30)	Tai Chi Subjects (*N* = 31)	Older Control Subjects (*N* = 30)	*P*
Age (yr)	24.2±3.1	70.3±5.9†	72.3±7.2†	0.000*
Height (m)	1.67±0.08	1.59±0.07†	1.58±0.08†	0.000*
Arm-length (cm)	70.5±4.3	67.2±4.3†	65.3±5.8†	0.000*
Gender (M/F)	15/15	15/16	15/15	0.989
MMSE score	-	26.6±1.9	6.7±2.0	0.966
Physical activity level				0.364
Light ≤ 4 METs	-	*N* = 10	*N* = 15	
Moderate ≤ 5.5 METs	-	*N* = 16	*N* = 11	
Heavy > 5.5 METs	-	*N* = 5	*N* = 4	

NOTE. Values are mean ± SD for this and all subsequent tables.

- Denotes “not tested.”

Abbreviations: F, female; M, male. MMSE, Mini Mental Status Examination; MET, metabolic equivalent.

* Denotes a significant difference at the $P<0.05$ level using one-way ANOVA.

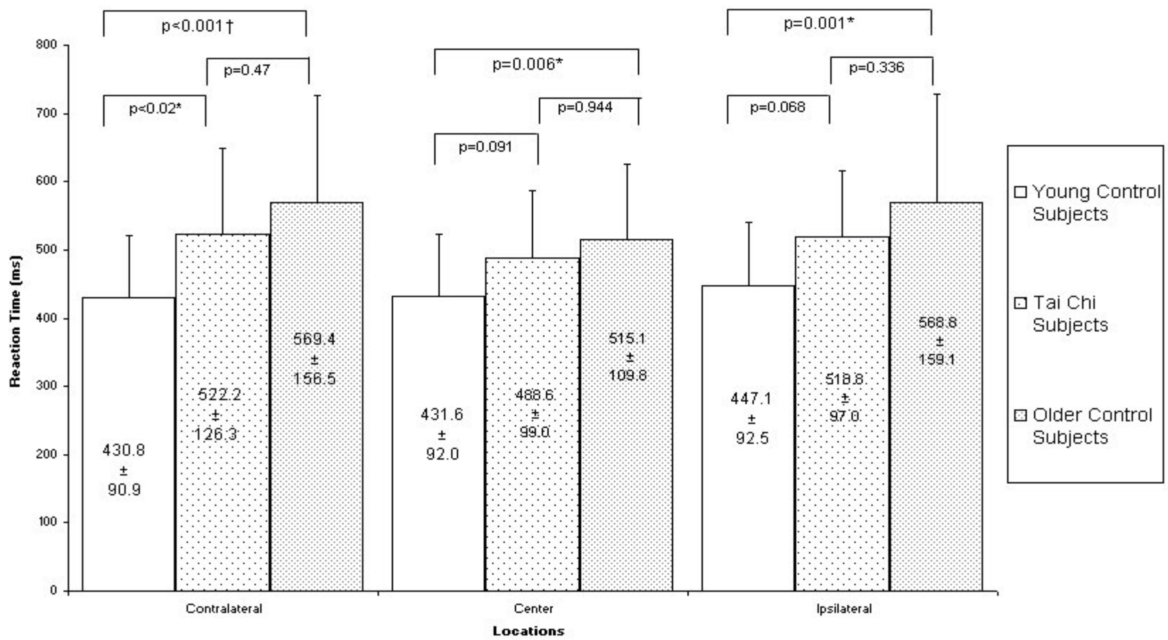
† Denotes a difference from the young controls significant at the $P<0.05$ level by means of *post hoc* analysis using Bonferroni’s adjustment.

4.4.2 Test-retest reliability

Among the 61 older adult participants, 6 males (3 Tai Chi subjects) and 14 females (9 Tai Chi subjects) with mean age = 69.2±7.1 yr, returned to laboratory one week after the first finger-pointing trials for a second assessment. The ICC values for the reaction time, movement time, and accuracy were 0.66 (confidence intervals 0.41-0.80), 0.85 (confidence interval 0.74-0.91), 0.68 (confidence interval 0.41-0.82), respectively, which indicated moderate to satisfactory reliability. The ICC value for the number of wrong movement was 0.464 (confidence interval -0.513-0.803). It is considered as fair reliability. The result might reflect the learning effect of the participants using such testing paradigm. Although the findings of the present study were of cross-sectional nature, the results should be interpreted with caution.

