THE HONG KONG POLYTECHNIC UNIVERSITY

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KINESTHETIC MOTOR IMAGERY AMONG TAI-CHI PRACTITIONERS – AN EVENT-RELATED POTENTIAL STUDY

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Philosophy

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CERTIFICATE OF ORIGINALITY

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April, 2011

DEDICATION

I dedicate this work to my parents and my wife, Michelle who have fully supported me throughout the Master study.

ABSTRACT

Tai-chi is a mind-and-body activity involving top-down intention (*yi*,意) for guiding and monitoring sequence of body movements called "forms". This study aimed to explain the preparatory processes associated with tai-chi using the motor imagery theory. It was hypothesized that mental preparation of tai-chi is composed of visualization and transformation processes. The visualization process was represented by the N250 component whilst the transformation process was represented by the N400 followed by the late positive component (LPC) elicited from the motor-related regions. Using a motor imagery paradigm, tai-chi masters who had experiences in practicing the forms would show differences in the task behaviors as well as in the amplitudes and latency of N250 and N400 with normal counterpart.

Sixteen tai-chi practitioners (8 males, 8 females) were recruited in this study. Their mean year of practicing tai-chi was 13.9 (SD=8.80). Their experience in tai-chi was further quantified with two custom-made questionnaires: Tai Chi Questionnaire (TCQ) and Tai Chi Motor imagery Questionnaire (TCMIQ). The TCQ collects evidence on subjects' experience in practicing tai-chi whilst the TCMIQ measures the tendency of the tai-chi subject employing kinesthetic or visual motor imagery style when receiving training in the study. Twenty health subjects (8 males, 12 females) who were age (p=0.645) and education level (p=0.562) matched were recruited as the control group. The two experimental tasks used for eliciting subjects' event-related potentials were the kinesthetic motor image generation and transformation tasks. All subjects were trained to memorize the position and movements of each body part involved in each tai-chi form and associate a Chinese character with each of the six forms. The training ended when the subject achieved 80% accuracy on the naming and memorization of all the forms. An image

generation trial was always followed by a corresponding image transformation trial. In a generation trial, the subject was required to recall the first-person image representing the 1^{st} movement sequence of a form prompted by viewing a character on the computer screen. The subject was to maintain the recalled image till the end of the trial. In a transformation trial, the subject viewed a number (2^{nd}, 3^{rd} or 4^{th}) displayed on the screen which showed the movement sequence step which the visualization ended. The subject was to begin visualizing the images associated with the changes in positions of body parts from the 1^{st} to the designated movement sequence (e.g. 3^{rd} movement sequence). By the end of 3,000ms, the subject was asked to verify the direction of the movement of a specific body part (e.g. left hand shifting to the left) displayed on the screen at the moment when the movement had ended by pressing the “Y” (for yes) and “N” (for no) key. The response time and accuracy rate in making the responses were recorded. The trials were organized in six blocks with 60 trials in one block giving a total of 180 generation and 180 transformation trials. The total administration time was 54 minutes included 6 minutes for one block with a two-minute break in between the blocks.

The behavioral results on the motor imagery tasks indicates that the tai-chi group was more accurate than the control group in both the generation (p=0.020) and transformation (p=0.004) tasks. In contrast, the tai-chi group performed significantly slower than the control group on both tasks (generation: p<0.001; transformation: p=0.006).

The electrical activities of subjects in the two groups captured in the generation task were significantly different in their amplitudes (P200 ($p \leq 0.003$) and N250 ($p \leq 0.003$)). The differences in the amplitude of P200 were found in the anterior (centro-parietal) regions which was associated with retrieval of motor-related information from long term memory. The years of experience in practicing tai-chi was significantly correlated with the P200 amplitude (r=-0.43 to 0.66, p<0.01). The N250 was found significantly more negative-going in the tai-chi than control group over the frontal, central and parietal regions ($p \leq 0.003$), which was associated with perceiving meaningful motor actions. The years of tai-chi experience was found to moderately correlated with the amplitude of N250 elicited at the frontal-central region (r=-0.33 to -0.54, p<0.05) These findings suggest that the tai-chi subjects tended to engage more intensively than those without tai-chi experience when generating familiar stationary motor image displayed in the 1st motor sequence.

For the transformation task, tai-chi group were revealed to have shorter latency than non tai-chi group in most of the ERP components, except the N100. The P200 elicited by the tai-chi group during the transformation of images were less-positive than the non tai-chi group and its topography covered extensive anterior to posterior regions. The N250 elicited was also more negative-going over extensive anterior to posterior regions. Different from P200, the N400 elicited by the tai-chi group was more positive-going than the non tai-chi group over fronto-central areas. The differences in LPC between the two groups were less obvious. Topography indicated that tai-chi group displayed more negative-going N400. Instead, the former group had significantly shorter N400 latency than the latter group over fronto-centro-parietal sites, and higher accuracy rate in manipulation of images of tai-chi forms. Whilst, between-group differences in LPC amplitudes and latency were statistically non-significant. The years of tai-chi experience was found to moderately correlated with the amplitude of P200 elicited at the frontal-central region (r=-0.53 to -0.89, p<0.01) and the amplitude of N250 elicited at the frontal-central–parietal region (r=-0.52 to -0.79, p<0.01). Whilst, the year of tai-chi experience was found moderately correlated with the amplitude of N400 elicited at the frontal-central-parietal region (r=-0.44 to -0.64, p<0.05) in the transformation task.

These findings suggest tai-chi forms is likely to first involve generation of these images. More importantly, the retrieval of motor-related images and had them maintained for manipulation in the motor-related working memory (Chow et al., 2007; Fallgatter, Muelle & Strik, 1997; Kekoni et al., 1996; Romero et al., 2000) would be more intensive.

Despite the stimuli used in the tasks might have biased against the control subjects, tai-chi subjects appear to generate and transform the motor images more effectively. The differences in the between-group ERPs suggest that tai-chi subjects tended to rely more on retrieval of motor information, visuo-spatial, sequencing and integrating motor plan functions to generate and transform tai-chi related body movements. This suggests that practice of tai-chi apart from modifying body movements may modulate subjects' mental processing in particular on motor-related images. This perhaps can explain findings from previous studies that individuals who practiced tai-chi had higher cognitive functions than those who did not. Our findings shed light on the cognitive and mental components of tai-chi and the potential gains in practicing tai-chi. They are useful for designing tai-chi interventions for rehabilitation of patients.

ACKNOWLEDGEMENTS

I would like to forward my thankfulness to a number of people who have assisted me in my study. Without them, my study might not have completed. First of all, he is my supervisor, Prof. Chetwyn Chan. He has supported me throughout the entire study, both technically and spiritually. His valuable advice has helped me to develop a clearer direction and mindset towards my research. Secondly, I would like to extend my gratefulness to Prof. Tatia Lee who served as my co-supervisor. In addition, I would also wish to show my gratitude to Dr. Kin Hung Ting and Mr. Sam Chan for sharing their research experience and technical assistance on the issue of data processing and data analysis. Moreover, I am also thankful to my lab mates in the Applied Cognitive Neuroscience Laboratory, for that they are always willing to spare time for discussion when I encounter problems. Lastly, I would like to thank my family and friends for their support and consideration during my period of studies.

TABLE OF CONTENTS

CHAPTER I
INTRODUCTION

This chapter includes the background and overview of the present study. It also provides the basic concept of tai-chi and justification of the study.

Statement of purpose

Previous studies from the Applied Cognitive Neuroscience Laboratory of The Hong Kong Polytechnic University suggest that increase loading of working memory would increase the demand of updating, comparing and rehearsing the tapping contents. This study was designed making reference to previous findings to investigate how individuals who are practicing tai-chi would be different in mental processes from those who do not practice tai-chi. This study employed event-related potentials to explore the possible mental processes related to the motor preparation possibly involved in kinesthetic imagery of tai-chi forms. Tai-chi practitioners and individuals without prior experience practicing tai-chi were recruited as subjects for the study. All subjects received training on the recognition, memorization and visualization of six tai-chi forms. There are two experimental tasks. The image generation task required the subjects to generate a static image of one of the six tai-chi forms learnt in the training. The image transformation task required the subjects to transform series of images of a tai-chi form. Event-related potentials (ERPs) were used to capture the electrical activity elicited and recorded over the scalp during the two tasks. The event-related components elicited during the motor preparation processes of tai-chi forms were compared between the two subject groups.

Background and justification

Tai-chi is a mind-body action exercise that is popular and practiced in the community especially for elderly people. Numerous studies found that practicing tai-chi could have an enhancement effects on physical ability and health (Gatts & Woollacott, 2007; Gyllensten, Hui-Chan & Tsang, 2010; Hong, Li & Robinson, 2000; Jacobson et al., 1997; Mao et al., 2006; Shih, 1997). Nevertheless, the extent to which practice of tai-chi might benefit mind-body and the cognitive function of individual has still received less attention.

The neural processes underlying mental imagery has been previously studied (Chow et al., 2007; Wu et al., 2006). The results indicated that imagery would involve generation and transformation of images with the former involving access to long term memory, whilst the latter involving manipulation of information in the working memory. Motor imagery is a common modality that people employ. For instance, athletes practice on a complex motor skill (Cumming & Hall, 2002; Murphy, 2004; Roure et al., 1999). Motor imagery has been widely used in promoting functional recovery of people suffering from trauma, Parkinson's disease (Tamir, Dickstein & Huberman, 2007), post-stroke (Liu et al., 2004a) and brain injury (Liu et al., 2004b).

Previous ERP studies indicated common neural processes between motor imagery and execution tasks (Caldara et al., 2004; Thayer et al., 2001; Thayer & Johnson, 2006). Most of these studies employed simple motor-related tasks such as mental rotation in imagery (Vingerhoets et al., 2002) and finger tapping in execution (Harrington, 2000). Recent studies involved more complex tasks such as tango dancing (Sacco et al., 2006) and self-feeding (Reid & Striano, 2008). Other studies revealed that tasks involving motor sequencing as simple as in finger tapping would tap spatial working memory (Fletcher et al., 1995), visual control (Stephan et al., 1995) and storage of motor sequencing information (Sadato et al., 1996). In this study, we used a kinesthetic imagery paradigm with the support of motor control theory to investigate the neural processes associated with the generation and transformation of images of tai-chi forms. The comparisons of the processes between tai-chi and non tai-chi group would elucidate the possible differences in motor preparation function attributable to the practice of tai-chi. The results will contribute to better understanding of the mind-body and cognitive component of this traditional Chinese martial art.

Research question and hypotheses

This study aimed to explore how prior experience on practicing tai-chi would modulate kinesthetic imagery which is related to motor plan and control. The task used involved participants to mentally generate a snapshot image of a human in a posture of a tai-chi style and then transform images of sequential postures of the style. The research questions are: (a) What are the ERP components associated with generation and transformation of the tai-chi related images? (b) How would the ERP components be differed between those with and without prior experience in practicing tai-chi?

We hypothesized that prior experience on practicing tai-chi would have significant modulating effects on processing tai-chi related images. To be specific, it was hypothesized that generation of tai-chi related images would elicit: (a) an early N100 elicited at the occipital region which reflected attentional process; (b) P200 elicited at the central and parietal regions associated with retrieval of motor related information; (c) N250 elicited at the frontal-central-parietal regions representing image visualization; and (d) N400 at the frontal and central regions related to semantic and motor manipulation processes. There would be between-group differences in amplitude and latency of P200 and N250generated in the image generation task and N250 and N400 generated in the image transformation task.

Organization of chapter

This thesis consists of seven chapters, including the present introduction chapter. Chapter 2 is a literature review of the current knowledge of the neural mechanism and cognitive processes involved in motor imagery, motor control theory and the possible changes of mechanism. Chapter 3 describes the design and result of the validation of the Tai Chi questionnaire (TCQ) and Tai Chi motor imagery questionnaire (TCMIQ) for this study. Chapter 4 is the method of the ERP experimental tasks, procedures for data capturing using electroencephalograms, the offline data pre-processing and data analysis. Chapter 5 presents result of the main study. Chapter 6 is a discussion on the results and related the revealed previous studies to the present study finding and the implication of tai-chi in rehabilitation. Chapter 7 provides the last chapter which is conclusion, limitation of the study, and the recommendation of future study.

CHAPTER II
LITERATURE REVIEW

Introduction

This chapter provides a general account on tai-chi. It then introduces motor control model and theory of mental imagery including visual and motor imagery. The relationship between tai-chi and mental imagery will be established. The potential neural processes associated with the motor preparation and control of the movements involved in tai-chi will be also be explored.

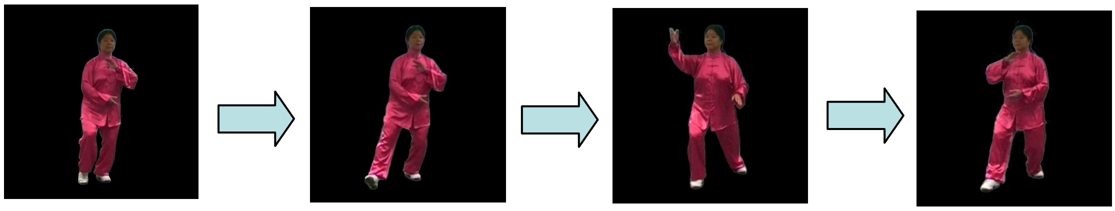
What is tai-chi?

Tai-chi is a mind-body exercise, which involves continuous movements of the body in series of "forms". Each form is composed of several posture changes. The body movements in tai-chi are almost exclusive of circular movement despite these movements are with many variations. These variations can be emptiness and fullness, strength and softness, weight shifting forward to backward, and weight shifting from one side to another side (Li, Hong & Chan, 2001). Tai-chi had been widely promoted and spread to the community since the late Ming dynasty (A.C.1368 – 1644) in China. Over centuries of its history, there have developed many schools of tai-chi and the common ones are - *Chen*, *Yang*, *Sun*, *Wu* and *Mu*. Each of these schools is characterized with its own styles and forms. Very often, variations are mainly to cater to the needs of those who practice it in the community, for example, modified simpler forms for elderly people for fall prevention program called "太極不倒翁". While most of the tai-chi practitioners would learn from their teachers (usually called 師傅 *master*). Those forms have smooth transaction from one form to another.

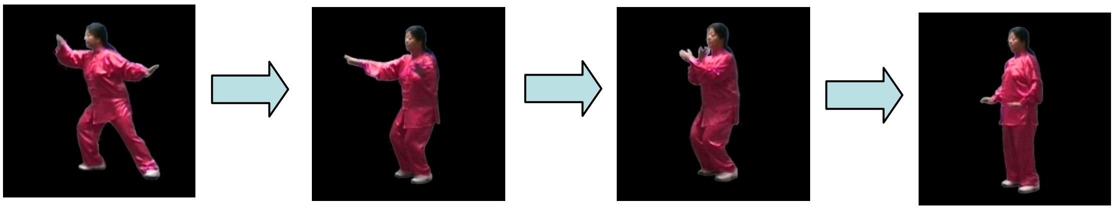
Figure 2.1

Example of the movement sequence of three tai-chi forms.

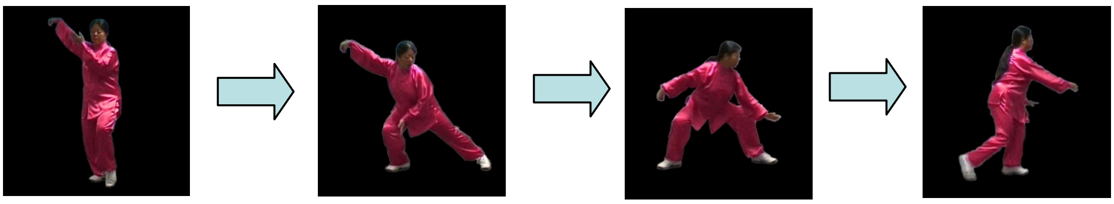
摟膝拗步



十字手



海底針



Tai-chi originated as a means to enhance people's physical fitness and capacity for self defense. In recent years, its focus has shifted to maintaining the homoeostasis between the body's internal mind and the environment (Wang's book cited in Li, Hong & Chan, 2001). Researchers also have explored how tai-chi can benefit people's health and be used as a therapy in rehabilitation. Results of randomized control trials and case studies on tai-chi practitioners showed that tai-chi can improve many physical aspects such as posture control and capacity with vision (Li, Hong & Chan, 2001; Schaller, 1996; Tse et al., 1992; Yeh et al., 2004), balance and strength, functional mobility and joint flexibility (Gatts & Woollacott, 2007; Gyllensten, Hui-Chan & Tsang, 2010; Hong, Li & Robinson, 2000; Jacobson et al., 1997; Mao et al., 2006; Shih, 1997; Tsang & Hui-Chan, 2006), and fear of falling (Kin et al., 2006; Wolf et al., 1996). The TC practitioners were reported to show significantly better cardiac functions than the non-TC practitioners (Lan et al., 1999; Scahller, 1996; Wolf et al., 1996; Wolf et al., 2001).

Studies published by the Centre for East-meet-West in Rehabilitation Sciences, The Hong Kong Polytechnic University, further indicated that tai-chi was effective for enhancing sensori-motor and balance functions by improving knee joint proprioception and postural stability (Tsang & Hui-Chan, 2003, 2004b). Four-weeks of intensive tai-chi training was found to improve balance control of elderly people (Tsang & Hui-Chan, 2004a). Other therapeutic values were on improving cardio-respiratory function and self esteem (Li, Hong & Chan, 2001).

Aside from the physical aspect, tai-chi has been revealed to be beneficial for enhancing "mind-body" activity and cognitive function (Docker, 2006). For instance, Shapira et al. (2001) reported that, after two to four years of practicing tai-chi, patients with traumatic head injuries showed improvements in attention and memory. Hernandez-Reif and colleagues (2001) also found that adolescents with attention deficit had enhancement in attention and reduced anxiety level after attending 30 minutes tai-chi session weekly for 10 weeks. Nevertheless, the neural mechanisms mediating these changes are still not known. Some studies postulated that its therapeutic effects on cognition probably came from memorization of the names and steps of the difference forms throughout the practice (Li et al., 2003; Shapira et al., 2001; Wayne et al., 2004).

This study is designed to gain a better understanding of tai-chi by exploring the possible neural processes associated with the preparatory and control processes of the physical movements involved in tai-chi. We used a motor imagery paradigm – visualization and transformation of tai-chi related images for initiating these preparatory and control processes. The study was made possible by making contrast between tai-chi practitioners and those without tai-chi experience.

This study began with a pilot study which gathered information from tai-chi practitioners on the thinking (or mental processes) associated with practicing the tai-chi forms. Findings of this pilot study helped design the generation and transformation of images of tai-chi forms.

Mental component of tai-chi

A fundamental principle of tai-chi is the manipulation of mental intention "用意不用力" *jung6 ji3 bat1 jung6 lik6* (Cantonese). This mental intention was previously described as visualizing the tai-chi forms in mind, and use internal awareness to guide the form practice rather than use physical strength to act out (Li et al., 2003; Wayne et al., 2004). Practice of tai-chi was reported to require mentally rehearsing the steps and forms (李德印, 2006). As a result, practice of tai-chi demands attending to and memorizing the movement sequences. In other words, such mental process would involve a top-down intention "意" *ji3* (Cantonese) for controlling and guiding the actions. For example, when individual performs a tai-chi such as “摟膝拗步” *lau4 sat1 aau3 bou6* as in Figure 2.1, one would first shift the weight from right to left, and then swing the right foot forward, and produce circular movements with both upper limbs. The weight is then shifted to the right with the whole body leaning forward. Finally, the individual shifts the weight shift to the left and their body leans backward. All the movements forming the “摟膝拗步” form. In this form, “摟膝” means turning for shifting the body weight and “拗步” means swinging the leg forward.

The second principle underlying tai-chi practice is consistency and continuity “上下相隨、連綿不斷” *soeng6 haa6 xiang1 sui2 - lin4 min4 bat1 dyun3* (Cantonese). This would require coordination of the upper limbs, middle body, lower limbs, and the eye-sights “手動、腰動、足動、眼神亦隨之動” *sau2 dung6, jin1 dung6, zeoi3 dung6 - ngaan5 san1 jik6 ceoi4 zi1 dung6* (Cantonese)(李德印, 2006). This would demand the synchronization between the mind and body “意念合一” *ji3 lim6 hap6 jat1* (Cantonese) and internal and external awareness 內外相合 *noi6 ngoi6 soeng3 hap6* (Cantonese). During the learning phase of tai-chi, one would learn from visualizing the movements performed by others (called 3rd person) or by himself (called 1st person). This was further verified in the pilot study that the masters who are familiar with tai-chi forms would mentally imagine others or themselves practicing the forms. In fact, these processes are quite similar to people learning sports. Training of the motor acts and skills are very often associated with visualization of oneself performing the motor actions.

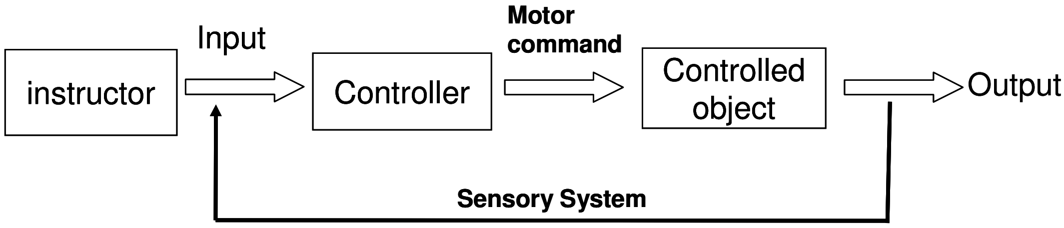
The third principle is to resemble the forms of tai-chi during practices. As most of the forms carrying figural features such as “Part the Wild Horse's Mane” “野馬分鬃” *je5 man5 fan1 zung1* (Cantonese), which resembles riding a horse, and “Play the Lute” “手揮琵琶” *san2 fai1 pei4 paa4* (Cantonese), which resembles playing a pipa (a Chinese music instrument). According to the respondents, imagination of oneself as if one is riding a horse or were playing a pipa would facilitate the practice of these forms. (李德印, 2006). It suggested that tai-chi is a kind of activity that requires consistency and continuity throughout the practice. There is a lot of specification on the movement including relative joint position, the height of body parts and standard trunk rotation, etc. This is highly related to the motor control system. The following paragraph will explain the feed-forward and feedback motor control system. The tai-chi practice will then be explained by the motor control system model.

Feed-forward and feedback motor control system

Previous studies attempted to use principles for constructing robotics to explain planning and execution of motor movements by human (Desmurget & Grafton, 2000; Itao, 2008). The feed-forward control system, which has an instructor, controller and controlled object is used to explain human movements. Human operator (instructor) first inputs instructions into a controller. This controller gives a motor command to control the robot body part (controlled object). Movement of a particular robot body part is an output. The feedback control system is a "feedback loop" added to the feed-forward system of which the output returns back to the controller and serves as the external feedback for fine adjustment of the action (figure 2.1). The complex human actions further require an internal model inside the brain to generate the derivatives and refinements of the prototypic movements. This internal model can be defined as a mental processes that the prefrontal controller construct and manipulate a mental model as a controlled object. While mental model is a small-scale model to realize on the reasoning of a real situation by using previous event and to anticipate future event (Craik idea (1943) cited in Ito, 2008). This mental model is further elaborated from perception, imagination that is the ability of a subject to imagine visual scene or represent even some situation that cannot be visualized (e.g. kinesthetic imagery). For example, in a feedback model, raising an arm up to the shoulder level might require numerous feedback loops of the contractions of the muscle surrounding the shoulder girdle (forearm, scapular, shoulder and thorax), the nerve sensation including the joint proprioception sense even with the visualization of subject's eye, while for the internal model, subject could mental process the definition of the motor situation by previous experience then motor plan on how to raise an arm, these model can go before the feed-forward model or even keep updating the information by the feedback model so that the forearm can be flexed to 90 degree to the vertical axis. The feedback signal from the lower motor center (spinal cord) or from the internal model of the brain is therefore required. This motor control process becomes important for our understanding on the brain process.

Figure 2.1.

Basic diagram of motor control system (Adapted from Itao, 2008, p 307)



Ito's study (2008) suggested that the neural activation of feed-forward motor control system starts from an "instructor" somewhere in the pre-motor and supplementary motor cortices and the anterior cingulate gyrus that gives a motor command or motor instruction to a "controller" in the motor cortex or prefrontal cortex. The instructor can be defined as the initiation center to decide what to do and at what moment to initiate a voluntary act (Deccke, 1996). This "controller" manipulates the output called "controlled object". This controlled object was assumed in Ito's study to be a body part or lower motor center in the spinal cord. Feedback motor control system would provide an extra sensory system to collect the signal to compare with the feed-forward motor control system. The sensory system in this model mediates feedback from the output movement like raise an arm up to shoulder. The output of this movement would bring back some feedback as the example mentioned above like the proprioception or visual feedback, all this feedback is return to the controller which can function separately from the internal models. Previous animal studies conducted by Tsunoda and colleagues (2001) found that sensory information (e.g. light brightness or color) was first analyzed in the sensory area and then would combined and formed perception information (e.g. circle) in the inferotemporal association area when a monkey visualize an object. This perception can be a feedback signal to compare with the target location (initiate by the instructor) and decide the final location in the inferior olive nucleus, which is part of the motor association area.

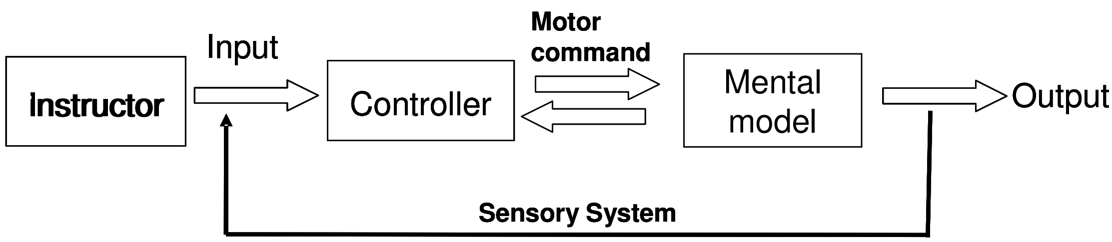
The motor control system described in there is useful for explaining the internal system and possible neural processes underlying the motor execution associated with practice of tai-chi. Motor execution of tai-chi is common to commence with the master (or individual) focusing on the name of a form (e.g. "手揮琵琶" *san2 fai1 pei4 paa4* (Cantonese). Along with the assumption of motor images, these images would be translated into instruction signals and then motor commands for sending to the controller in the motor cortex. Practitioner would then physically execute the tai-chi form (e.g. Resembles playing a pipa"琵琶"). As tai-chi is a whole body exercise, the whole body of the subject worked as "controlled object" to revive motor command in a top down approach and each movement steps manipulate different body parts associated with different output. For example, the joint proprioception sense would serve as a feedback to the motor control system for fine adjustment of the movements associated with this tai-chi form.

Mental model of motor control system

Feed-forward and feedback motor control model is useful for explaining the cognitive process involved in execution of motor actions. Previous study suggested that merely mental model without motor execution can achieve motor-related learning (Kosslyn, Behrmann & Jeannerod, 1995; Wei & Luo, 2009). Itao (2008) hypothesized that the mental model was driven by a controller, which was mediated by the prefrontal cortex. The processes described by Itao (2008) were that the controller would send a motor command to a mental model as the feed-forward input (Figure 2.2). In other words, inputs to the mental model would not necessarily come from periphery body parts such as limbs or body. Feedback input would then be sent from the mental model back to the controller at the prefrontal cortex (Itao, 2008). Recent study proposed that the temporo-parietal cortex was likely to mediate the activity of the mental model (Fang, Stepniewska, & Strick, 2005). Previous study was found to also support these propositions that prefrontal cortex received somatosensory, auditory and visual pathways through tempo-parietal cortex (Fuster, 1997).

Figure 2.2.

The role of mental model in motor control system (Adapted from Itao, 2008*, p.307*)



Mental Imagery

Visual imagery

Mental imagery was first studied in the context of visual imagery. It is used to illustrate the processes associated with mental imagery. Mental imagery occurs when perceptual information is retrieved from long term memory, giving rise to the experience of 'seeing with the mind's eye', or 'hearing with the mind's ear' (Kosslyn, Ganis & Thompson, 2001). Studies showed that cortical activations associated with imagining a modality overlapped with those associated with the actual execution of the modality such as movements of a limb (Ganis, Thompson, & Kosslyn, 2004).

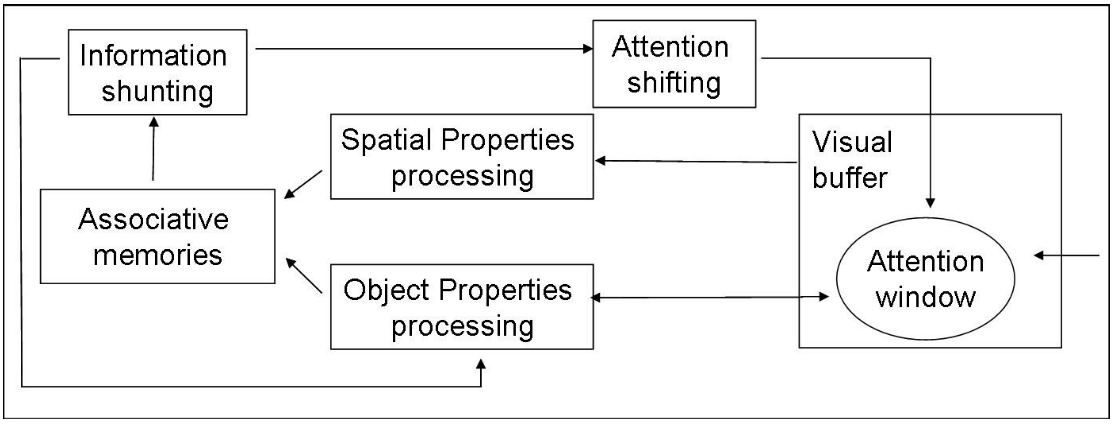
Kosslyn (1994) argued that imagery and actual execution closely linked to one another. The process begins with an external image perceived by one's eyes, which connect to the primary visual cortex in the occipital lobe. The information is organized which requires attention at the visual buffer or working memory. At the buffer, visual information is further processed which taps on the spatial or object sub-system. Spatial subsystem is involved when the information is spatial-like such as location or rotation which activates the dorsal pathway (from occipital lobe to posterior parietal lobe). Object subsystem is involved when the information is object like such as shape and color that activates the ventrolateral pathway (from occipital lobe to inferior temporal lobe). Information from these two subsystems then processes to associative memories. This associative memories system is mediated by the dorsolateral prefrontal cortex which is associated with multimodal knowledge about the images.

There is a shunting system located at the prefrontal cortex that is responsible for accessing the information stored in the associative memory. This shunting system relies on top-down processes to generate more images as required by the task. These images are previously stored in the associative memory system. For example, when an individual sees a car passing by and then forms an image of that car, he may interpret whether this image resembles a taxi or private car. The interpretation involves the individual to generate the image of the taxi and at the same time cross check the characteristics between these two images, i.e. the passed-by car and the generated image of a taxi. These processes henceforth are regarded as object imagery.

To conclude, visual perception begins from sensory processes through the sense organ. The perceived information determines and accesses both working memory and long term memory. While the imagery process begins from information shunting system, information is retrieved from the long term associative memory then the information accesses to the object related or spatial related properties processing subsystems which activate the representation of the visual properties of an object. Kosslyn & Thompson (2003) further elaborated when someone needed to imagine a task, they required generating that image. This generation of an image is the beginning of the mental process of imagery. It can be separated into the activation of representation in long term memory and then display on visual short term memory (Bruyer & Scailquin, 2000). Previous fMRI study revealed the neural substrate associated with prefrontal and ventral occipito-temporal region was related to image generation (Ishai, Haxby & Ungerleider, 2002) when subject perform visual imagery on famous faces. This is suggested that mental images generated from the long term memory might store in the occipito-temperal region. While recent ERPs study by Chow et al. (2007) on vibrotactile imagery suggest a P300 ERP component is the beginning of the imagery process in the vibrotactile sensation imagery task and probably involved in the retrieval and maintenance of the images and the dipole sourcing found it elicited at the superior parietal region which is concurred with previous study on object (faces, house and chairs) visual imagery task that the intrinsic connections linking the precuneus, the superior parietal and ventral occipito-temporal regions forming an imagery network. Following the image generation, the next step is the maintenance of the image. This requires brain capacity to store and keep the information, which can be similar to the visual spatial working memory (Bruyer & Scailquin, 2000) to allow interaction between the retrieval of visual representations, inspection, copying, matching and transformation process to occur. For example, rotating and translating the image. This process is thought to be similar to that of priming effects created by top-down approach to test in perception through the attention shifting system. Furthermore, this priming can activate a backward bottom-up process by which an image representation can be formed (Figure 2.3). These processes go through the same object and spatial relations of the visual images to be inspected and identified by the same mechanism as perception.

Figure 2.3.

Major subsystems used in visual imagery model (Adapted from Kosslyn, S.M., *Image and Brain.* Cambridge, MA: Harvard University Press; 1994)



<u>Motor imagery</u>

Motor imagery can be simply defined as imagining an action without actually performing the action. Motor imagery can be further divided into kinesthetic (1st person) and visual motor imagery (3rd person). The example of kinesthetic imagery (KI) is to visualize oneself grasping the right hand mentally without actually doing it, whilst visual motor imagery (VMI) is to visualize others or a third person doing the grasping movements mentally which is similar to the internal model mentioned in the motor control theory above that the mental process could either visualize the motor act.

VMI is different from the KI because visual motor imagery does not contain the kinesthetic representation of action (Jeannerod, 1994), since the subject could purely watch other doing a task then visualize the image without any kinesthetic experience. On the other hand, it is not the case on the KI which was revealed to have overlapping on the VMI. This KI would involve motor anticipation, motor preparation and refinement in a movement (Jeannerod, 2001). Both types of imagery have been widely used for learning complex motor skills (Szameitat, Shen, & Sterr, 2007) and sports (Atienza, Balaguer & Garcia-Merita, 1998; Murphy, 1994), re-learning of motor and functional skills among patients with neurological deficits (Dijkerman et al., 2004; Liu, 2004a, 2004b, Lotze et al., 2006) and motor training for rehabilitation in people with stroke. (Muller et al., 2007 ; Sutbeyaz et al., 2007 and Verbunt et al., 2008).

Neuro-processes of different imagery modalities

According to Kosslyn, Behrmann & Jeannerod (1995), motor and visual imagery shares common neural substrates suggesting overlapping neural processes between the two modalities when performing the action related tasks. Vingerhoets and his colleagues (2002) showed that transformation of the motor-related images resulted in increased activations in the premotor and cerebellum regions. In this study, the subjects were to visualize and then compare the orientation of different pairs of rotated object images such as hands or tools. The results revealed common and modality-specific neural processes in imagery of different modality images.

Motor imagery and execution

The main difference between motor-related imagery and execution is that the former is related to intention of performing an action while the latter is the physically performing the action. The motor imagery and execution shared common mechanisms and neural substrates but do not completely overlap (Lotze & Halsband, 2006).