4.4.3 Pointing tasks with a cognitive component

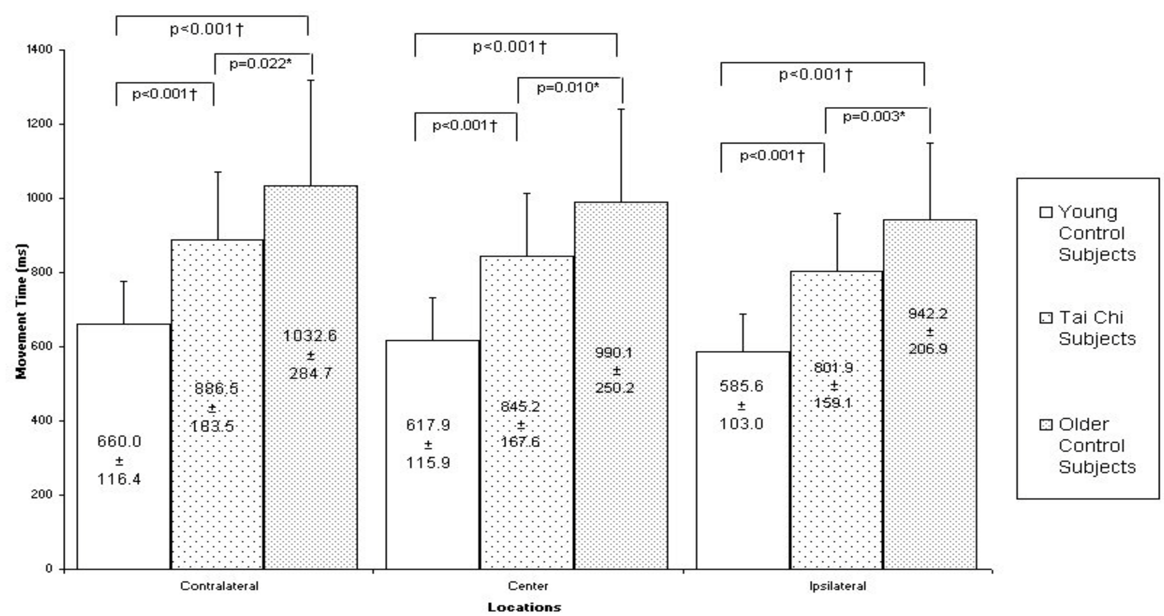
Young university students achieved significantly faster reaction and movement times, with significantly greater accuracy, and less wrong movements than did older control subjects in all three locations of visual signals (Figure. 9). The Tai Chi practitioners achieved a significantly faster movement time and made less wrong movements in all three locations than older control subjects. They also attained significantly better accuracy with visual targets appearing contra-laterally to their pointing hand. Of special interest is that the improvements in the latter two outcomes were even similar to those of the young subjects (Figure. 9).



Reaction time (ms)

† Denotes significant difference at P<0.01

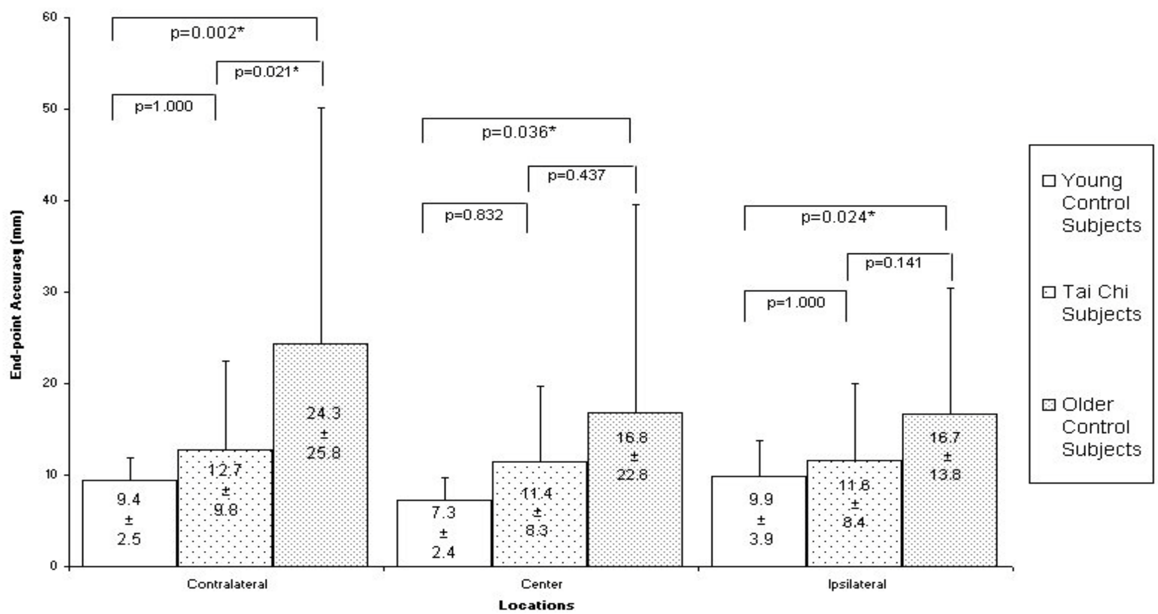
* Denotes significant difference at P<0.0



Movement time (ms)

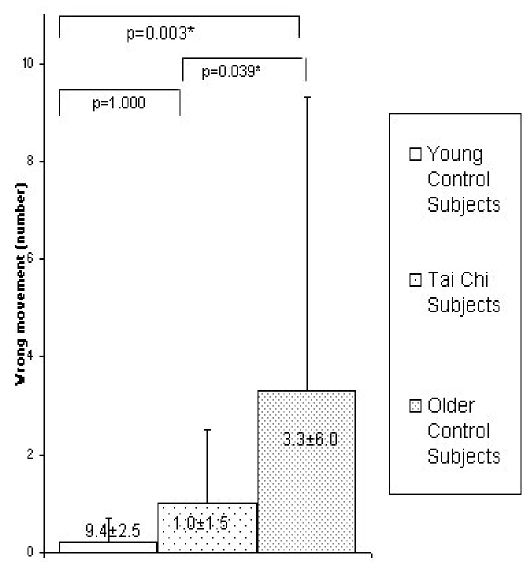
† Denotes significant difference at P<0.01

* Denotes significant difference at P<0.05



Accuracy (mm)

Denotes significant difference at P<0.05



Wrong movement(number)

* Denotes significant difference at P<0.05

Figure. 9 Comparison of reaction time, movement time, accuracy, and numbers of wrong movement among young control, older Tai Chi and older control subjects in the finger-pointing performance with a cognitive component at 3 locations.

4.5 Discussion

A protocol on finger-pointing tasks that involved cognitive processing in a choice paradigm was adopted in this study. In daily life, there are situations that require us to set priorities and choose responses to different signals. This is essential in dangerous situations, like receiving a sudden warning to withdraw from something unsafe before reaching it.