Previous neuroimaging studies would help understand the differentiation of the neural processes associated with motor imagery and execution. Imagery and execution of movements were found to associate with stronger BOLD signals in the supplementary motor area (SMA), primary motor cortex (M1), rolandic region, ventral premotor cortex (PMv). In this experiment, the subjects were required to perform sequential dorsiflexion and plantarflexion movements with the feet (Lafleur et al., 2002). Another study asked subjects to perform bending or imagine bending left index finger (Rodriguez et al., 2004). Other studies involved subjects to memorize and perform novel sequential digit-to-thumb opposition tasks (Kim et al., 1995; Lacourse et al., 2005). In contrast, increased BOLD responses in the posterior parietal, premotor and supplementary motor cortex were found to uniquely associate with motor imagery but not execution. The posterior parietal, premotor and supplementary motor cortex was previously suggested that it played an important role on motor preparation and motor planning. Rushworth et al. (2003) suggested that premotor cortex has a role for the selection of movement and the role of parietal cortex in movement control appears to be related to the preparation and redirection of movement. The left parietal cortex is important in motor sequencing of a motor sequencing task and redirecting attention from the motor instruction to the eye movement task.

Neural processes associated with kinesthetic versus visual motor imagery

Anquetil and Jeannerod (2007) conducted a behavioral study involving subjects to perform grasping tasks with their hands. Subjects were to imagine using the tips of the thumb and index finger to grasp on a certain corresponding marks on a dowel. The relative position of the marks on the dowel from the subject can be from the orientation of the subject (subject facing the dowel indicating visual motor imagery (VMI)) or the orientation of another person (opposite to the subject indicating kinesthetic imagery (KI)). The difficult levels of the grasping tasks in the two conditions were determined. The results indicated that the reaction times for completing the grasping tasks were not significantly differed between the two conditions. The results concurred with previous studies that visualizing one's own actions did not differ from visualizing the actions taken by other individuals as they were functionally compatible (Jeannerod, 2001; Rizzolatti et al., 1996). As a result, the time taken in completing the two processes would be similar (Wohlschläger et al., 2003). The findings suggested that behaviorally first and third person’s visualization of motor actions are likely to share similar mental processes.

Neuroimaging experiments indicated that similar neural networks mediated actual execution of the movements and imagine one’s own performing (kinesthetic motor imagery) the movements. The neural subjects constituting both networks were the premotor cortex, primary motor cortex (M1), primary sensory cortex (S1) and posterior parietal cortex (Hamilton et al., 2006). Solodkin and her colleagues (2004) compared the neural substrates associated with motor execution; kinesthetic motor imagery and visual motor imagery. The tasks were sequential movements of thumb to fingers opposition by following the coded digit-number shown on the screen. The blood oxygen level dependent (BOLD) responses captured in the three task conditions were contrasted with the rest control (remain observe the random digit number). The study revealed that the M1 and S1 were involved during the actual execution and kinesthetic motor imagery conditions but not in the visual motor imagery condition. The activations in the occipital region were found to exist only in the visual motor condition. The findings are further supported by other studies (Ruby & Decety, 2001; Ramnani & Miall, 2004; Saxe et al., 2006). Kinesthetic motor imagery was found to also activate the primary sensorimotor areas (Neuper et al., 2005). Visual motor imagery in contrast was found to associate with activations in the parieto-occiptial (Neuper et al., 2005).

The training effects on motor imagery were investigated. Sacco et al. (2006) used a pre- and post-training design to investigate possible changes in the imagery processes among a group of healthy subjects engaged in a one-week basic tango foot steps course. Each tango lesson was ended with mental rehearsal of the performed steps. The results showed that training induced an increased spread of the activations in the bilateral motor areas (MSA, M1 and pre-motor cortex) but a reduced activations in the lingual gyrus, fusiform gyrus, anterior and posterior cerebellum (Sacco et al., 2006). In this study, the findings in Sacco et al.'s study offered insight into the learning of TC by the practitioners. It was plausible that the learning of TC would involve firstly observing the forms to be performed by TC masters. These visual images would then be mentally visualized by the practitioners. The visualization processes would initially be visual motor imagery, which then be progressed to kinesthetic imagery. The visualization performed by the TC masters would dominantly be kinesthetic imagery but less visual motor imagery. For previous vibrotactile imagery study, it was found that both perception and imagery task had similar waveform but imagery condition elicited a less negative going N400 with dipole sourcing at right middle frontal gyrus, right anterior cingulate gyrus, left precuneus and less positive-going P600 (as long latency of P300) than the control condition with dipole sourcing at right precuneus of the parietal lobe and left medial frontal gyrus which author suggests that imagery process started from P300 (dipole source at right superior temporal gyrus, left postcentral gyrus and right superior parietal lobule included retrieving experiences from memory, generating images and maintaining images. Another auditory imagery study conducted by Wu et al. (2006) tried to investigate the neural correlates of imagined animal sounds revealed imagery effect started with enhancement of P2 component. Authors suggested that P2 is possibly a top-down allocation of attention to the imagery task. When comparing the imagery minus control task, a more positive going deflection arranged 350-60 ms suggested as the formation of auditory imagery. Centro-parietal distribution over a late positive complex is the subprocesses of imagery formation and representation in working memory.

Tai-chi related motor execution and imagery

Practice of tai-chi would involve substantial mental imagery. When a tai-chi practitioner recalls a learnt tai-chi form, he would retrieve the form by accessing long term memory. The percepts associated with the form such as the body posture and limb positions would be generated in the working memory. These images may be in the form of first person, which is visualizing himself performing the form or of a third person, which is visualizing another person (could be the master) performing the form. Personal communication with three tai-chi trainers, who have more than 15 years' of teaching experience, indicated that beginners of tai-chi are likely to visualize images of a person (usually the teacher) practicing the form (VMI or 3rd person), whereas experts of tai-chi would visualize images of themselves practicing the form (KI or 1st person). However, these trainers commented that the visualization, if any, is conceptualized as internal awareness, proprioceptive sense, or "Qi" (as they called it) rather than in the form of motor- or visual-related images.

Previous Positron emission tomography (PET) studies showed that actual practice together with mental practicing of a novel task would facilitate its learning (Jackson et al., 2003; Lafleur et al., 2002). Jackson (2003) demonstrated that increases in brain activities at the medial orbito-frontal cortex and decreases in the cerebellum when subjects went through actual practices on the same tasks. Author suggested that motor imagery improves performance by acting on the preparation and anticipation of movements. Mental practice is a crucial component in the learning and daily practice of tai-chi. Gentilir et al. (2006) found that the mental practice (called internal movements) enhanced subjects' learning of novel three-dimensional arm movement patterns; whilst the learned movements were found to be able to generalize to other movement patterns. However, no study has been found to reveal the role of mental imagery in practice and learning of tai-chi forms. This study was designed to reveal the possible neural processes associated with imagery of tai-chi forms by a group of tai-chi practitioners. To further differentiate the processes, this study employed a non tai-chi group as the control.

There are two levels of tai-chi practice: beginner and expert. At the beginner level, individuals put more effort on learning and memorizing the pattern and nature of each of the forms. Beginners would tend to involve visual motor imagery, i.e. 3rd person, of which the movements of the teacher can be mimicked. At the expert level, tai-chi masters would tend to attend to their internal awareness and flows across forms which possibly involve kinesthetic imagery, i.e. 1st person. It comes to a question that whether tai-chi practitioners would employ kinesthetic imagery rather than visual motor imagery when visualizing tai-chi forms? How would the kinesthetic imagery be reflected from recording of the event-related potential during the experimental motor imagery task?

Neuper et al. (2005) found that the kinesthetic (1st person) and visual movement (3rd person) representations of motor actions elicited different EEG (ERD/ERS) patterns in terms of both spatial distribution and frequency wavebands. Subjects were involved in the paradigm to imagine clenching the ball with their right hand in the kinesthetic imagery condition and to imagine somebody's right hand performing grasping movements in the visual motor imagery condition. The results showed significant interactions between the condition, brain locations, and hemisphere effects. Kinesthetic imagery condition elicited the highest amplitude component at C3 (left central area) between 8 and 36 Hz than that in the visual-motor imagery. The authors further explained that the unexpected non-significant result at O2 possibly was due to the individual differences rather than the task itself. The kinesthetic imagery condition also found to elicit higher power of upper alpha waveband than the visual imagery condition at the occipital region. Those studies suggested some potential locations for motor imagery but the neural processing still not clear. Based on the previous study, neural activation associated with the motor control system and motor imagery was also recruited in the following session.

This study made reference to previous imagery tasks with different modalities such as vibrotacile sensation (Chow et al., 2007) and auditory stimili (Wu et al., 2006).

Event related potential – possible neural processes associated with motor imagery

In this study, event-related potentials (ERPs) were used to capture and analyze the imagery processes associated with mental practices of Tai-Chi. ERPs offer high temporal resolution for investigating neural activities as the signals can be locked to the specific processes occurring in a carefully defined mental task. ERPs have been widely used for studying different cognitive processes such as attention and memory (Howard & Chaiwutikornwanich, 2006; Kimura, Katayama & Murohashi, 2008; Robitaille et al., 2007) visual imagery (Qiu et al., 2007; Yamazaki et al., 2007), and sensori-motor imagery (Romero et al., 2000; Thut et al., 2000). Recent study used ERP to reveal the neural processes (temporal sequence) associated with imagining the sensation of vibration (vibrotactile sensation) (Chow et al., 2006). Subjects were required to image vibrotactile sensation perceived 200ms vibrotactile stimulus by the right-hand second finger and imagine this stimulus in the following 4000ms. Subject then received another 200ms vibrotactile stimulus after preparation time and s/he was asked to compare whether these two stimuli were the same frequency or not. The result indicated that the imagery condition elicited a less negative going N400 and then a less positive going P600 than the control condition (perceived without imagining).

A recent study further revealed the ERP components associated with motor actions (Reid and Striano, 2008). The study involved subjects watching an anticipated action, such as eating with a spoon. Results showed that processing of the action sequences was associated with a positive-going N400 elicited over the frontal (F3, Fz, F4), central (C3, Cz, C4) and parietal regions (P3, Pz, P4). The N400 was explained to be related to goal directed actions (Reid & Striano, 2007). Thayer and Johnson (2006) used a mental rotation of the hand task to elicit an early P1–N1–P2 complex over at the bilateral occipital regions (O1, O2). This was followed by the P300 complex (300-600 ms) with maximal amplitude elicited in the midline and right parietal regions (Pz, P4). A late less negative-going P600 was also identified elicited in the midline central (Cz) and midline and lateral parietal areas.

ERP components related to this study design

N100 component

This early component is characterized by a negative deflection that peaks at 70-150 ms post-stimulus in the anterior electrode sites. The N100 component in the lateral occipital cortex was found associated with attention and discrimination processes after the detection of the visual stimuli (Hopfinger, Buonoocore & Magnum, 2000; Vogel, Woodman & Luck, 2001). Schafer and Marcus (1973) found that the N100 was less negative-going for repetitive stimuli but more negative-going for stimuli presented at random.

P200 component

This component follows the N100 component which peaks at 150-300 ms. A more positive-going P200 maximized at the frontal region (was found to associate with a short-term working memory and recognition task when subjects were asked to hear reverse order of digit series (Lefebvre et al., 2005). A more positive-going P200 elicited in the posterior regions was found to relate to visualizing sentences involving in language processing. Other studies further substantiated differentiation of P200 elicited in the anterior with that in the posterior regions. The P200 elicited a more positive-going amplitude at the posterior sites which was related to word matching in language processing (Federmeier, Mai & Kutas, 2005). In contrast, P200 elicited in the in the anterior regions (frontal and central) was found related to generation of visual images when subjects heard animal sounds (Wu et al, 2006) and visual search for task information (Luck & Hillyard, 1994). The functionality of the anterior P200 was revealed to associate with selection, encoding, and recognition processes in working memory (Dunn et al., 1998; Lefebvre et al., 2005)

N250 component

The N250 component peaks at 270-400 ms. This component when elicited in the frontal region (left premotor area) was found to associate with spatial working memory (Yamamoto & Mukai, 1998), engaging working memory (Yamamoto & Mukai, 1998) and motor preparation and manipulation of force when its elicited in the parietal region (Romero et al., 2000). The N250 when followed by a more negative-going N400 elicited in the frontal and parietal regions was suggested to reflect motor actions conducted without a goal (such as woman cutting bread with a saw in the kitchen) (Proverbio & Riva, 2009) whilst a less negative-going N400 when the actions and goals were congruent.

N400 component

The N400 component has been found to commonly relate to semantic processing involving language (e.g. Balconi & Pozzoli, 2005; Friederici, 2002). Its distribution is over the central to parietal regions and peaks within the 375 – 520 ms time-window. Kutas and Hillyard (1984) suggested that the more negative-going amplitude of N400 elicited at the posterior region were associated with familiar or less expected language-related items such as sentence with unexpected endings: 'don't touch the wet dog', where the 'dog' is not semantically related to the expected ending 'paint'. Recent study concluded that the functionality of posterior N400 was related to word meaning and knowledge were accessed, stored and integrated in the lexical semantic system included (Proverbio & Riva, 2009). Along this line of thinking, Debrulle (2007) conducted a review on the N400 suggesting that it was associated with the effort on integrating stimulus into its context instead of purely language-related semantic processing. For instance, N400 was found to relate to incoherent relationship between object and action (Bach et al., 2009; Sitnikova et al., 2008).

Reid and Striano (2008) reported that N400 elicited over frontal, central and parietal regions was related to viewing goal-directed sequence of actions such as depicting a plate of corn with a spoon. The actions were playback in short video clips: a spoon was picked up and (a) collected a corn or (b) did not collect a corn. The spoon, with or without a corn, was brought to mouth. In another study, N400 elicited over the parietal region was found to associate with generation and rehearsal of vibration stimuli in the motor-related working memory (Chow et al., 2007). West and Holcomb (2002) found that the anteriorly distributed N400 was associated with viewing series of action cartoon, whilst Paynter, Reder and Kieffaber (2009) revealed that posteriorly distributed N400 was associated with perception and recollection of stimuli in linguistic task.

The results of these studies suggest that N400 probably is associated with general processing of meaningful information which can be semantic, auditory or motor in nature. Debruille (2007) also postulated that the N400 would elicit by all types of meaningful stimuli and its negativity is increased with the intensity of processing of the stimuli.

The relationship between language processing and action representation has been study in recent 10 years. Previous study suggested that a verb with an action content or meaning may modulate the motor area (Rizzolatti & Craighero, 2004). They further explained that the mechanisms involved in perception (such as observation) of action sequences may be similar to those associated with processing of semantic information in language, (Reid et al., 2008).

<u>Late positive component (LPC)</u>

The LPC is a positive-going component elicited at the central and parietal regions within the 520-800 ms time-window relating to to recognition memory (Friedman & Johnson, 2000; Munte et al., 2000). Leynes, Grey and Crawford (2006) related LPC to monitoring and manipulating motor (or action) images (Leynes, Grey & Crawford, 2006). In particular, the more positive-going component peaked at around 600 ms in the parietal region was found to be prominent in old than new sources of motor images. Other studies attributed this to the recollection of information stored in memory (Paller et al., 1995; Wilding, 2000; Wilding & Rugg, 1996). Nevertheless, other studies on action sequencing (Reid and Striano, 2008), motor imagery of human complex action (Naito & Matsumura, 1994) and visual processing and planning of human action (Jin et al., 2011; Proverbio & Riva, 2009) failed to reveal the association with a LPC. The discrepancy in findings on imagery of motor actions can be further explored in this study.

This study used two experimental tasks: image generation and image transformation. The rate limiting step of the image generation task would be on retrieval and generation of the retrieved images of tai-chi forms (presumably kinesthetic images) which would elicit early components such as N100, P200 and N250. The rate limiting step of the image transformation task would be on the maintenance and manipulation of images of tai-chi forms which would elicit later components such as N400 and late positive component (LPC). Details of the task design will be presented in Chapter IV.

Objectives of study

Previous imaging studies investigated motor imagery by comparing either a visual representation (visual motor imagery) or mental stimulation movement (kinesthetic motor imagery) with execution, but those studies did not investigate the both type of the kinesthetic imagery and visual motor imagery. While more recent studies (Neuper et al., 2005; Solodkin et al., 2004) tried to investigate the functional connectivity among different types of motor imagery, but they were unable to reveal the temporal sequencing of the neural process.

This study was designed to gain a better understanding of the mental processes associated with tai-chi by exploring the possible neural processes associated with the visualization associated with tai-chi forms. In this study, tai-chi is conceptualized as mental experiences which might involve mental imagery in particularly visual and motor imagery. This study began with a pilot study which gathered tai-chi masters' information on the mental processes associated with practicing the forms. Findings of this pilot study would help design the imagery tasks used in the main study and comparisons between experienced and less experienced tai-chi masters.

CHAPTER III
PILOT STUDY -
DEVELOPMENT OF TAI CHI QUESTIONNAIRE AND TAI CHI MOTOR IMAGERY QUESTIONNAIRE

This chapter reports the development of two tailor-made questionnaires for the main study - Tai Chi Questionnaire (TCQ) and Tai Chi Motor Imagery Questionnaire (TCMIQ). They were employed in the main study to screen tai-chi practitioners for inclusion. The method of investigation and the psychometric properties of these two questionnaires will be presented.

Background

The purpose of this pilot study was to design two questionnaires for tapping on the variability of practices of tai-chi among its practitioners. It was anticipated that years of experience in practicing tai-chi may not be the most important factor of individual variations among tai-chi practitioners but their competency level in the practice of tai-chi. The main reason is that years of experiences can be confounded by the time spent on and effort put in the practices. In the pilot study, the Tai Chi Questionnaire (TCQ) was constructed to measure the competency level of the practitioners. The Tai Chi Movement Imagery Questionnaire (TCMIQ) was constructed to explore the possible involvement of mental imagery processes when individuals practice tai-chi. The study processes involved: (1) development of the TCQ and TCMIQ; (2) establish evidence on content–related validity of the two questionnaires; and (3) field test for establishing the relationships between tai-chi and mental imagery. The results obtained from this pilot study were used to define and control the behavioral variables in the main study. The findings also formed the basis for designing the experimental motor imagery tasks for this study.

Step 1: Design of the TCQ and TCMIQ

Three tai-chi masters who had more than 15 years of experience in teaching tai-chi were invited to participate in a face-to-face interview. The content of the interview covered obtaining the input from the masters on the content and potential items of the two questionnaires. Before the interview, each master participant was explained the meaning of kinesthetic and visual motor imagery and the definitions of each of the imagery techniques before he was asked to comment on the initial set of items developed by the researcher. The initial set of items for the TCQ and TCMIQ came from reviewing the literature on tai-chi.

Tai Chi Questionnaire

The purpose of the TCQ was to measure individual's competency in practicing tai-chi. The text content should be able to differentiate practitioners who have more experience (such as advanced level) from those who have less experience (such as basic level).

Tai Chi Movement Imagery Questionnaire

The purpose of the TCMIQ was to measure the extent to which tai-chi practitioners would rely on mental imagery during their practices and how likely the mental imagery can be further refined into kinesthetic and visual motor imagery. The test items were likely to consist of processes involved in either type of motor imagery.

Step 2: Establish content–related validity

Expert panel review

An expert panel was composed of six tai-chi masters who had 15 years or more experience in teaching tai-chi. These masters were recruited using convenient sampling from different tai-chi associations in Hong Kong. The panel members were asked to review the relevance of the initial pool of test items proposed for the TCQ and TCMIQ to the constructs underlying each of the questionnaires. After obtaining the consent from the panel members, they were asked to evaluate the items according to a custom-design review form (see Appendix, Form 3). The responses gathered from the panel members were used to guide the revision of TCQ and TCMIQ prior to the field test. During the expert review meeting, panel members were asked to rate each of the items against a five-point Likert Scale with: 1=Totally Disagree and 5=Totally Agree. For ratings which were 3 or below, the panel members were encouraged to give comments and make recommendations on the ways to further improve the content of the items. After the panel members completed the questionnaire, the researcher initiated the discussion among the members so as to confirm the final recommendations for modifying the item content.

Step 3: The field test

Sampling

The target sample of the study was recruited by convenient sampling from Hong Kong Tai Chi association and Zhao Youbin Yang's Taichi Quan Aossociation (Hong Kong). The inclusion criteria were: 1) subject who practiced Tai Chi Quan for at least 1 year; 2) subject's educational level was at least primary and able to read and understand the questionnaire; and 3) subject who did not have any psychotic problem. The TCQ and TCMIQ were administered to the subjects. Besides, the subjects were required to complete the Vividness Visual Imagery Questionnaire (VVIQ) (Mark, 1973), Motor Imagery Questionnaire (MIQ) (Hall, Pongrac and Buckholz, 1985), and Object and Spatial Imagery Questionnaire (OSIQ) (Blajenkova, Kozhevnikov & Motes, 2006).

Measures

The VVIQ is a measure of individual's ability on visualizing visual images. It consists of 16 items subdividing into four subscales (four items in each subscale). The subject was to respond to each item for describing the level of imagination of visual scenes. The vividness of the images of the scenes was rated against a five-point Likert scale. Cui and his colleagues (2007) found that the VVIQ scores correlated with visual cortex activities of the early visual cortex while visualizing visual motor images.

The MIQ is a measure of individual's ability on mentally visualizing movements. It is comprised of 18 items with each depicts movements initiating from a standard starting position to specific movement patterns and acts. The subject was to follow the instructions given in each item and execute the movements. The subject then rated the level of difficulty in visualizing the movements when compared with the actual execution against a seven-point scale.

The OSIQ is a self-reported questionnaire which measures the cognitive styles associated with visual imagery: object versus spatial. Those who are regarded as preferring an object imagery style would construct vivid, concrete and detailed images, whilst those who are regarded as preferring a spatial imagery style would construct spatial relations among objects and perform complex spatial transformations relatively easily.

Data analysis

All the questionnaires and instruments were administered. Factor analysis was conducted for testing the structural validity of the TCQ and TCMIQ. The scores on each of TCQ and TCMIQ were correlated with those from the external criteria: VVIQ, MIQ and OSIQ.

Results of the field test

One hundred and ten questionnaires were sent to the potential subjects and 60 of them were received. Two out of the 60 returned questionnaires were excluded from analysis because of incomplete data. The response rate henceforth was 54%. Among those who returned the questionnaire (N=58), there were 26 males and 32 females. The mean age of male subjects was 50.8 years (SD=7.3 years) whilst the mean age of female subjects was 49.2 years (SD=7.0 years) (Table 3.1). The mean years of subjects practicing tai-chi were 3.9 years (SD=2.2 years) and 4.5 years (SD=1.8 years) for the male and female subjects respectively. No significance differences in the age and years of practice of tai-chi were found between the two gender groups (t-tests, $p > 0.05$).

Table 3.1

Descriptive statistics of age and gender of subjects in the field test

	Gender	N	Mean(SD)	t-values	p-values (2-tailed)
Age (years)	Male	26	50.8(7.3)	.861	.393
	Female	32	49.2(7.0)		
Years of practice	Male	26	3.9(2.2)	-1.043	.301
	Female	32	4.5(1.8)		

Each subject completed five questionnaires: VVIQ, OSIQ, MIQ, TCQ and TCMIQ. The mean scores on the questionnaires are summarized in Table 3.2. No significance differences in all questionnaires were found between the two gender groups (t-tests, $p > 0.05$).

Table 3.2

Mean scores on VVIQ, OSIQ, MIQ, TCQ and TCMIQ

Instruments	Gender	N	Mean (SD)	t-values	p-values (2-tailed)
VVIQ	Male	26	57.9(11.1)	-1.01	.316
	Female	32	60.9(11.3)		
OSIQ-spatial	Male	26	40.4(9.7)	.412	.683
	Female	32	39.2(8.3)		
OSIQ-object	Male	26	44.5(9.8)	-1.135	.264
	Female	32	48.5(10.8)		
MIQ-KI	Male	26	41.4(8.3)	.146	.884
	Female	32	41.0(8.7)		
MIQ_VMI	Male	26	43.2 (10.1)	.089	.930
	Female	32	43.0(7.2)		
TCQ	Male	26	41.1(5.0)	.301	.765
	Female	32	40.6(5.7)		
TCMIQ	Male	26	74.5(14.5)	1.092	.281
	Female	32	67.6(22.7)		

Note:

VVIQ=Vividness of Visual Imagery Questionnaire, OSIQ-spatial = Object and Spatial Imagery Questionnaire-spatial subscale, OSIQ-object = Object and Spatial Imagery Questionnaire-object subscale, MIQ-KI= Motor Imagery Questionnaire-Kinesthetic Motor Imagery

MIQ-VMI= Motor Imagery Questionnaire-Visual Motor Imagery

TCQ = Tai Chi Questionnaire, TCMIQ = Tai Chi Motor Imagery Questionnaire

Construct validity of TCQ and TCMIQ

Tai Chi Questionnaire

Content-related validity of TCQ

The results obtained from the panel review by six tai-chi masters seem to suggest that competence of tai-chi practice had two themes, which were rather independent from one another. The first theme was "competence on external skill (ES)". This theme was commented to be dominated by the ability on mastering the physical form style, such as form appearance and form consistency. The second theme would be "competence on internal skill (IS)". It was commented to be the internal awareness of tai-chi, such as manipulation of mental force. The review panel members suggested further modification to four out of the seven items, which were rated as "3" or below out of the five-point Likert scale (Table 1 in Appendix I). The modification were elaboration of the sentence in order to have a clear understanding and amendment on the tai-chi related term stated by tai-chi master. Such as Item 1 old sentence "我能夠清楚了解太極拳中各式的要求。" "I could clearly understand every requirement in Tai Chi Quan" was changed to "我能夠清楚了解太極拳中各式的動作及外形的要求。" "I can understand the requirement of the form of Tai Chi Quan".

Construct-related validity of TCQ

Explorative factor analysis was conducted using the principal component extraction followed by Varimax rotation on the results of TCQ. Kaiser-Meyer-Olkin measure showed sampling adequacy of KMO = 0.799. Barlett's test of sphericity indicated the appropriateness of the factor model ($p < 0.0001$). The results after the rotation suggested a two-factor solution, which explained 72.8% of the total variance. The two-factor structure was further confirmed by scree-plot (Figure 3.1). The eigenvalues for the 1st and 2nd identified factors were 3.44 and 1.65, respectively. The variances explained were 49.18% and 13.01%. The factor loadings for each of the items onto the two latent factors are presented in Table 3.3.

Figure 3.1

Scree plot of factor analysis on 7 items of TCQ

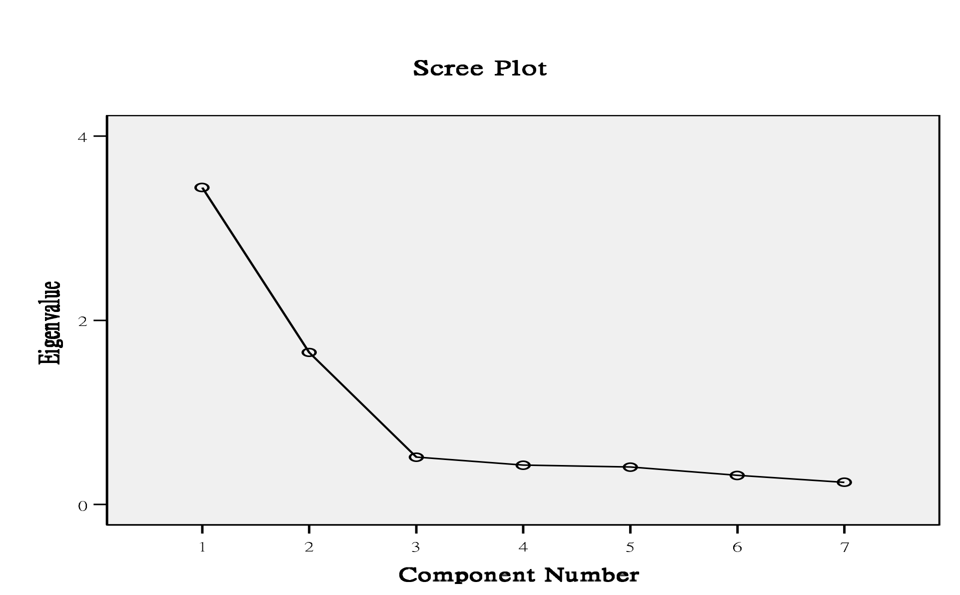


Table 3.3
Factor loadings of the 7 items of TCQ on two identified latent factors.

Items	Factor ES	IS
1. 我能夠清楚了解太極拳中各式的動作及外形的要求。(I can understand the requirement of the form of Tai Chi Quan)	.757	.288
2. 打太極的時候，我能做到全身放鬆，上下相隨。(I can relax my entire body while playing Tai Chi)	.376	.749
3. 每次耍太極時我都清楚知道是否打出正確姿勢。(I know whether I am performing the correct position/ action every time I play Tai Chi)	.825	.327
4. 打太極時，我的專注力會集中在身體內在的感覺。(I can focus the attention on my body feeling while playing Tai Chi)	.103	.850
5. 耍太極時，我會能用意念帶動身體的動作。(I can use my thought to lead my body action while playing Tai Chi)	-.011	.885
6. 我能每次都打出相似的姿勢。(I can perform the same position/ action every time)	.833	-.014
7. 我正在改善一些招式的細微動作，如身體各部份之間的距離及彎曲的角度。(I am doing minor adjustments to some the movements, some of which include the body distance and bending angle)	.859	.013

Note: ES=competence on external skill; IS= competence on internal skill. Underlined factor loadings indicates the factor on which the item is loaded.

The results of factor analysis suggested four items loaded under the first factor, whilst three items were loaded under the second factor. The first factor was suggested to relate to “competence on external skill”. This “competence on external skill” factor related to the detail of the form action like position angle which tai-chi practitioner would be concerned on when practicing tai-chi whereas the second factor was related to “competence on internal skill” such as internal awareness, internal feeling and manipulation of mental force during tai-chi practice.

Item properties of TCQ

Internal consistency of the external skill subscale of TCQ was 0.85 (Cronbach alpha). Item difficult of the four items ranged from .51 to .84, whilst item discrimination index ranged from 0.644 to 0.766 (Table 3.4).

Table 3.4.

Item statistics of external skill subscale of TCQ

Item	Mean	Std. Deviation (SD)	Item Difficulty index	Item discriminative index
Tce1	3.36	1.003	.672	.667
Tce3	3.12	.957	.624	.766
Tce6	3.57	.993	.714	.644
Tce7	4.21	.695	.841	.706

Sample Size N = 58

Internal consistency of the internal skill subscale of TCQ was 0.80 (Cronbach alpha) (Table 3.5). Item difficulty index of the three items ranged from 0.54 to 0.66, whilst item discrimination index ranged from 0.63 to 0.68. No item was required to be deleted or modified for the two subscales of TCQ.

Table 3.5.

Item statistics of the internal skill subscale of TCQ

Item	Mean	Std. Deviation SD	Item Difficulty index	Item discriminative index
Tce2	2.86	1.017	.572	.626
Tce4	3.29	1.140	.659	.648
Tce5	2.71	1.257	.541	.684

Sample Size N = 58

Tai Chi Movement Imagery Questionnaire (TCMIQ)

Content validity

Results suggested that the items covered two separate themes. The first theme was “kinesthetic motor imagery (KI)”. This theme appeared to be related to practice style on using kinesthetic imagery (first person) such as imagine one’s proprioceptive sense. The second theme was “visual motor imagery (VMI)”. This theme appeared to be related to practice style on using visual motor imagery (third person) such as imagine other performing tai-chi for imitation. Six tai-chi masters composed an expert panel which gave further modification to four items rated as "3" or below out of the five-point Liket scale (Table 2 in Appendix I). The modification included elaboration more on the imagery content such as Item 14: old sentence "當我看到或聽到一個太極的式名時（如「野馬分鬃」），我會很容易地呈現有關於該式的動作。" "When I see or listen to a Tai Chi form, I could be easily pop up the related action" changed to new sentence "當我看到一個太極的式名時（如「野馬分鬃」），腦海能不自覺地呈現自己在耍該動作。" "Whenever I see a name of Tai Chi movement (such as 「野馬分鬃」), this action will be pictured in my mind unconsciously.". Or further clarification of the sentence, such as item 17: old sentence "我會很容易地想像太極招式的要求。" "I could imagine the requirement of the Tai Chi form easily" change to new sentence "我能很容易地想像太極招式的要求。(如動作是否到位)" "I can easily imagine the requirement of Tai Chi movement. (such as the accuracy of action)" as tai-chi had a lot of required on the precise movement action.

Construct related validity

Factor analysis was conducted using principal component extraction followed by Varimax rotation on the results of TCMIQ. Kaiser-Meyer-Olkin measure showed sampling adequacy of KMO = 0.761. Barlett's test of sphericity indicated the appropriateness of the factor model ($p < 0.01$). The method of extraction used principle component and varimax rotations. The result indicated a possible two-factor solution which explained 65.8% of the total variance. The two-factor structure was further confirmed by the scree-plot (Figure 3.2). The eigenvalues for the 1st and 2nd factors were 7.17 and 2.05. The variances explained were 51.20% and 14.62%. The factor loading of each of the items onto the two latent factors are presented in Table 3.6.

Figure 3.2.