4.5.1 Pointing tasks involving a choice paradigm: Effects of aging

The young students achieved significantly faster reaction and movement times, with significantly greater accuracy in all three visual target locations and made less wrong movements than the older control subjects. These results demonstrate that eye-hand coordination in finger-pointing task with a cognitive component declines with age and agree with our previous investigation with finger-pointing tasks toward static and moving targets (Kwok et al. 2008), and other eye-hand coordination investigations (Inui 1997; Yan et al. 2000; Ketcham et al. 2002). Moreover, with the adding of a choice paradigm, the declines in eye-hand performance are comparatively more in the older subjects.

When comparing to a fast and simple finger-pointing task toward a static visual signal, both the young university students and older adults experienced slower reaction and movement times when a choice paradigm was added. Using the central visual target location as illustration, the reaction and movement times of young students in the simple task were 289.6 ms and 583.2 ms (Kwok et al. 2008) while their performance in a choice paradigm were 431.6 ms and 617.9 ms, an increase of

49% and 6%, respectively. The increases for the older adults were more than those of young subjects. Their performances in the simple task were 322.2 ms (515.1 ms in the choice paradigm, an increase of 60%), and 768.7 ms (990.1 ms, an increase of 29%) on reaction and movement times, respectively. The accuracy of touching the center of visual target in the young subjects was similar in simple and choice paradigms, being 7.28 mm and 7.33, respectively, an increase of only 0.7% error. However, the older adults performed poorer in the choice paradigm, 16.8 mm when compared to simple task, 12.8 mm (an increase of 31% error). It shows that the effects of a cognitive component on eye-hand coordination performance toward young and older groups are different. The classical Fitts' law describes the characteristics of arm movements using the equation $MT = a + b \log_2 2D/W$, where MT represents the movement time, D is distance moved, and W is the width of the target, whereas a and b are constants (Fitts 1992). Such equation doesn't take into consideration of the arm movement if a cognitive component is added into the eye-hand coordination task. Also, the degrees affecting the young and the older subjects on movement time are not the same as reflected in the present study.

In the older controls, all movement times corresponding to all targets were significantly slower than the young students (Table 2). This may be due to aged-related declines in muscle mass, strength and speed of muscle contraction. The possible explanation for decline in muscles mass includes muscle fiber atrophy and loss of muscle fibers. The diameter and total number of individual fast-twist type II fibers decrease with age. According to the order of recruitment of motor units and muscle fibers, type II fibers with particularly IIb fibers will rarely be recruited and therefore are subjected to disuse atrophy and hypoplasia during aging process (D'Antona et al. 2003). Also, age-related decrease in muscle strength is also caused by: 1) decreased central drive and a decrease in the ability to voluntarily active a muscle. The threshold of excitability of the corticospinal tract increases progressively with age and significantly higher in older adults; 2) reduced fraction of myosin head producing force. The structural changes in the myosin head provide a molecular mechanism for the reduction in force-generating capacity of muscle fibers. The slowing of muscle contracting velocity with age is observed in both type I and type II fibers. This age-related change in contractibility may be caused by a mechanism of change in kinetics of the cross-bridge cycle secondary to intrinsic changes in the myosin molecule (D'Antona et al. 2003). Therefore, both the structural changes of muscle and competition for central resource with adding of a cognitive component may explain the significantly slower reaction time of older controls in the eye-hand coordination performance. However, previous studies on motor coordination have focused mainly on the leg and postural muscles. The arm and shoulder muscles may not be equally affected during the aging process, not to mention about the cognitive component. Further investigation is warranted.

4.5.2 Pointing tasks involving a choice paradigm: Effects of Tai Chi practice

4.5.2.1 Accuracy

Tai Chi practitioners had better accuracy than older control subjects in pointing to the contra-lateral visual signal (12.7 mm versus 24.3 mm, respectively), despite they were moving significantly faster (movement times = 886.5 ms versus 1032.6 ms; Figure. 9). Our previous studies had shown that experienced Tai Chi practitioners had better joint proprioception (Tsang and Hui-Chan 2004a; Tsang and Hui-Chan 2003), and more accurate control of arm movement in a fast and simple finger-pointing task toward static and moving visual targets (Kwok et al. 2008). These factors could have led to improved end-point accuracy of the hand despite the requirement for more cognitive contribution in the present finger-pointing with a choice paradigm. Why Tai Chi practitioners achieved significantly better accuracy only in the contra-lateral visual location?

Pointing to central and ipsilateral visual target locations might not provide a challenging condition to differentiate between the two older groups. During ipsilateral reach, the responding hand and the hemi-field of the visual signal location are on the same side. Both visual and motor stages of the response are processed on the same contra-lateral hemisphere (uncrossed condition). During contra-lateral reach, the hand and visual signal target are opposite (crossed condition), the visual input is received by the hemisphere contra-lateral to the stimulus side and the motor response is generated by the other hemisphere. This necessitates inter-hemispheric transmission of information (Fisk and Goodale 1985; Hay and Velay 2003) and the main structural basis for inter-hemispheric transfer appears to be the corpus callosum. Anatomical studies revealed a decrease in size of the corpus callosum with aging, and this structural decline is associated with an increased deficit of inter-hemispheric communication in the older adults (Moes et al. 1995). Moreover, the visual feedback during pointing is received by the hemisphere contra-lateral to the target side and the corrective motor response is generated by the other hemisphere. Interhemispheric transmission of information is also needed and yields additional response latency in the immediate visual-motor feedback (Boisseau et al. 2002). This may also deteriorate in the aging process and affect the end-point accuracy of the hand. Exercises that involve the contra-lateral arm movements, like Tai Chi practice may help to prevent the deterioration process. The practice of Tai Chi forms often involves hand movements crossing the mid-line of body, like the "waving hands like clouds" and "fair lady works the shuttles" maneuvers (Tsao 1995). Repeated practice with great emphasis on the exact joint position and direction (Tsang and Hui-Chan 2004b; Tsang and Hui-Chan 2003) may help in maintaining eye-hand coordination in responding to visual target contra-laterally to the pointing hand.