Scree plot of factor analysis on 14 items of TCMIQ

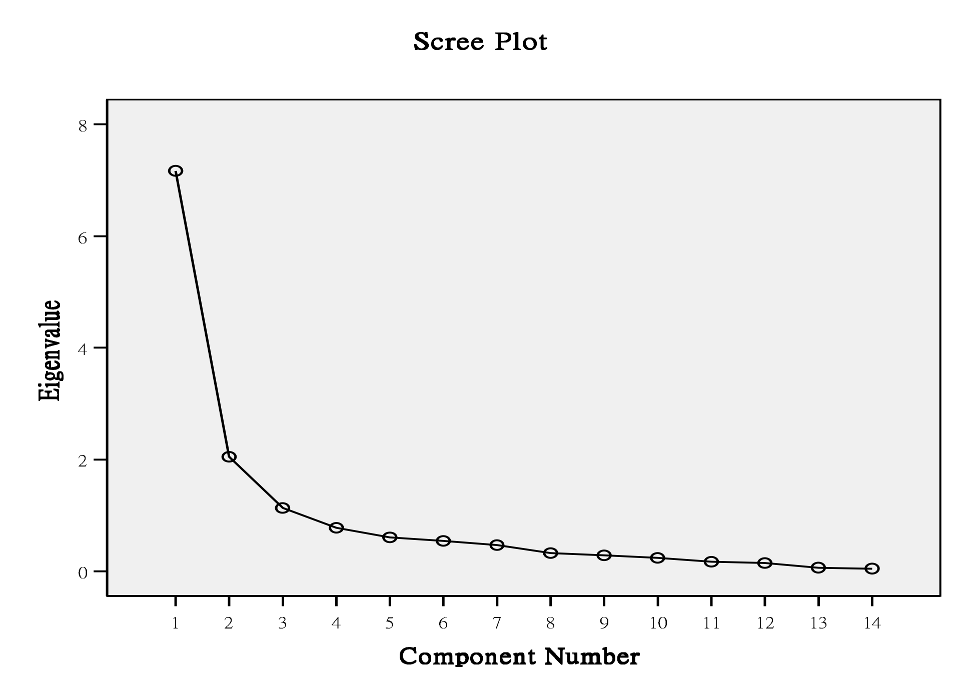


Table 3.6.
Principal component loadings, after varimax rotation, of the TCMIQ items

Items	Factor KI	VMI
1. 打太極的時候，我習慣在腦海中呈現一個接一個的動作。(I used to picture/ project the action series in my mind while playing Tai Chi)	.614	.316
2. 我能很容易地想到別人(如師父)在耍太極。(I can easily think of others (like the master) playing Tai Chi)	.214	.681
3. 平日有些時候，我會在腦海中默想自己在耍太極。(I will image myself playing Tai Chi in my mind at times	.737	.259
4. 我能很容易地想像別人耍太極的影像，而且影像清晰鮮明。(I can easily think of the images/ pictures of others playing Tai Chi. The images/ pictures appear to be very real and clear)	.288	.561
5. 我能很容易地想像打某一招式時，身體動作的感覺。(I can easily imagine the body feeling as if I were playing a certain movement)	.882	.005
6. 我很容易地想像自己在打太極。(I can easily imagine I am playing Tai Chi)	.816	.358
7. 當我在溫習一個新的動作或招式，我會在腦海呈現第三者(如師傅，或別人)在打該式的影像。(My mind will flash the image of another person (like master or others) playing the same new movement or action while I am revising it)	.277	.781
8. 當看到別人在打太極的招式時，我能很容易地想像他接下來要出的動作。(I can easily imagine the person’ s next action while I see him playing Tai Chi movement)	.371	.661
9. 我能在腦海中不自覺地呈現出自己在打太極時的情況。(Images of myself playing Tai Chi can appear in my mind unconsciously)	.683	.296
10. 我能容易地呈現出別人在耍太極的清晰及鮮艷的影像。(I can easily picture clear images of others playing Tai Chi)	.080	.869

Table 3.6. (continue)

11. 我能很容易地想像太極招式的要求。(如動作是否到位) (I can easily imagine the requirement of Tai Chi movement (such as the accuracy of action)	.336	<u>.718</u>
12. 我可以在腦海中呈現第三者(如師傅)在打太極的招式。 (I can picture another person (like the master) playing Tai Chi movement in my mind)	.125	<u>.880</u>
13. 我能容易地呈現自己打出一個接一個的太極動作。(I can easily picture myself performing a series of Tai Chi actions)	<u>.879</u>	.257
14. 當我看到一個太極的式名時（如「野馬分鬃」)，腦海能不自覺地呈現自己在耍該動作。(Whenever I see a name of Tai Chi movement (such as “野馬分鬃” *je5 maa5 fan1 zung1* (Cantonese)), this action will be pictured in my mind unconsciously)	<u>.786</u>	.270

Notes: KI = Kinestheic Motor Imagery, VMI = Visual Motor Imagery. Underlined type of factor loading indicated the factor on which the item is loaded most highly

<u>Item analysis of TCMIQ</u>

Internal consistency of the KI subscale of TCMIQwas 0.92 (Cronbach alpha) (Table 3.7). Item difficulty of the seven items ranged from 0.61 to 0.73, whilst the item discrimination index ranged from 0.57 to 0.87.

Table 3.7.

Descriptive statistics of TCMIQ-KI sub-items

Item	Mean	Std. Deviation <u>SD</u>	Item Difficulty index	Item discriminative index
tc1	3.67	1.082	.734	.566
tc3	3.03	1.389	.607	.733
tc5	3.76	.904	.752	.752
tc6	3.38	1.254	.676	.870
tc9	3.19	1.162	.638	.693
tc13	3.45	1.187	.690	.872
tc14	3.62	1.121	.724	.734

Sample Size N = 58

Internal consistency of the VMI subscale of TCMIQ was 0.89(Cronbach alpha) (Table 3.8). Item difficulty of the seven item ranged from 0.60 to 0.75, whilst the item discrimination index ranged from 0.58 to 0.82.

Table 3.8.
Descriptive statistics of TCMIQ-VMI sub-items

Item	Mean	Std. Deviation SD	Item Difficulty index	Item discriminative index
tc2	3.83	1.365	.766	.636
tc4	3.43	1.061	.686	.552
tc7	3.52	.978	.703	.755
tc8	3.45	1.157	.670	.658
tc10	3.33	.925	.666	.790
tc11	3.17	.994	.634	.663
tc12	3.62	1.152	.724	.798

Sample Size N = 58

Cluster analysis of TCO and TCMIQ

All the test results of 58 participants on TCQ and TCMIQ were entered into a two-step cluster analysis. Two clusters were identified using the Smallest Schwarz's Bayesian criterion (BIC) =175.68, ratio of BIC changes = 1.00 and ratio of distance measure = 1.41. Among them, 21 participants (36.2%) were grouped within cluster 1 and 37 (participants (63.8%) were grouped within cluster 2. The descriptive results of the four grouping variables are presented in Table 3.9. There was no significance differences revealed in age of the participants between the two cluster groups (t-tests, $p > 0.05$).

Table 3.9.

Result of cluster analysis using TCQ and TCMIQ results on classifying TC participants.

Subscale	Cluster group	Mean	SD	T score
TCQ – ES	Cluster 1	4.30	.25	8.172***
	Cluster 2	3.11	.64	
TCQ – IS	Cluster 1	3.21	.71	2.849**
	Cluster 2	2.59	.82	
TCMIQ - KI	Cluster 1	4.27	.48	6.653***
	Cluster 2	2.97	.82	
TCMIQ - VMI	Cluster 1	4.08	.46	4.790***
	Cluster 2	3.14	.83	
Age	Cluster 1	51.00	8.75	.386
	Cluster 2	49.30	6.04	
Year of practice	Cluster 1	5.00	2.41	2.331*
	Cluster 2	3.78	1.57	

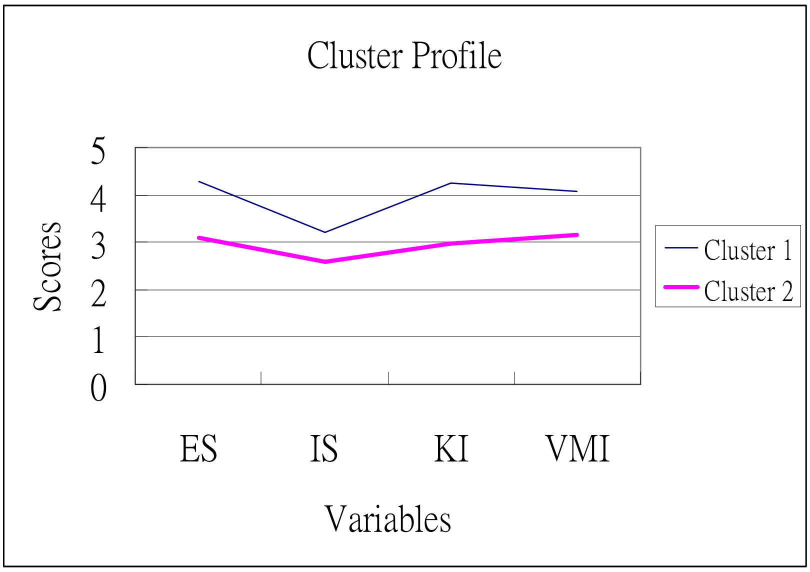
Note: TCQ-ES refers to Tai Chi Questionnaire – external skill, TCQ-IS refers to Tai Chi Questionnaire – Internal skill, TCMIQ –KI refers to Tai Chi Movement Imagery Questionnaire –Kinesthetic Imagery, TCMIQ –VMI refers to Tai Chi Movement Imagery Questionnaire –Visual motor Imagery

$*p < 0.05$, $**p < 0.01$, $***\ p < 0.001$

Cluster profile for the two grouped indicated that participants in cluster 1 scored higher on all TCQ and TCMIQ subscales than those in cluster 2 (Figure 8). There were significant differences in the year of practice between the two groups (t (1, 56) = 2.331, $p < 0.050$) with the mean years of practice was 5.00 years (SD= 2.41) and 3.78 years (SD = 1.57) for the cluster 1 and 2 groups, respectively. These results tend to suggest that cluster 1 was likely to be composed of masters level tai-chi practitioners whilst cluster 2 was likely to be composed of beginner level tai-chi practitioners.

Figure 3.3.

TCQ and TCMIQ profiles of cluster 1 and 2 groups



Note: Cluster 1 was likely to be composed of master level TC practitioners and cluster 2 was likely to be composed of beginner level TC practitioners.

A 2 (TCQ) × 2 (TCMIQ) × 2 (cluster group) repeated measure MANOVA was conducted to investigate the possible interaction effects among the TCQ and TCMIQ results and the cluster groups. TCQ (external skill, internal skill), TCMIQ (kinesthetic imagery, visual motor imagery) were the within-subjects factors, and the subject group (master group, beginner group) was the between-subject factor.

Significant TCQ ($F(1,56) = 9.29$; $p = .004$] and TCMIQ ($F(1,56) = 22.60$, $p < .0001$] main effects were found. Result further indicated significant interaction effects between TCMIQ and cluster group ($F(1,56) = 7.33$, $p < 0.01$). Participants in the master group tended to rate higher on the KI than VMI subscale in TCMIQ, whilst the beginner group tended to rate higher on the VMI than KI subscale in TCMIQ. No significant differences were revealed between the scores on the TCQ, TCMIQ and cluster groups.

Discussion

The purpose of these two questionnaires was to describe and quantify kinesthetic experience of tai-chi practitioners recruited in the main study. Previous studies indicated that neural processes associated with the performance of tasks would change after learning through practices on the task (Kelly & Garavan, 2005). These observations were further substantiated in a study on professional sportsmen, which associated differences in neural activities with performance on motor tasks

(Wei & Luo, 2009). The changes in behaviours as results of plastic changes in the brain can be measured with self-report questionnaires.

The findings suggested that TCQ had a two-factor structure: competence on external skill (ES) and competence on internal skill (IS). The result revealed that tai-chi practitioners with less experience expressed more competence on the external skill (ES) such as general appearance of the form, the form sequence and details on the limbs and body movement but not on the internal skills (IS). In contrast, tai-chi practitioners with more experience expressed competence on both ES and IS. For example the internal skill could be the abilities in control the equilibrium of static/moving, active/passive, tension/relaxation, forceful/yielding through the integration of "意" ji3 (Cantonese)(Liang & Wu idea cited in Li et al., 2003, p.207). According to the learning theory, people will usually learn task through imitation or coping the appearance first. This step could be classify as "external skill" in our questionnaire then practitioner would focus on refinement of internal processes to improve the movement such as speed, precision and mental intention "用意不用力" *jung6 ji3 bat1 jung6 lik6* (Cantonese) especially for practicing tai-chi forms.

The purpose of TCMIQ is to differentiate the tendency of tai-chi practitioners performing on different types of motor imagery (KI and VMI). Previous studies investigated motor skill learning between expertise and novice learners on tango dancing, playing piano (Elbert et al., 1995; Haslinger et al., 2004) and diving (Wei and Luo, 2009). Experts were found to be more familiarize with and use kinaesthetic motor imagery, while novices tended to use visual motor imagery. All these previous evidence further support our findings that the two groups of individuals experts and novices can be differentiated. Participants with more experience in tai-chi tended to rate higher on the KI than VMI subscale in TCMIQ, whilst the participants with less experience tended to rate higher on the VMI than KI subscale in TCMIQ. To conclude, the result from these two questionnaires provided further information on the competency level on practice of tai-chi, subjects belonging to the more experience group were recruited for participating in the main study.

CHAPTER IV
METHOD OF MAIN STUDY

The main study - ERP on visualization involved in tai-chi

Sampling

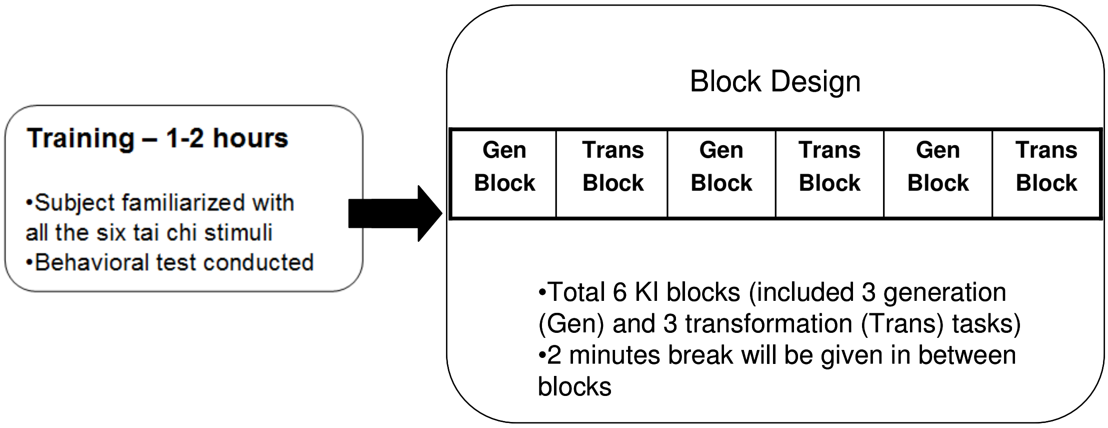
Sixteen participants with experience in practicing tai-chi (called practitioners) and 20 non tai-chi practitioners participated in the main study. All subjects were right-handed and with no prior experience in engaging in locomotion or mental imagery related experiments. Participant's gender, age and educational level were matched between the groups. All participants did not have a known history of neurological or psychiatric illness. The tai-chi practitioners did not have experience practicing *Yang* style tai-chi forms. This was to minimize the memory and/or practice effect biased against the non tai-chi group as the experimental task used *Yang* style forms. The purpose of the experiment and the rights as a subject in the study was explained. Informed consent was obtained before commencing the experiment. All participants received a small sum of cash for compensating the costs of transportation for attending the session at the Applied Cognitive Neuroscience Laboratory, The Hong Kong Polytechnic University.

Experimental procedures

All subjects completed the TCQ, TCMIQ, VVIQ, MIQ and OSIQ before engaging in the experimental tasks. The schedule of the experiment is summarized in Figure 4.1. Prior to performing the experiment tasks, each subject received one to two hours of training. The training involved learning the names and content of the tai-chi forms employed in the experimental tasks. Subjects were tested on the level of familiarization of the names of the forms and the first person representations of these forms. The criterion for passing the training was set at 80% accuracy rate. The subject would commence the experiment after meeting the performance criterion.

Figure 4.1.

Summary of the ERP experiment



Note: Gen Block refers to Image Generation Block and Trans Block refers to Image Transformation Block.

<u>Training of tai-chi forms</u>

Tai-chi experts were invited to select the tai-chi form with similar complexity and difficulty level with ranged from 3.6 to 4.3 in the 5-point scale. According to previous study, all the tai-chi forms with only unilateral bodily movement were excluded out because of the difference ERP waveforms if we only select either left hand or right foot (Morash et al., 2008). Six tai-chi forms with bilateral hand and foot movement were selected for preparing the tai-chi stimuli. Each subject was shown the names and actions involved in this six tai-chi forms: "白鶴亮翅 baak6 hok6 loeng6 ci3"，"摟膝拗步 lau4 sat1 aau3 bou6"，"野馬分鬃 je5 maa5 fan1 zung1"，"左下勢 zo2 haa6 sai3"，"攬雀尾 laam5 zoek3 mei5"，"雲手 wan4 sau2" (in Cantonese). The abbreviated names of these forms were used in the experimental task. The subjects were required to associate the abbreviations (which were new to the subject) with the forms. An example of the abbreviated name is "攬雀尾 *laam5 zoek3 mei5*" as "攬 *laam5*". The principles for setting up the abbreviation were that it had face-validity and were made of only one single Chinese character. The subject was shown the full name of the form and its abbreviation on a computer screen at least for five times. The subject was to learn the content. The researcher repeated the procedure on the next form after the subject indicated confidence with the learning. The learning of the form took place after the subject showed mastery of the full and abbreviated names association. Learning of a tai-chi form involved the subject to memorize in detail the sequence of movements of body and upper/lower limbs in four-second duration. The subject was shown the playback of a four-second video clip which captured physical movement specific to one form. Each video clip was shown at most two times to the subject in order to minimize the visual memory effect. The subject was required to attend to the details of body/limb positions and their changes throughout the four-second clip. To facilitate learning, the subject was offered the opportunity to actually practice on the form by following standard verbal descriptions and instructions on the body/limb positions. The fundamental principle was that the subject practiced without relying on viewing how others were acting on it (including the video playback). The subject was reminded to focus on the movements in the elbows, hands, knees, and ankles. At the time when the subject performed on the form, s/he was instructed to associate the one-second rhythm with the movements by counting "One" during the first (1st) second, "Two" during the second (2nd) second, "Three" during the third (3rd) second, and "Four" in the last second of movements. The reason for training the temporal-rhythm when learning the physical movements of each forms was that the subject would require extracting images appeared at different timeline of a form in the experimental task.

The training would end when the subject indicated confidence in memorizing the body movements and postures in each form. A behavioral test was conducted in which the subject was required to answer questions related to the details of the body/limb positions. The subject then practiced on the experimental tasks by completing 30 image generation trials and 30 image transformation trials. Subject was to repeat practice on the trials if not attaining 80% or higher accuracy.

Task design

The experimental task was constructed with Stim^2 software (NeuroScan Inc., Herndon, VA, USA). It was composed of two sub-tasks. They were the kinesthetic tai-chi image generation task (called image generation task) and kinesthetic tai-chi image transformation task (called image transformation task). The image generation task had the subject generate a kinesthetic image of a tai-chi form, which represented the start of the form, i.e. zero second. The image transformation task had the subject search for a kinesthetic image which corresponded to a specific temporal sequence of a form, e.g. 3rd second of the "攬" *laam5* (Cantonese) form. The design of the experimental task followed a block design with one image generation task block followed one image transformation task block. There were three paired blocks totaling six task blocks. There was a two-minute rest break in between the two task blocks (Figure 4.1). Each block had 60 trials. The 180 trials covered 8 body-parts x 6 Tai Chi forms. Each trial would repeat 2 to 4 times. The duration of the experiment task was around 54 minutes.

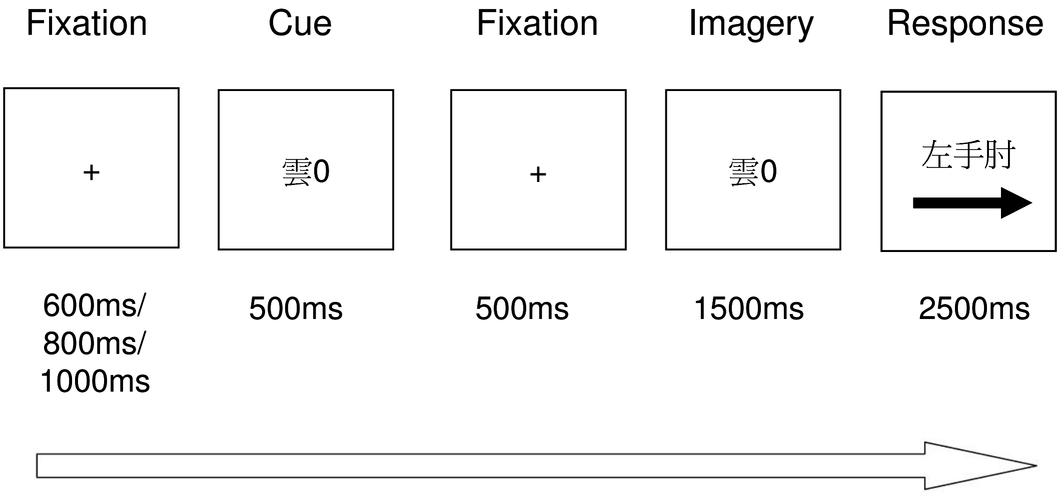
Kinesthetic image generation task

A trial began with a fixation point “+” appearing at the center of the screen, which lasted for 600, 800 or 1000 ms (in random order across the trials). The subject was prompted by a single-Chinese-character and a number such as “雲 0” indicating the “雲手” *wan4 sau2* (Cantonese) form, previously learnt in the training, and “0” timing of the movement sequence, which was the starting posture of the form. This visual cue was presented for 500 ms. This was followed by a second fixation point “+” appeared at the center of the screen, which lasted for 500 ms. The single-Chinese-character “雲 0” reappeared and lasted for 1500 ms. A 2,500 ms visual cue was presented, which indicated the direction of a specific body part such as ”左手肘” → meaning “left elbow pointing to the right” (Figure 4.2). The subject was then to indicate whether the designated body part (i.e. the left elbow) in the motor image generated for the “雲手” form would have pointed according to the direction shown on the screen (i.e. right direction) as “Yes” or “No” by pressing on the left and right buttons on the keyboard respectively (Figure 4.2).

During the trial, the subject would generate an image of the starting posture of a designated form according to the single-Chinese-character and zero time. This would involve access to the long term memory for recalling the abbreviation of the name of the form, the movements associated with the form, and the starting posture appeared at the beginning of the form. These processes were anticipated to occur during the 1,500 ms presentation of the single-Chinese-character. This was followed by a detailed visualization of the designated body part on the image generated previously of which the subject was asked to judge its spatial orientation. It was expected that the visualization of a Tai Chi form was in the form of higher resolution. This would enable the subject to make a valid response on the limb position involved in the form. It was also anticipated that the subject would tap on kinesthetic imagery as the experience gained in learning the forms involved 1st person practiced without an visual input.

Figure 4.2.

A typical trial in the image generation task.



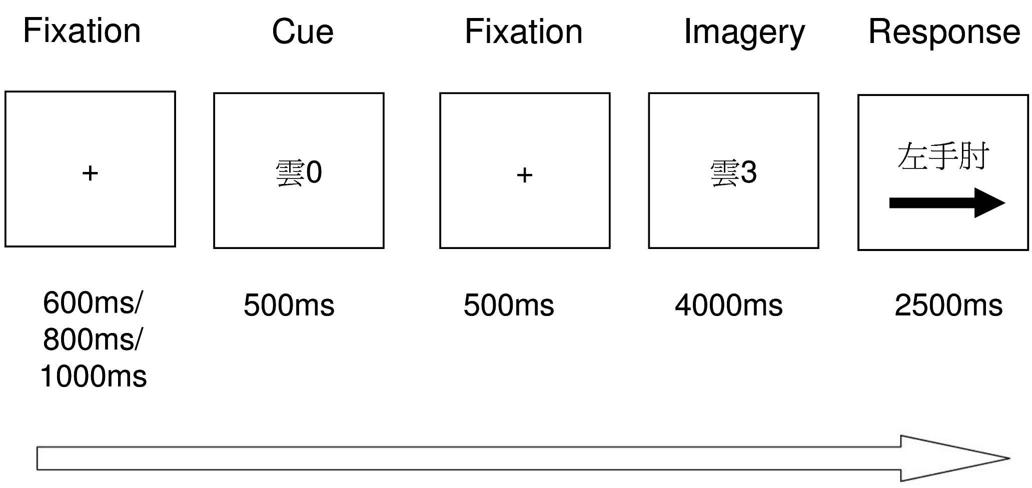
Kinesthetic image transformation task

A trial began with a fixation point "+" appearing at the center of the screen which lasted for 600, 800 or 1000 ms (in random order across the trials) (Figure 4.3). Similar to the image generation task, the subject was prompted by a zero-time single-Chinese-character such as "雲 0. This was followed by a second fixation point "+". Different from the image generation task, the second single-Chinese-character coupled with a time such as "雲 2" was presented, with "2" referred to the 2nd in the four-second movements in the form. The presentation of this timed single-Chinese-character "雲 2" stipulating the instance when the subject was to end the kinesthetic imagery which lasted for 4000 ms. Afterward, the subject saw a 2,500 ms visual cue, which indicated the direction of a specific body part such as "左手肘" → meaning "left elbow pointing to the right" (Figure 4.3). The subject was then to make the response by pressing on the keyboard.

Similar to the image generation task, at the beginning of the trial, the subject would undergo the processes with which the starting posture of a form was generated once when the zero-time single-Chinese–character stimulus was shown. Different from the image generation task, the subject when presented with the timed single-Chinese-character stimulus (i.e. "雲 2") would need to generate the series of images progressing from zero time to 2nd second. It was anticipated that the subject would tap long term memory for the series of body movements corresponding to the form and transform them into their working memory until the end of the 2nd second. These image generation and transformation processes were anticipated to occur during the 4000 ms presentation of the second single-Chinese-character stimulus. The response to be made by the subject after the transformation process was similar to that of the generation task. This would involve high resolution visualization of the designated body on the image maintained from the earlier part of the trial.

Figure 4.3.

A typical trial in the image transformation task



Experimental apparatus and setup

<u>Construction of stimuli</u>

A Tai Chi master having more than 15 years of practice experience was invited to demonstrate six *yang*-style Tai Chi forms. The performance of the master on each of the designated forms was recorded with a video camera (Sony DCR-PC10E). The video clips were edited and condensed into four-second clips. The zero, 1st, 2nd, 3rd and 4th second snapshots were extracted. Both the video clips and snapshots were used in the training and experimental task respectively.

<u>Position of subjects in ERP study</u>

In the actual experiment, the subject sat in a fixed and comfortable armchair in front of a 17 inches CRO monitor at a distance of 1.3 m, inside an electrically shielded soundproof chamber located in Applied Cognitive Neuroscience Laboratory of The Hong Kong Polytechnic University. Before each task condition, verbal instructions were given and 60 training trials were presented to the subject. The subject was reminded to assume a relaxed posture with the eyes open and to avoid any body movements during the experiment. The responses made by the subject were recorded and monitored by the STIM software.

Acquisition of event-related potential (ERP)

EEG recording

Scalp voltages of the subject were recorded using a 128 channel electrocap array of silver-silver chloride electrodes placed in an extended International 10-20 System (Jasper, 1995). The nasion-inion distance of the subject's head was measured and an appropriate cap was selected for use on subject. The researcher placed a tape on head to measure the distance between the landmarks of nasion (the indentation between the forehead and the nose) and the inion (the bony protuderance at the back of head near the occipital region). Besides, the left-right distance of the head was measured by placing the tape between the left and right periauricular points (the indentations just above the cartilage covering the external ear opening).

The cap was placed on the subject's scalp with the edges lain at a level at 10% of the nasion-inion distance. The vertex electrode (marked as "ref" in the cap between electrodes 63 and 64) was located at the junction half of the left-right measurement. The ground electrode was set between electrodes 59 and 60. The NuAmps Digital DC EEG Amplifier (NeuroScan Labs, Sterling, VA) was used for capturing the electrical activities of the brain over the scalp.

Bipolar vertical electro-oculogram (VEOG) was used for monitoring subject's eye movements. Electrodes recorded the vertical activity of the eyes were placed at the supra-orbital notch and infra-orbital notch positions over the left eye. Bipolar horizontal electro-oculogram (HEOG) was used by attaching one electrode to the left and one electrode to the right orbital rims to record the left-right activity of the eyes. Two reference electrodes were attached to left and right mastoid processes. Electrical activities captured from electrodes on the scalp were referenced to the average of those recorded from these two electrodes. The signals were amplified with a band-pass filter of 0.1 – 100 Hz and sampled at a rate of 1024 Hz. Electrode impedance was kept at < 5 kΩ.

Data preprocessing

Online signal acquisition and offline data preprocessing used Scan 4.3 software (NeuroScan Inc, Herndon, VA, USA). Data preprocessing included linear derivation adjustment to the data, data filtering, ocular artifact correction, segmentation, noise reduction, baseline correction and averaging. The continuous EEG was filtered with band-pass "zero phase shift" filter with 0.5 Hz (high-pass) and 30Hz (low-pass), 24 dB/oct. The filtered EEG was corrected for ocular artifact with the regression algorithm available in Scan 4.3 software.

Noise reduction of ERP data

The EEG signals captured in this experiment were prone to contamination with non-biological and biological artifacts. In this study, data capturing was conducted in a sealed room in order to minimize the non-biological artifacts such as those signals originated from computer monitors, overhead lighting, intercom and power cables. Subjects were instructed to minimize body movement, fix their eyes on the screen, avoid excessive eye movement. Subjects were reminded to relax as much as possible during the data capturing. This would minimize biological artifacts such as electromyographic (EMG) activities that occurred near the recording sites arising from gross head/ body movement or eye blinking. The noise due to eye movements was reduced by conducting artifact rejection and averaging process. Epochs with voltage exceeding -100 to +100 μV were rejected. The ocular artifacts associated with eye blinks were removed using the combined regression analysis and averaging method which proposed by Semlitsch, Anderer, Schuster, and Presslich (1986), and Picton et al. (2000). This method assumes that the potential associated with ocular artifacts is a linear function of EOG. The signals captured from the ocular electrodes that exceeded 10% of the maximum eye movement potentials were averaged. Transmission coefficients can be computed as follows:

$$b = \text{covariance (EOG, EEG) / variance (EOG)}$$

where b is transmission coefficient. EOG was subtracted from the EEG channels on a sweep-by-sweep, point-by-point basis as follow:

$$\text{Corrected EEG} = \text{Original EEG} - b \bullet \text{EOG}$$

Data epoch

Trials with correct responses were identified and included in the analysis. For the image generation task, the epoch was cut 200 ms before presentation of the second single-Chinese-character stimulus (lasted for 1500 ms, Figure 4.2) till 1000 ms after the presentation of the stimulus. For the image transformation task, the epoch was cut 200 ms before the second timed single-Chinese-character stimulus (lasted for 4000 ms, Figure 4.3) and 1000 ms after the presentation of this stimulus. Trials with artifacts were rejected if their amplitude voltage was larger than 100 μV or smaller than -100 μV were rejected before the averaging. Averaging of the ERP signals was conducted for each of the image generation and transformation conditions. The averaged ERPs were then baseline corrected against the pre-stimuli interval (-200ms). The ERP signals were averaged across all subjects to form grand mean waveform. Average reference signal was sum of the activity recorded in all channels divided by the number of channels. The grand mean ERPs were then rescaled against this average reference signal.

ERPs capturing

Mean amplitude was the method used to obtain the amplitudes of ERP components. The advantages of using mean amplitude are: 1) less sensitive to high frequency noise than peak amplitude measure; and 2) mean amplitude would reduce biases due to long time window (Luck, 2005).

Sources localization of the ERP components

Source localization was conducted to estimate dipoles associated with various components elicited during the image transformation process with CURRY 5 (NeuroScan Inc., Herndon, VA, USA). A boundary element method (BEM) head model was used in the computation process. Iterations were performed to minimize the residual variance (RV) between the model and the observed ERP components. Localization of the dipoles was based on the online Talairach applet (talairach.org)

Statistical analysis

Analysis of variance models were constructed to test the differences in the electrical activities elicited by the image generation and image transformation tasks between the subjects in the tai-chi and non tai-chi groups. A two-way repeated measure ANOVA: Group (tai-chi and non tai-chi) x Site (Fz, Cz, CPz, Pz and Oz) was conducted to test the differences in latency and amplitude of the electrical activities captured at specific midline electrodes between the two groups.

A three way repeated measure ANOVA: Group (tai-chi and non tai-chi) x Laterality (left and right) x sites (F3, C3, CP3, P3, O3, F4, C4, CP4, P4 and O4) was conducted to test the differences in latency and amplitude of the electrical activities over the specific sites between the two groups.

Pearson's correlation correlations were computed to explore the relationships between the years of practice and the amplitudes of the significant ERP components, and between the scores on the TCMIQ and the amplitudes of the significant ERP components among the tai-chi subjects.

All statistical analyses were computed by SPSS 18.0. The significant level for was set as $p \leq 0.05$. For all within-subject effects in the repeated measure ANOVA, Greenhouse-Geisser was reported to correct the significance to compensate for the violation of sphericity. Bonferroni adjustments were applied to the significance levels of all post-hoc comparison among electrode sites which was $p \leq 0.010$.

CHAPTER V

Main Study Result

Introduction

This chapter is divided into four parts. The first part presents the demographic characteristics of the subjects, scores on the questionnaires and the results of the subjects' performance on the behavioral tasks. The second part presents the identification of the ERP components in the image generation and transformation task conditions. The third part represents the comparison of the ERP waveform for the image generation and transformation task conditions between subjects in the tai-chi and non tai-chi groups. The fourth part presents the relationship between the years of practice and the ERPs electrical activity.

Demographic characteristics of subjects

Sixteen subjects with experience of practicing tai-chi were recruited as members of the tai-chi group (8 males, 8 females, mean age = 46.4, SD = 6.7). Their mean year of practice was 13.9 years (SD=8.8 years). The non tai-chi group was composed of 20 healthy adults (8 males, 12 females, mean age = 44.8, SD = 12.7) who did not have experience practicing tai-chi prior to the study. There was no significant difference in age ($t(34)=0.47$, $p=0.645$) between the tai-chi and non tai-chi groups. The educational level of subjects between the two groups was not significantly differed ($t(34)=-0.59$, $p=0.562$). All tai-chi practitioners completed the TCQ and TCMIQ and were categorized as tai-chi masters as defined by the two questionnaires. Subjects in tai-chi group rated 3 or above on all items in the TCQ and TCMIQ. The scores on TCQ-ES were slightly higher than those on TCQ-IS; whilst the scores on TCMIQ-KI were higher than those on the TCMIQ-VMI. No significant gender differences were revealed in the scores on these questionnaires: TCQ-IS ($t(14)=-1.11$, $p=0.287$), TCQ-ES ($t(14)=0.82$, $p=0.428$), TCMIQ-KI ($t(14)=0.70$, $p=0.493$), TCMIQ-VMI ($t(14)=1.81$, $p=0.092$) (Table 5.1).

Table 5.1.

TCQ and TCMIQ scores of subjects in the tai-chi group (male: n=8, female: n=8)

	Gender	Mean (SD)	t	*p*
TCQ-IS	Male	9.9(2.6)	-1.11	0.287
	Female	11.2(2.3)		
TCQ-ES	Male	14.5(4.0)	0.82	0.428
	Female	13.3(1.6)		
TCMIQ-KI	Male	28.1(2.1)	0.70	0.493
	Female	27.3(2.8)		
TCMIQ-VMI	Male	27.6(2.0)	1.81	0.092
	Female	25.3(3.1)		

Note: TCQ-ES refers to Tai Chi Questionnaire – external skill, TCQ-IS refers to Tai Chi Questionnaire – Internal skill, TCMIQ –KI refers to Tai Chi Movement Imagery Questionnaire –Kinesthetic Imagery, TCMIQ –VMI refers to Tai Chi Movement Imagery Questionnaire –Visual motor Imagery

Results on imagery questionnaires

VVIQ

The mean scores on VVIQ of subjects in tai-chi group was 54.0 (SD=9.5) and that of subjects in non tai-chi group was 58.3 (SD=8.0). No significant differences in the scores on the VVIQ scores were found between the two groups (t(34)=-1.48, *p*=0.149).