4.5.2.2 Movement time

The Tai Chi practitioners achieved significantly faster movement times toward all the three locations than that of older controls (Figure. 9). This is in contrast with our previous findings that both performed similarly in the movement times under the fast and simple finger-pointing tasks toward static and moving visual targets (Kwok et al. 2008). The mechanism of eye-hand coordination includes perceptual, cognitive and motor stages. The musculoskeletal and neuromuscular factors including range of movement and strength may not explain the present findings, as both groups could reach the static visual targets with shorter movement times in the without-choice paradigm. The mean movement time of the Tai Chi practitioners needed to touch the visual target in the furthest location (upper left) of the visual display unit was 844.9 ms in the static protocol versus the "middle left" location of 886.5 ms in the choice paradigm. For the older control subjects, the "upper left" location required a mean movement time of 876.3 ms in the static protocol versus 1032.6 ms in the present protocol. The difference of the two findings may be explained in the cognitive stage. Shumway-Cook and Woollacott (2001) (Shumway-Cook and Woollacott 2001) elaborate the key cognitive skills in eye-hand coordination tasks which include "problem solving, selective attention, planning, memory, and intention, among others". While one can reach for objects with ample neuromuscular components, "one's ability to acquire a range of solutions for difficult tasks and correctly identify the usefulness of objects is affected by cognition".

4.5.2.3 Wrong movement

The fact that Tai Chi practitioners had made less wrong movements may be due to their better attention in the signal encoding process, and their better registration of the visual signal in the retrieval process of memory. In our previous study, community-dwelling subjects older than 60 yr were recruited and classified into three groups, namely Tai Chi practitioners, non-cognitive demanding aerobic and non-exercise healthy control subjects. Attention and memory were assessed using Color Trail Form A- 1 and 2; Rivermead Behavioural Memory Test and Hong Kong List Learning Test, respectively. The results demonstrated that the Tai Chi practitioners had significantly better performance than the other two groups similar in age, gender and education level in attention (sustained and divided attention) and memory (every day memory function and encoding, recall/organization of verbal information). The possible explanation is that Tai Chi practice requires the attention to and the recall of the many forms (usually from 24 to 108) which could have a cognitive benefit for older adults (Man et al. 2006). The mental training including heightened attention, monitoring movement from memory and self-initiated action may lead to better attention to stimuli and information encoding and retrieval (Shumway-Cook and Woollacott 2001). Since cognitive declines are common in older adults and may become a major global health issue in an aging population (Craik and Jennings 1992), the findings that Tai Chi practice might supply the mental training provide an option for older subjects' choice of exercise. Recently, there has been the advocate of simpler Tai Chi style, such as 10 forms (Wolf et al. 1997). These forms have been focused on the balance control in the context of fall prevention. In respect to maintain and improve older adults' eye-hand coordination with a cognitive component, it is uncertain whether simpler forms should be recommended.

Since this study used a cross-sectional design, a causal relation between Tai Chi practice and better finger-pointing could not be established. A longitudinal study would be required to establish the causal relation. Because only healthy older adults were examined, the findings cannot be extended to younger or frail older individuals, or those who have a history of visual or cognitive problems. Limitations aside, the findings from this cross-sectional study demonstrate that experience Tai Chi practitioners attained significantly faster movement times, better accuracy and less wrong movements than the control subjects similar in age, gender and physical activity level. The fact that Tai Chi practitioners could perform complex finger-pointing tasks at a level generally similar to that of young healthy subjects would suggest that they would function well in daily activities that require eye-hand coordination with objection recognition, such as reaching for a spoon in an assortment of mixed cutlery, or reaching for a full instead of an empty glass of water.

CHAPTER 5

SUMMARY AND CONCLUSION

5.1 Introduction

5.1.1 Rationale of the Study

Eye-hand coordination is required when performing the many daily activities and actions involving precise visual and motor control (Williams, 1990). However, degeneration of the central nervous system, visual function and joint sense are common with aging, and this is usually reflected in deteriorating eye-hand coordination, slowed reactions, slower movement and poor accuracy. In extreme cases, it becomes impossible to live independently with very poor eye-hand coordination.

According previous research results, eye-hand coordination may benefit from regular exercise such as running, racket games or golf. These exercises can help the elderly maintain better reaction times, faster movement and greater accuracy than inactive older adults (Lobjois et al., 2006; Rikli et al., 1986; Spirisudo & Clifford, 1978; Spirisudo, 1975). However, such exercises are physically demanding, expensive and/or need a lot of space, which can be troublesome for older adults.

Practicing Tai Chi has been proved beneficial for older adults in terms of improving cardio-respiratory function, muscle strength, balance, flexibility and psychological well-being (Lan et al., 2002; Tsang & Hui-Chan, 2003; Tsang et al., 2004). Such practice does not need any equipment, is inexpensive and requires little space, which makes it a good choice of exercise for older adults. There have also been studies showing that practicing Tai Chi can improve arm trajectory, promote faster movement and cultivate better kinesthetic sense (Pei et al., 2008; Yan, 1998; Jacobson et al., 1997), all of which contribute to good eye-hand coordination.