MIQ-C

The mean scores on MIQ-KI of subjects in tai-chi group was 37.9 (SD=13.0) and that of subjects in non tai-chi group was 40.4 (SD=8.3). The mean scores on MIQ-VMI of subjects in tai-chi group was 41.3 (SD=7.4) and that of subjects in non tai-chi group was 42.4 (SD=9.1). No significant differences in the scores on the KI and VMI subscales of MIQ-C were found between the two groups (t(34)=-0.37, *p*=0.712 and t(34)=-0.69, *p*=0.492 respectively) (Table 5.2). The correlations between the scores on the two subscales were strong and statistically significant for both tai-chi (r=0.73, *p*=0.001) and non tai-chi group (r=0.85, *p*<0.001).

Table 5.2.

Scores on the MIQ-C subscales of subjects in tai-chi and non tai-chi groups

		Mean (SD)	t	*p*
MIQ-KI	Tai-chi	37.9 (13.0)	-0.60	0.550
	Non tai-chi	40.4 (8.3)		
MIQ-VMI	Tai-chi	41.3 (7.4)	-0.94	0.355
	Non tai-chi	42.4 (9.1)		
Pearson's correlation between KI and VMI	Tai Chi	r = 0.73		0.001
	Non Tai Chi	r = 0.85		<0.001

Note: VMI refers to visual motor imagery subscale; KI refers to kinesthetic imagery subscale.

Behavioral results of experimental task

All subjects managed to attain an accuracy rate 83% or above (Table 5.3). The mean accuracy rates of subjects in the tai-chi and non tai-chi groups on the image generation task were 89.7% and 86.5% respectively; and their reaction times were 1744.0 ms and 1607.3 ms respectively. Similarly, the mean accuracy rates of subjects in the tai-chi and non tai-chi groups on the image transformation task were 86.8% and 83.3% respectively; and their reaction times were 1890.4 ms and 1840.3 ms respectively. The results indicated that the tai-chi group had significant higher accuracy rates in both the image generation ($t(34)= 2.93$; $p=0.006$) and transformation tasks ($t(34)= 3.12$; $p=0.004$) than non tai-chi group. In contrast, tai-chi group performed significantly slower on the image generation ($t(34)= 5.35$; $p< 0.001$) and transformation tasks ($t(34)= 2.44$; $p=0.020$) than non tai-chi group.

Table 5.3.

Mean accuracy rate and reaction time of subjects in tai-chi and non tai-chi groups on the image generation and transformation tasks

Tasks	Groups	Mean (SD)	t	*p*
Image Generation RT (ms)	tai chi	1744.0 (95.8)	5.35	<0.001
	Non tai-chi	1607.3 (55.9)		
Image Transformation RT (ms)	tai chi	1890.4 (51.2)	2.44	0.020
	Non tai-chi	1840.3 (51.9)		
Image Generation accuracy rate (%)	tai chi	89.7 (3.6)	2.93	0.006
	Non tai-chi	86.5 (4.3)		
Image Transformation accuracy rate (%)	tai chi	86.8 (4.7)	3.12	0.004
	Non tai-chi	83.3 (1.6)		

Note: RT = reaction time; degree of freedom of all t-values is 0.05.

Identification of ERP component

The peak identification was based on the largest amplitude differences found in comparisons of the waveforms between the tai-chi and non tai-chi groups. The peak latency method was used to obtain the latency of the grand averaged N100, P200, N250 and N400 components whilst the component-of-interest method (Picton et al., 2000) was used for obtaining the latency of the late positive component (LPC). The reason for using the latter method was that there were no obvious peaks identified in the LPC grand-averaged morphology.

The electrical activity captured was within pre-stimuli 100 ms to post-stimuli 1000 ms in each trial. The identification of the five ERP components was first based on the following latency: N100 (80-155 ms), P200 (150-290 ms), N250 (270-400 ms) and N400 (375-520 ms) and LPC (520-800ms) reported in Luck (2005). The time-windows set for inspecting the peak amplitude of each component were $\pm$2 SD of the mean latency revealed for the N100, P200, N250, N400 and LPC. The amplitudes and latency of each component were then obtained. The between-group and between-condition analyses were based on a 3 x 5 electrode site montage. They were midline (Fz, Cz, CPz, Pz and Oz), left hemisphere (F3, C3, CP3, P3 and O3) and hemisphere (F4, C4, CP4, P4 and O4).

Tai-chi and non tai-chi groups on image generation task

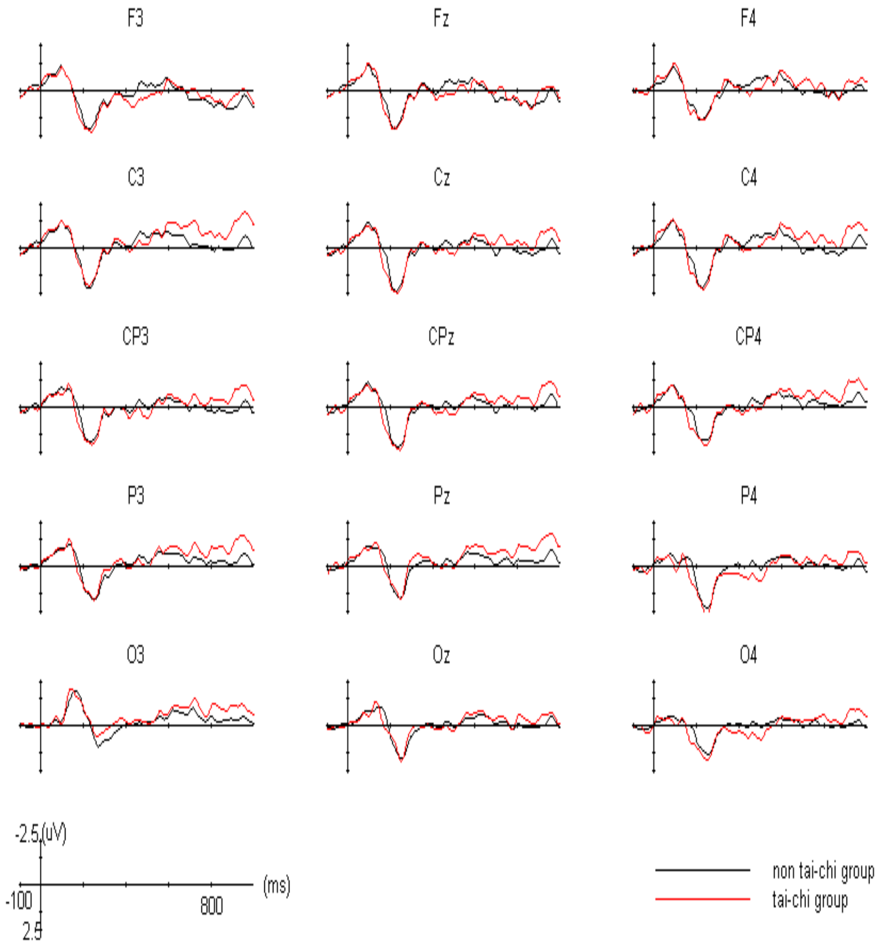
Repeated measures ANOVAs were conducted to examine the differences in amplitude and latency of N100, P200 and N250 between the two subject groups on the image generation task. The N400 and LPC were excluded from the analysis as the generation task design required subject to retrieve a static motor image with little motor planning and complex cognitive function. The first Group (tai-chi and non tai-chi) x Site (Fz, Cz, CPz, Pz and Oz) ANOVA model was conducted on the midline electrodes while the second Group x Laterality (left and right) x Site ANOVA was conducted on the left and right electrodes.

Overall ERP waveform

The morphology of N100, P200 and N250 of the tai-chi and non tai-chi groups in the image generation task are labeled and shown in Figure 5.1. The morphology of the first 100 ms was similar between the two groups. A distinct P200 was observed with tai-chi group gave a broader waveform than the non tai-chi group in all 15 sites. The amplitude of N250 was rather similar between the two groups.

Figure 5.1:

Grand-averaged ERPs of the electrical activities captured on scalp in the image generation task for tai-chi (red line) and non tai-chi group (black line), at 15 electrodes from -100 ms to 1000 ms.



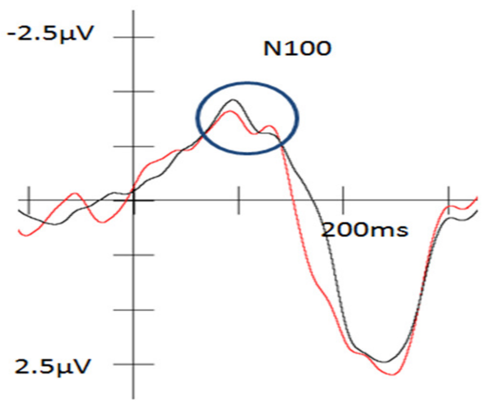
N100

For the image generation task, the Group ($F(1,34)=0.36$, $p=0.554$) and Midline Site ($F(1,34)=0.08$, $p=0.775$) effects on the N100 amplitude were not statistically significant (Table A1 in Appendix II). Similarly, the Group x Midline Site interaction effect was not significant ($F(1,34)=0.81$, $p=0.373$). The testing of the Lateral Site effect indicated that it was statistically significant ($F(4,31)=73.55$, $p<0.001$) but the Group ($F(1,34)=0.28$, $p=0.601$) and Laterality effects ($F(1,34)=0.18$, $p=0.673$), and Group x Laterality x Site effects were all not significant ($F(4,31)=2.42$, $p=0.052$) (Table A2 in Appendix II).

The Group($F(1,34)=88.37$, $p<0.001$), the Midline Site ($F(1,34)=141.21$, $p<0.001$), and Group x Midline Site effects ($F(1,34)=14.14$, $p<0.001$) on the N100 latency were statistically significant. Post-hoc comparisons however did not reveal significant differences in each of these factors (Bonferroni adjustments). In contrast, the test of lateral electrodes indicated that all main and interaction effects were significant ($F=10.64$ to 177.69, $p\leq0.003$) except the Group x Lateral Site effect ($F(4,34)=3.87$, $p=0.027$). Post-hoc comparisons revealed that tai-chi subjects had significantly shorter latency at P4, and O3 ($t(34)=-2.74$ to 2.77, $p\leq0.01$) than the non tai-chi group (Table B1-B3 in Appendix III).

Figure 5.1a:

Grand-averaged ERPs captured on scalp in the image generation task for tai-chi (red line) and non tai-chi group (black line), of N100 component at Pz from -100ms to 250ms.



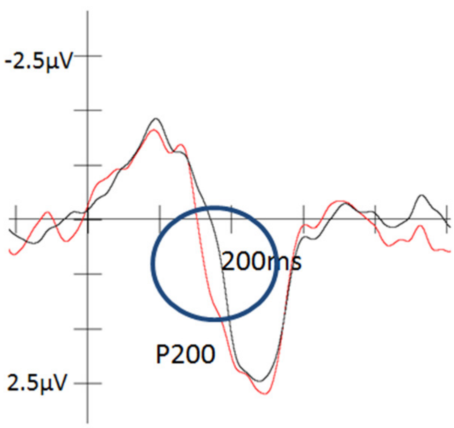
P200

For the image generation task, the Group ($F(1,34)=5.73$, $p=0.022$) and the

Midline Site ($F(1,34)=74.45$, $p<0.001$) effects on the P200 amplitude were statistically significant (Table A3 in Appendix II). However, the Group x Midline Site interaction effect was found not significant ($F(1,34)=5.73$, $p=0.003$). Post-hoc comparison indicated that the tai-chi group had less positively-going amplitude than the non tai-chi group at Fz and CPz ($p \leq 0.003$) (Table A4 in Appendix II). The testing of the Lateral Sites ($F(4,31)=50.33$, $p<0.001$), Laterality ($F(1, 34)=47.78$, $p<0.001$) and the Group ($F(1, 34)=12.40$, $p<0.001$) were statistically significant. While the Group x Laterality x Site ($F(4,31)=26.61$, $p<0.001$) and the Laterality x Group ($F(1,34)=11.97$, $p=0.001$) and the Lateral Site x Laterality ($F(4,31)=23.97$, $p<0.001$) interaction effects were statistically significant, but the Group x Lateral Site interaction effect was not significant. ($F(4,31)=0.56$, $p=0.592$) (Table A5 in Appendix II). Post-hoc comparison indicated that the tai-chi group had less positively-going amplitude than the non tai-chi group at F3, C4, CP3, and P4 ($p \leq 0.003$) (Table A6 in Appendix II).

The Group ($F(1,34)=3.69$, $p=0.063$) and the Group x Midline Site ($F(1,34)=1.34$, $p=0.257$) effects on the latency of P200 were not significant, but the Midline Site effect ($F(1,34)=21.70$, $p<0.001$) was statistically significant. In contrast, the test of lateral electrodes indicated that majority of the main and interaction effects were not statistically significant except the Lateral Site ($F(4, 31)=238.43$, $p<0.001$) and laterality x Site effects ($F(4, 31)=111.43$, $p<0.001$) (Table B4-B5 in Appendix III).

Figure 5.1b:
Grand-averaged ERPs captured on scalp in the image generation task for tai-chi (red line) and non tai-chi group (black line), of P200 component at CPz from -100ms to 500ms.



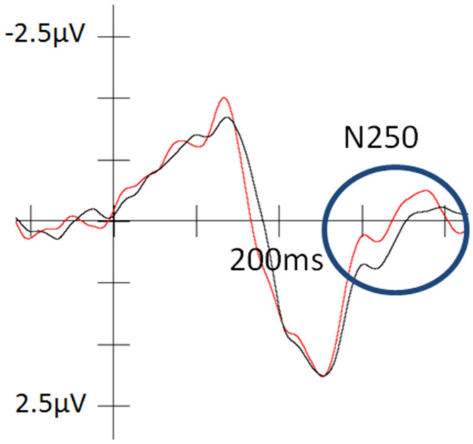
N250

For the image generation task, the Group ($F(1,34)=0.36$, $p=0.554$) effect on the N250 amplitude was not statistically significant, but the Midline Site ($F(1,34)=8.91$, $p<0.001$) and the Group x Midline Site interaction effects ($F(1,34)=4.55$, $p=0.005$) were statistically significant (Table A7 in Appendix II). Post-hoc comparison indicated that the tai-chi group had more negatively-going amplitude than the non tai-chi group at Oz ($p=0.003$) (Table A8 in Appendix II). The testing of the Lateral Site ($F(4,31)=73.55$, $p<0.001$), the Lateral Site x Laterality ($F(4,31)=71.24$, $p<0.001$) and Group x Laterality ($F(1, 34)=12.20$, $p=0.001$), and the Group x Laterality x Site interaction ($F(4,31)=31.99$, $p<0.001$) effects were found statistically significant but other main and interaction effects were not significant ($F=0.18\text{-}0.35$, $p=0.601\text{-}0.690$) (Table A9 in Appendix II). Post-hoc comparison indicated that the tai-chi group had more negatively-going amplitude than the non tai-chi group at F3, C4 and P3 ($p \leq 0.001$) (Table A10 in Appendix II).

The Group effect on the latency of N250 was not significant ($F(1,34)=0.85$, $p=0.364$), but the Midline Site ($F(1,34)=66.61$, $p<0.001$) and Group x Midline Site ($F(1,34)=17.30$, $p<0.001$) effects were statistically significant. Post-hoc comparisons however did not reveal significant differences in each of these factors (Bonferroni adjustments). In contrast, the test of lateral electrode indicated the Group ($F(1,34)=1.87$, $p=0.181$) was significant, but the Laterality ($F(1,34)=33.76$, $p<0.001$) and Lateral Site ($F(1,34)=25.36$, $p<0.001$) effects were statistically significant, but all interaction effects were not statistically significant ($F=0.67\text{-}1.87$, $p=0.181\text{-}0.432$), except the Site x Laterality effect ($F(4, 31)=4.59$, $p=0.036$) was significant (Table B6-B7 in Appendix III).

Figure 5.1c:

Grand-averaged ERPs captured on scalp in the image generation task for tai-chi (red line) and non tai-chi group (black line), of N250 component at CP3 from -100ms to 400ms.



In summary, between-group differences were revealed in the amplitude, latency and the significant post hoc sites comparison (with Bonferroni adjustments) respectively of specific ERP components when subjects performed on the image transformation task. Significant differences in amplitudes of P200 and N250 among the midline sites (Table 5.15a). Similarly, the differences in amplitudes among the lateral sites were found for the P200 and N250 (Table 5.15a). Significant between-group differences in latency were revealed among the midline sites for N100 and N250, and lateral sites for the N100 but not the P200 and N250 (Table 5.15b).

Table 5.15a.

Statistically significant interaction effects in the Amplitude of Group x Midline site repeated measure ANOVA and Group x Laterality x Site repeated measure ANOVA on the image generation task

	Interaction Effect	Df	F	*P*	*Post hoc comparison*
P200	Gp x Midline Site	1, 34	5.73	0.003	Fz, CPz
N250	Gp x Midline Site	1, 34	4.55	0.005	Oz
P200	Gp x Site x Laterality	4, 31	26.61	<0.001	F3, C4, CP3, P4
N250	Gp x Site x Laterality	4, 31	22.392	<0.001	F3, C4, P3

Note: Gp=Group (tai-chi and non tai-chi), Site=Site (F, C, CP, P and O), Laterality=Laterality (left and right), Post hoc comparison=significant sites with $p \leq 0.01$(Bonferroni adjustments)

Table 5.15b.