However, there have been very few studies of Tai Chi and eye-hand coordination. This study, therefore, investigated the effect of Tai Chi on eye-hand coordination by assessing subjects' reaction time, movement time and accuracy in finger-pointing tasks. Tai Chi requires the practitioner to move both hands continuously in different directions with the eyes focusing on one hand all the time, and Tai Chi's emphasizes attention to the exact positions of joints and memorizing a long series of movements. This may help maintain eye-hand coordination in responding to a moving visual target and, due to repeated firing of nerves along the gamma route from muscle spindles during the memorization of joint positions and the long series of movements, promote structural changes in the organization and number of connections among neurons and plastic change in the central nervous system (Fong and Ng, 2006, Tsang & Hui-Chan, 2003, 2004a, 2004b). This study thus investigated finger-pointing task with a moving visual target and also a finger-pointing task with a cognitive component.

5.1.2 Study Design

All 3 protocols were applied in a cross-sectional study investigating eye-hand coordination in Tai Chi practitioners, elderly controls and young adult controls. Reaction times, movement times and accuracy in finger pointing were measured with static targets, moving targets and in tasks with a cognitive component.

The subjects were recruited from elderly centers or community Tai Chi classes, whereas the younger subjects were recruited at universities. All the Tai Chi practitioners had practiced Tai Chi more than one and a half hours per week for 3 years or more. The controls had no previous experience of practicing Tai Chi. All of the elderly subjects and controls scored at least 24 on the MMSE, and 20/20 or above in Snellen's visual acuity test. They had sufficient active range of motion in their upper limbs without any pathology which might have affected their performance.

The subjects sat in front of a visual display unit with 3 electrodes recording EMG responses from their anterior deltoid, biceps and extensor carpi radialis longus muscles. The subject's upper trunk was strapped into a height-adjustable, non-rotating chair by a Velcro belt to prevent trunk movement. The angles of the elbow, hip, knee, and ankle joints were all approximately 90 degrees. The subject wore a headphone which delivered a preparatory signal (a "Ding" sound) to alert them before the appearance of a target ball in each test. There were tests in which no target appeared after the preparatory signal to inhibit anticipation.

Subjects had to place their dominant hand in the starting position between trials, or the target would not appear. After hearing the preparatory signal, the visual signal appeared and subjects tried to touch the target as quickly and as accurately as they could. Spoken encouragement "fast and accurate" was delivered (in Cantonese) in the middle of each set of tests to counter any decrease in attention span. Familiarization trial runs were given for each protocol.

In protocol A (pointing to a static visual signal), 1 static target appeared at one of 5 locations on the screen. The sequence of locations appeared random, but in fact was the same for all subjects. The target appeared 10 times at each location.

In protocol B (pointing to a moving target), 1 moving target appeared from the left of the screen and moved along the same horizontal path at 12 cm/s 10 times. The subjects were required to point to the target as quickly and as accurately as possible.

In protocol C (the task with a cognitive choice component), the subjects were required to respond differently according to instructions from the examiner: 1) If a black ball appeared, they had to touch it; 2) If a white ball appeared they should not touch it; 3) If both a black ball and a white ball appeared, they were to touch only the white ball target. Again, the target locations appeared random, but actually were the same for all subjects.

5.1.3 Statistical Analysis

Intraclass correlation coefficients (ICCs) were employed to analyze the test-retest reliability of all the testing protocols. Twelve Tai Chi practitioners and 8 elderly controls completed all three protocols, and repeated the whole procedure after 1 week.

Age, height, and arm-length data for all three groups were compared using one-way analysis of variance (ANOVA). The MMSE scores of the two older adult groups were also compared using independent-t tests, and their physical activity levels were compared using a chi-square test.

In the finger-pointing task with the static visual signal and finger-pointing task with a cognitive component, the subjects' reaction times, movement times and accuracy were compared using multi-variate analysis of variance (MANOVA).

When there were statistically significant differences in the multivariate tests, univariate tests were conducted with the data for each location. When the univariate test also found a significant difference, a post hoc analysis using Bonferroni's adjustment was performed.

In the moving signal tests and the wrong movement in finger-pointing task with a cognitive component, one-way ANOVA was used to compare the outcome measures (reaction time, movement time and accuracy) of the three groups. Where there was a statistically significant difference, post hoc analysis using Bonferroni's adjustment was then carried out. The significance level (**α)** was set at 0.05. The ICCs of the three protocols for reaction time, movement time, and accuracy (table 2) ranged from 0.68 to 0.97, which showed moderate to very good data repeatability. All of the protocols had reliable outcome measures.

5.2 Summary of results

5.2.1 Finger-pointing with a static target

1) The young controls performed significantly better than the elderly controls. The Tai Chi practitioners showed better accuracy than elderly controls with contra-lateral and central targets, and their results with such targets were similar to those of the young controls.

2) These results agree with those of previous studies showing that older adults have poorer eye-hand coordination than young subjects. Previous studies used pointing in the horizontal plane, while this study used vertical targets,

which may be better related with real life situations such as pressing a lift button or reaching for a cup.

5.2.2 Finger-pointing with a moving target

1) The young students had significant faster reaction and movement times, and better accuracy than the elderly controls. The Tai Chi practitioners achieved better accuracy than the elderly controls and were not significantly different from the young subjects.

2) Previous studies had shown that older subjects had faster movement times than young adults when reaching for a moving visual target. However, when the older subjects faced time and accuracy constraints, they had poorer accuracy than the young subjects.

3) The better accuracy of Tai Chi practitioners in this protocol may result from the sport's demands for dynamic movement coordination, which require practitioners to focus their eyes on a hand while moving other body parts. This might improve control of arm trajectory and better end-point accuracy.

5.2.3 Finger-pointing task with a cognitive component

1) The young university students performed better than the elderly controls at all 3 target locations in this protocol. When compared with the elderly controls, the Tai Chi practitioners had significantly faster movement times

and made fewer wrong movements at all 3 target locations, and had significantly better accuracy at the middle left location. Their wrong movements and accuracy were comparable to those of the young controls.

2) Again, aging impaired eye-hand coordination performance. Adding of a cognitive choice component degraded performance, but the effect on the older subjects was greater than with the young subjects.

3) Tai Chi practitioners had better accuracy with contra-lateral targets, which may be explained by the prevalence of hand movements across the mid-line of the body in Tai Chi. There seemed to be less decrease in the efficiency of inter-hemispheric communication in older adults who practiced Tai Chi.

4) The faster movement times for the Tai Chi group in this protocol could not have been due to musculoskeletal or neuromuscular factors, or else the Tai Chi group should have also have shown faster movement times in the first two protocols. It may, therefore, have been due to cognitive factors such as faster planning and/or better memory. This may also explain their fewer wrong movements when compared with the elderly controls. Tai Chi requires attention and memory to perform a long series of controlled movements.

5.3 Limitations and future studies

Due to this study's cross-sectional design, we cannot conclude a causal relationship between Tai Chi practice and better performance in finger pointing. A longitudinal follow-up is called for. Moreover, only healthy older subjects were tested. These findings should be extended to frail older people and those with eye problems.

The moving target in these experiments moved in only one direction (from left to right), but target motion is multi-directional in real situations, and they move at different speeds. Thus, further investigation of these dynamic situations is also needed.

5.4 Conclusions

Tai Chi practitioners demonstrated significantly faster movements, better accuracy and fewer mistakes when compared with matched elderly controls. Their speed and accuracy were comparable to those of young university students. Practicing Tai Chi can help the elderly perform better in daily life situations involving eye-hand coordination.

REFERENCES

1. Armstrong, L., Balady, G.J., Berry, M.J., Davis, S.E., Davy, B.M., Davy, K.P., et al., (2006). ACSM's Guidelines for Exercise Testing and Prescription (7th ed.). United State of America: Lippincott Williams & Wilkins.

2. Arrington, C. M., & Logan, G. D. (2004). The cost of a voluntary task switch. *American Psychological Society, 15,* 610-615.

3. Balylor, A. M., & Spirduso, W. W. (1988). Systematic aerobic exercise and components of reaction time in older women. *Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 43,* 121-126.

4. Bekkering, H., & Sailer, U. (2002). Commentary: Coordination of eye and hand in time and space. *Progress in Brain Research, 140,* 365-373.

5. Bellgrove, M. A., Phillips, J. G., Bradshaw, J. L., & Gallucci, R. M. (1998). Response (re-) programming in aging: A kinematic analysis. *Journal of Gerontology: Medical Sciences, 53A*, M222-227.

6. Birren, J. E., & Botwinick, J. (1951). The relation of writing speed to age and to the senile psychoses. *Journal of Consulting Psychology, 15,* 243-249.

7. Bock, O. (1986). Contribution of retinal versus extraretinal signals towards visual localization in goal-directed movements. *Experimental Brain Research. 64,* 476-482.

8. Boisseau, E., Scherzer, P., & Cohen, H. (2002). Eye-hand coordination in aging and in Parkinson's disease. *Aging Neuropsychology and Cognition. 9,* 266-275.

9. Brouwer, A., Brenner, E., & Smeets, J. B. J. (2002). Hitting moving objects: is target speed used in guiding the hand? *Experimental Brain Research, 143,* 198-211.

10. Carnahan, H., Vandervoort, A. A., & Swanson, L. R. (1998). The influence of aging and target motion on the control of prehension. *Experimental Aging Research, 24*, 289-306.

11. Chatput, S., & Proteau, L. (1996). Modification with aging in the role played by vision and proprioception for movement control. *Experimental Aging Research, 22*, 1-21.

12. Chen, K. M., Snyder, M., & Krichbaum, K. (2001). Tai chi and well-being of Taiwanese community-dwelling elders. *Clinical Gerontologist, 24,* 137-156.

13. Chiu, H. F. K., Lee, H. C., Chung, W. S., & Kwong, P. K. (1994). Reliability and validity of the Cantonese version of Mini-Mental Status Examination: a preliminary study. *Journal of Hong Kong College Psychiatry, 4*, 425-428.

14. Cooke, J. D., Brown, S. H., & Cunningham, D. A. (1989). Kinematics of arm movements in elderly humans. *Neurobiology of Aging, 10,* 159-165.

15. Craik, F. I. M., & Jennings, J. M. (1992). Human memory. In F. I. M. Craik & A. Salthouse (Ed.), *Handbook of aging and cognition* (pp. 51-110). Hillsdale, NJ: Erlbaum.

16. Cram, J. R., & Kasman, G. S. (1998). *Introduction to Surface Electromyography.* Gaithersburg, MD: Aspen Publication.

17. D'Antona, G., Pellegrino, M. A., Adami, R., & Rossi, R. (2003). The effect of aging and immobilization on structure and function of human skeletal muscle fibers. *The Journal of Physiology (London), 552,* 499-511.

18. Desrosiers, J., Hebert, R., Bravo, G., & Dutil, E. (1995). Upper-extremity motor coordination of healthy elderly people. *Age and Ageing, 24,* 108-112.

19. Elkington, A. R., Frank, H. J., & Greaney, M. J. (1999). *Clinical Optics* (3rd ed.). Oxford: Blackwell Science.

20. Esch, T., Duckstein, J., Welke, J., Stefano, G. B., & Braun, V. (2007). Mind/body techniques for physiological and psychological stress reduction: stress management via tai chi training – a Pilot Study. *Medical Science Monitor, 13,* CR488-497.

21. Fisk, J. D., & Goodale, M. A. (1985). The organization of eye and limb movements during unrestricted reaching to targets in contralateral and ipsilateral visual space. *Experimental Brain Research, 60,* 159-178.

22. Fitts, P. M. (1992). The information capacity of the human motor system in controlling the amplitude of movement. *Experimental Psychology, 121,* 262-269.

23. Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). "Mini-Mental State" A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research, 12,* 189-198.

24. Fong, S., & Ng, G. Y. (2006). The effects on sensorimotor performance and balance with tai chi training. *Archives of Physical Medicine and Rehabilitation, 87,* 82-87.

25. Gavea, V., Vindras, P., Prablanc, C., Pélisson, D., & Desmurget, M. (2003). Eye-hand coordination in reaching movements. In *The handbook of brain theory and neural networks.* M. Arbib (Ed.). Cambridge: MIT Press. pp. 431-434.

26. Goggin, N. L., & Meeuwsen, H. J. (1992). Age-related differences in the control of spatial aiming movements. *Research Quarterly for Exercise and Sport*, *63*, 366-372.

27. Gordon, J., Ghilhardi, M. F., & Ghez, C. (1995). Impairments of reaching movements in patients without proprioception. *Journal of Neurophysiology*, *73*, 347-360.

28. Gottsdanker, R. (1982). Age and simple reaction time. *Journal of Gerontology, 37*, 342-348.

29. Hay, L., & Velay, J. (2003). Interhemispheric relationships in 4- to 14-year-old children pointing to lateral targets. *Neuroreport*, *14*, 1041-1044.

30. Henriques, D. Y. P., Medendorp, W. P., Gielen, C. C. A. M., & Crawford, J. D. (2003). Geometric computations underlying eye-hand coordination: orientations of the two eyes and the head. *Experimental Brain Research, 152,* 70-78.

31. Hortobágyi, T., & DeVita, P. (2006). Mechanisms responsible for the age-associated increase in coactivation of antagonist muscles. *Exercise Sport Science Review, 34*, 29–35.

32. Inui, N. (1997). Simple reaction times and timing of serial reaction of middle-aged and old men. *Perceptual and Motor Skills, 84*, 219-225.

33. Jacobson, B. H., Chen, H. C., Cashel, C., & Guerrero, L. (1997). The effect of t'ai chi chuan training on balance, kinesthetic sense, and strength. *Perceptual and Motor Skills, 84,* 27-33.

34. Jin, P. T. (1992). Efficacy of Tai Chi, brisk walking, mediation, and reading in reducing mental and emotional stress. *Journal of Psychosomatic Research, 36*, 361-370.

35. Ketcham, C. J., Seidler, R. D., Van Gemmert, A. W. A., & Stelmach, G.. E. (2002). Age-related kinematic differences as influenced by task difficulty, target size, and movement amplitude. *Journal of Gerontology: Psychological Sciences, 57B,* 54-64.

36. Ko, G. T. C., Tsang, P. C. C., & Chan, H. C. K. (2006). A 10-week tai-chi program improved the Blood Pressure, Lipid Profile and SF-35 Scores in Hong Kong Chinese Women. *Medical Science Monitor, 12,* CR196-199.

37. Kwok, J. C. Y., Hui-Chan, C. W. Y., & Tsang, W. W. N. (2008). Does Tai chi improve finger-pointing task towards a moving visual signal? Paper presented at the meeting of The Six Pan-Pacific Conference on Rehabilitation, 52.

38. Lam, C. L. K., Lauder, I. J., Lam, T. P., & Gandek, B. (1999). Population based norming of the Chinese (HK) version of the SF-36 health survey. *The Hong Kong Practitioner, 21*, 460-470.

39. Lan, C., Lai, J., & Chen, S. (2002). Tai chi chuan. *Sports Medicine, 32,* 217-224.

40. Lobjois, R., Beguigui, N., & Bertsch, J. (2006). The effect of aging and tennis playing on coincidence-timing accuracy. *Journal of Aging and Physical Activity, 14,* 75-98.

41. Man, D. W. K., Tsang, W. W. N., & Hui-Chan, C. W. Y. (2006). Tai Chi, cognitive functions and mental health. Paper presented at The Fifth Pan-Pacific Conference on Rehabilitation and the Pre-FIMS World Congress of Sports Medicine, Hong Kong.

42. Marconi, B., Genovesio, A., Battaglia-Mayer, A., Ferraina, S., Squatrito, S., Molinari, M., Lacquaniti, F., & Caminiti, R. (2001). Eye-hand coordination during reaching. I. anatomical relationships between parietal and frontal cortex. *Cerebral Cortex. 11*, 513-527.

43. Moes, P., Jeeves, M. A., & Cook, K. (1995). Bimanual coordination with aging: Implications for interhemispheric transfer. *Developmental Neuropsychology, 11,* 23-30.

44. Nielson, K. A., Langenecker, S. A. & Garavan, H. (2002). Differences in the functional neuroanatomy of inhibitory control across the adult life span. *Psychology and Aging, 17,* 56-71.

45. Paillard, J., & Beaubaton, D. (1975). Basic neurophysiological structures of eye-hand coordination. In *Development of eye-hand coordination across the life span.* C. Bard, M. Fleury, & L. Hay (Eds.). Columbia: University of South Carolina. pp. 26 -74.

46. Pei, Y., Chou, S., Lin, P., Lin, Y., Hsu, T. H. C., & Wong, A. M. K. (2008). Eye-hand coordination of elderly people who practice tai chi chuan. *Journal of the Formosan Medical Association, 107*, 103-110.

47. Pigeon, P., Yahia, L., Mitnitski, A. B., & Feldman, A. G. (2000). Superposition of independent units of coordination during pointing

movements involving the trunk with and without visual feedback. *Experimental Brain Research, 131,* 336-349.

48. Rikli, R., & Busch, S. (1986). Motor performance of women as a function of age and physical activity level. *Journal of Gerontology, 41,* 645-649.

49. Rösblad, B. (1995). Reaching and eye-hand coordination. In *Hand function in the child: Foundations for remediation.* A. Henderson, & C. Pehoski (Eds.). Missouri: Mosby-Year Book, Inc. pp. 81-92.

50. Roy, S. H., De Luca, G., Cheng, M. S., Johansson, A., Gilmore, L. D., & De Luca, C. J. (2007). Electro-mechanical stability of surface EMG sensors. *Medical & biological engineering & computing, 45,* 447-457.

51. Ruff, R. M., & Parker, S. B. (1993). Gender- and age-specific changes in motor speed and eye-hand coordination in adults: normative values for the finger tapping and grooved pegboard tests. *Perceptual and Motor Skills, 76,* 1219-1230.

52. Schmid, M., Schieppati, M., & Pozzo, T. (2006). Effect of fatigue on the precision of a whole-body pointing task. *Neuroscience*, *139*, 909-920.

53. Schmidt, R. A., & Lee, T. D. (1999). *Motor Control and Learning: A Behavioral Emphasis* (3rd ed). Champaign: Human Kinetics.

54. Shrout, P. E., & Fleiss, J. L. (1979). Intraclass correlations–uses in assessing rater reliability. *American Psychological Association, 86,* 420-428.

55. Shumway-cook, A., & Woollacott, M. (2001). *Motor control: theory and practical applications*. Baltimore: Williams & Wilkins.

56. Spirduso, W. W. (1975). Reaction and movement time as a function of age and physical activity level. *Journal of Gerontology, 30,* 435-440.

57. Spirduso, W. W., & Clifford, P. (1978). Replication of age and physical activity effects on reaction and movement time. *Journal of Gerontology, 33,* 26-30.

58. Sugden, D. (1990). Role of proprioception in eye-hand coordination. In *Development of eye-hand coordination across the life span.* C. Bard, M. Fleury, & L. Hay (Eds.). Columbia: University of South Carolina Press. pp. 327.

59. Tsang, W. W. N., & Hui-Chan, C. W. Y. (2003).Effects of tai chi on joint proprioception and stability limits in elderly subjects. *Medicine & Science in Sports & Exercise, 35,* 1962-1971.

60. Tsang, W. W. N., Wong, V. S. W., Fu, S. N., & Hui-Chan, C. W. Y. (2004). Tai chi improves standing balance control under reduced or conflicting sensory conditions. *Archives of Physical Medicine & Rehabilitation, 85,* 129-137.

61. Tsang, W. W. N. & Hui-Chan, C. W. Y. (2004a). Effects of exercise on joint sense and balance in elderly men: Tai Chi versus Golf. *Medicine & Science in Sports & Exercise, 36,* 658-667.

62. Tsang, W. W. N. & Hui-Chan, C. W. Y. (2004b). Effect of 4- and 8-wk intensive Tai Chi training on balance control in the elderly. *Medicine & Science in Sports & Exercise, 36,* 648-657.

63. Tsang, W. W. N. & Hui-Chan, C. W. Y. (2005). Comparison of muscle torque, balance, and confidence in older Tai Chi and healthy adults. *Medicine & Science in Sports & Exercise, 37,* 280-289.

64. Tsang, W. W. N., Lee, K. Y. T., & Fu, A. S. N. (2007). Effects of concurrent cognitive task on pre-landing muscle response latency during stepping down activity in older adults with and without a history of falls. *Disability and Rehabilitation,* 1-7.

65. Tsao, S. W. (1995) *An in-depth analysis of Taijiquan*. Hong Kong: The Chinese University Press.

66. Van der Lubbe R. H. J., & Verleger R. (2002). Aging and the Simon task. *Psychophysiology, 39,* 100-110.

67. Van Heuvelen, M. J. G., Kempen, G. I. J. M., Ormel, J., & Rispens, P. (1998). Physical fitness related to age and physical activity in older persons. *Medicine and Science in Sports and Exercise*, *30,* 434-441.

68. Walker, N., Philbin, D. A., & Fisk, A. D. (1997). Age-related differences in movement control: adjusting submovement structure to optimized performance. *Journal of Gerontology: Psychological Science, 52,* 40-52.

69. Ware, J. E. J., Kosinski, M., & Gandek B. (2000). *SF-36 health survey: manual & interpretation guide* (2nd Ed). Boston Mass: Health Assessment Lab.

70. William, H. (1990). Aging and eye-hand coordination. In C. Bard, M. Fleury, & L. Hay (Ed.). *Development of eye-hand coordination across the life span* (pp. 327-357). Columbia: University of South Carolina Press.

71. Wolf, S. L., Coogler, C. E., & Xu, T. (1997). Exploring the basis for Tai Chi Chuan as a therapeutic exercise approach. *Archives of physical medicine and rehabilitation*, *78,* 886-892.

72. Xu, D., Hong, Y., Li, J., & Chan, K. (2004). Effect of tai chi exercise on proprioception of ankle and knee joints in old people. *British Journal of Sports Medicine*, *38,* 50-54.

73. Yan, J. H. (1998). Tai chi practice improves senior citizens' balance and arm movement control. *Journal of Aging and Physical Activity*, *6,* 271-284.

74. Yan, J. H., Thomas, J. R., Stelmach, G. E., & Thomas, K. T. (2000). Developmental features of rapid aiming arm movements across the lifespan. *Journal of Motor Behavior*, *32,* 121-140.

75. Yardley, L., Gardner, M., Bronstein, A., Davies, R., Buchwell, D., & Luxon, L. (2001). Interference between postural control and mental task performance in patients with vestibular disorder and healthy controls. *Journal of Neurology, Neurosurgery & Psychiatry*, *71*, 48-52.

76. Yu, K. P. (2002). *Concise dictionary of tai chi chuan*. Taiwan: Hsin Chao She.