Statistically significant interaction effects in the latency of Group x Midline site repeated measure ANOVA and Group x Laterality x Site repeated measure ANOVA on the image generation task

	Interaction Effect	Df	F	*P*	*Post hoc comparison*
N100	Gp x Midline Site	1, 34	14.14	<0.001	--
N250	Gp x Midline Site	1, 34	17.30	<0.001	--
N100	Gp x Site x Laterality	1, 34	11.19	<0.001	P4, O3

Note: Gp=Group (tai-chi and non tai-chi), Site=Site (F, C, CP, P and O), Laterality=Laterality (left and right), Post hoc comparison=significant sites with $p \leq 0.01$(Bonferroni adjustments)

To further illustrate the differences in the electrical activities over the scalp between tai-chi and non tai-chi groups in the image generation task, the morphology and topography of the subtracted waveform in N100, P200 and N250 were obtained (Figures 5.2 and 5.3). The subtracted waveform indicated that between-group differences were the most obvious in P200 followed by N250. The differences in the N100 were the most minimal.

Figure 5.2:

Grand-averaged ERPs of subtracted waveform on the image generation task (tai-chi minus non tai-chi group), at 15 electrodes from -100ms to 1000ms.

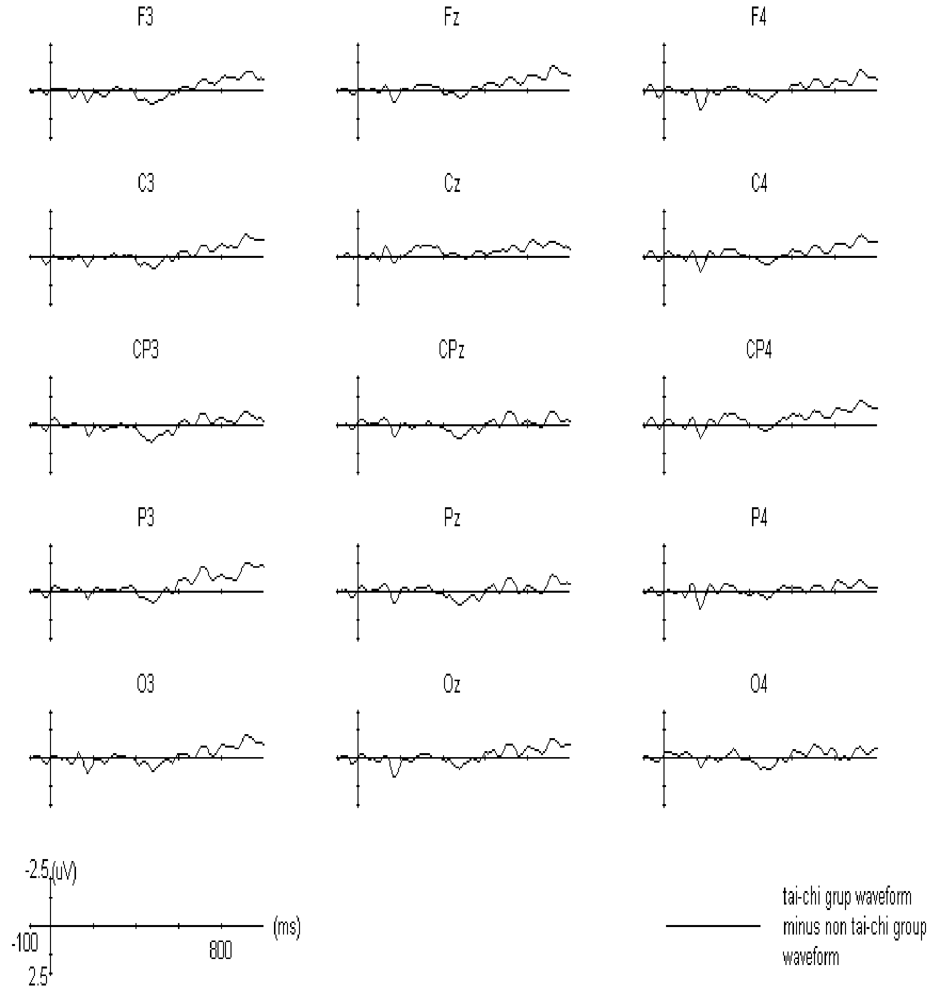
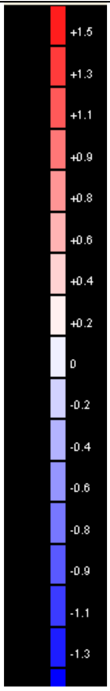
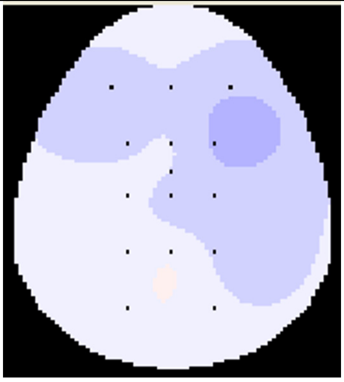
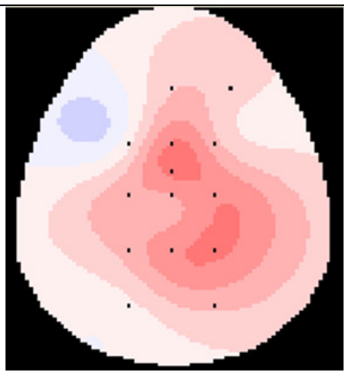
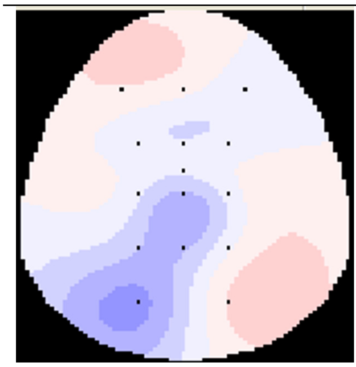


Figure 5.3:

Topography of grand-averaged ERPs of subtracted waveform (tai-chi minus non tai-chi) for the image generation task

N100 component (80-155ms)	P200 component (150-290ms)	
		
N250 component (270-400ms)		
		Note: Voltage = -1.5 - 1.5μV Red color = positive Blue color = negative

Dipole sourcing of the image generation task in tai-chi and non tai-chi group

The generation task of the two subject groups (tai-chi and non tai-chi) were further used for the source localization respectively. The four components were acquired by obtaining the Maps of scale voltage. The ERP components data was used for estimating dipole sources by CURRY 5 (NeuroScan Inc., Herndon, VA, USA). The residual variance (RV) between the model and the observed spatial-temporal component distribution was minimized by the iterative changes in the location and orientation of the dipole sources (Scherg, 1990).

<u>Source localization of image transformation task in tai-chi group</u>

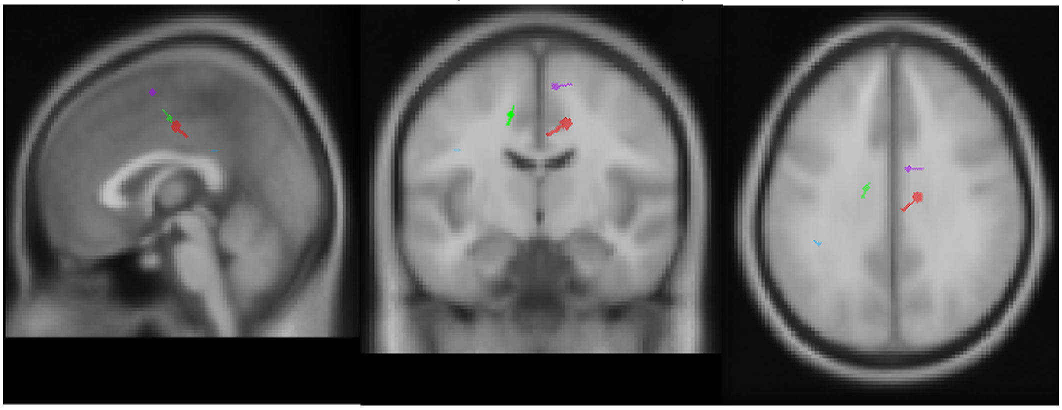
For N100, four distinct dipoles were identified. The multiple model derived with best SNR of 4.8 and the residual variance is equal to 9.8% accounting for 90.2% of the total variance. The results suggest the possibility of the medial frontal gyrus, superior frontal gyrus and the precentral gyrus in the frontal region to be the origins of the N100 component.

For P200, four distinct dipoles were identified. The multiple model derived with best SNR of 4.3 and the residual variance is equal to 12.8% which can account for 87.2% of the total variance. The results suggest the possibility of the superior frontal gyrus and precentral gyrus in the frontal regions and cingualte gyrus in the limbic region be the origins of the P200 component.

For N250, three distinct dipoles were identified. The multiple model derived with best SNR of 3.4 and the residual variance is equal to 28.6% accounting for 71.4% of the total variance. The results suggest that the middle frontal gyrus and paracentral lobule in the frontal region and cingulate gyrus in the limbic region be the origins of the N250 component

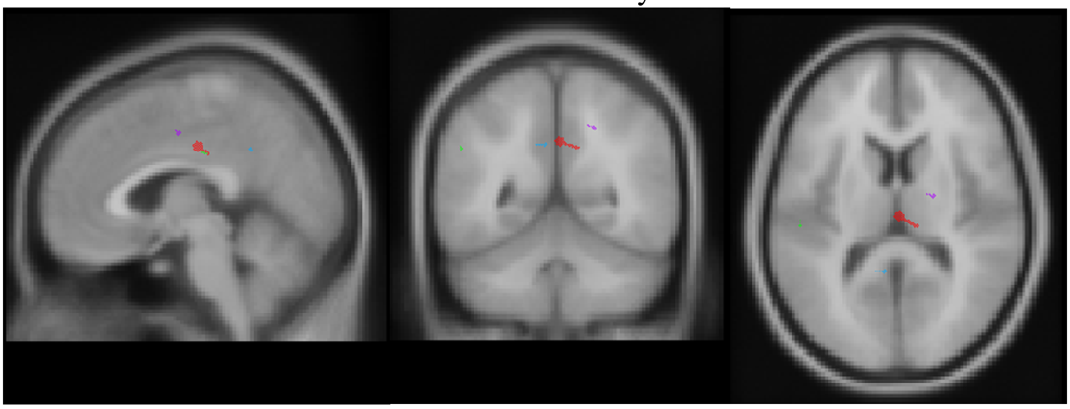
Table 5.7. Location an orientation of CURRY 5 fitted dipoles of grand averaged ERP expressed in Talairach cooidnates

Components	Total variance	Dipoles	X	Y	Z
N100 (80-155ms)	90.2%	Dipole 1 (Red) Right Cerebrum, Frontal Lobe, Medial frontal Gyrus	13	14	45
		Dipole 2 (Green) Right Cerebrum, Frontal Lobe, Superior frontal Gyrus	8	31	50
		Dipole 3 (Blue) left Cerebrum, Frontal Lobe, Precentral Gyrus (Brodmann area 4)	-40	-12	55
		Dipole 4 (Purple) Right Cerebrum, Frontal Lobe, Superior frontal Gyrus (Brodmann area 6)	-15	19	55



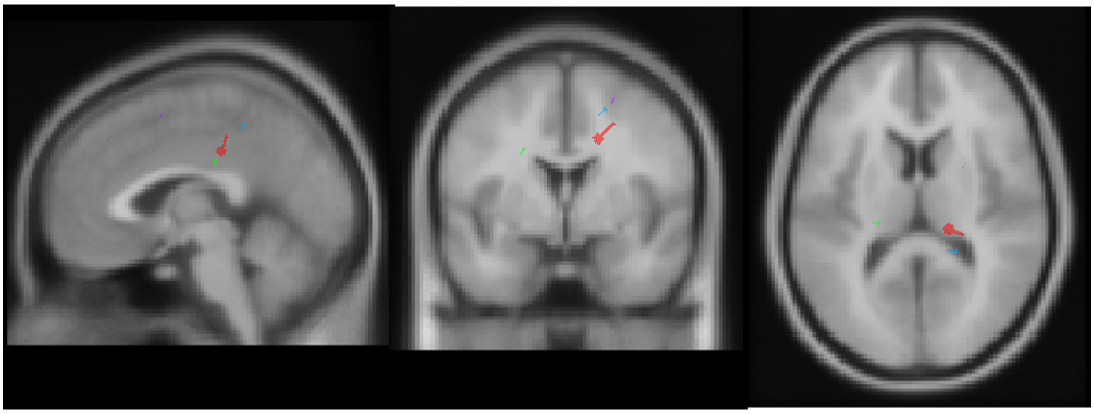
Note: Values are in mm. Total variance= the percentage of variability explained by the model

Components	Total variance	Dipoles	X	Y	Z
P200 (150-290ms)	87.2%	Dipole 1 (Red) Right Cerebrum Limbic Lobe Cingulate Gyrus	1	8	40
		Dipole 2 (Green) Right Cerebrum Frontal Lobe Superior Frontal Gyrus	20	20	45
		Dipole 3 (Blue) Left cerebrum Limbic Lobe Cingulate Gyrus	-7	-22	40
		Dipole 4 (Purple) Left Cerebrum, Frontal Lobe, Precentral Gyrus	-53	3	45



Note: Values are in mm. Total variance= the percentage of variability explained by the model

Components	Total variance	Dipoles	X	Y	Z
N250 (270-400ms)	71.4%	Dipole 1 (Red) Right Cerebrum Limbic Lobe Cingulate Gyrus	17	-1	40
		Dipole 2 (Green) Right Cerebrum, Frontal Lobe, Middle Frontal Gyrus	24	34	38
		Dipole 3 (Blue) Right Cerebrum, Frontal Lobe, Paracentral lobule	10	-21	45



Note: Values are in mm. Total variance= the percentage of variability explained by the model

<u>Source localization of image generation task in non tai-chi group</u>

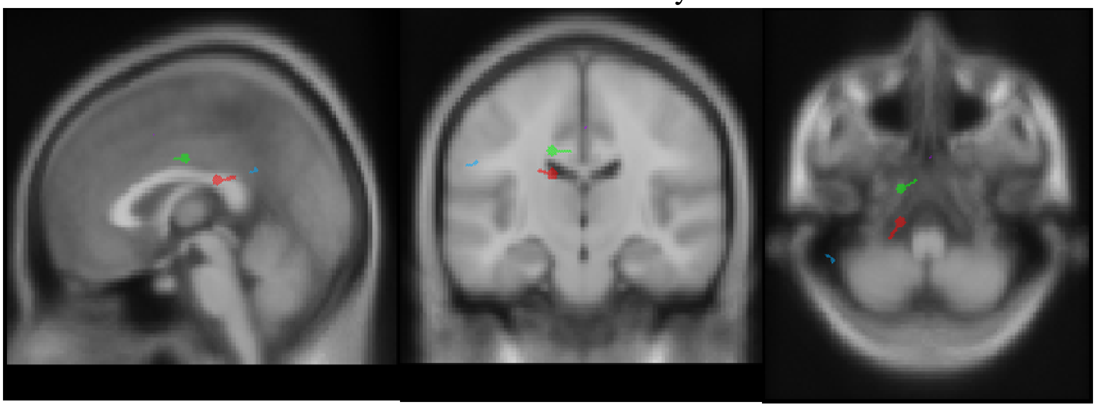
For the N100 component, three distinct dipoles were identified. The multiple model derived with best SNR of 3.7 and the residual variance is equal to 8.4% account for within the 91.6%. The results suggest cingulate gyrus in the limbic lobe region and postcentral gyrus in the parietal region and medial frontal gyrus in the frontal region could be regarded as the origins for the N100 component.

For the P200 component, four distinct dipoles were identified. The multiple model derived with best SNR of 4.5 and the residual variance is equal to 13.6% account for within the 86.4%. The results suggest medial frontal gyrus, middle frontal gyrus and paracentral lobule in the frontal region could be regarded as the origins for the P200 component.

For the N250 component, four distinct dipoles were identified. The multiple model derived with best SNR of 5.0 and the residual variance is equal to 9.5% account for within the 90.5%. The results suggest middle frontal gyrus and superior frontal gyrus in the frontal region and cingulated gyrus in the limbic region could be regarded as the origins for the N250 component.

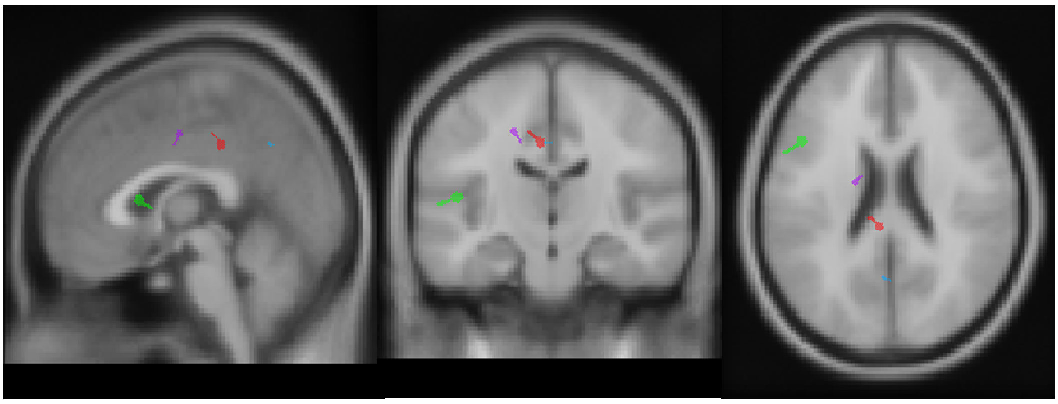
Table 5.8. Location an orientation of CURRY 5 fitted dipoles of grand averaged ERP expressed in Talairach cooidnates

Components	Total variance	Dipoles	X	Y	Z
N100 (80-155ms)	91.6%	Dipole 1 (Red) Left Cerebrum Limbic Lobe Cingulate Gyrus	-16	-1	35
		Dipole 2 (Green) Right Cerebrum Frontal Lobe Medial Frontal Gyrus	1	37	40
		Dipole 3 (Blue) Left Cerebrum parietal Lobe Postcentral Gyrus	-54	-22	36



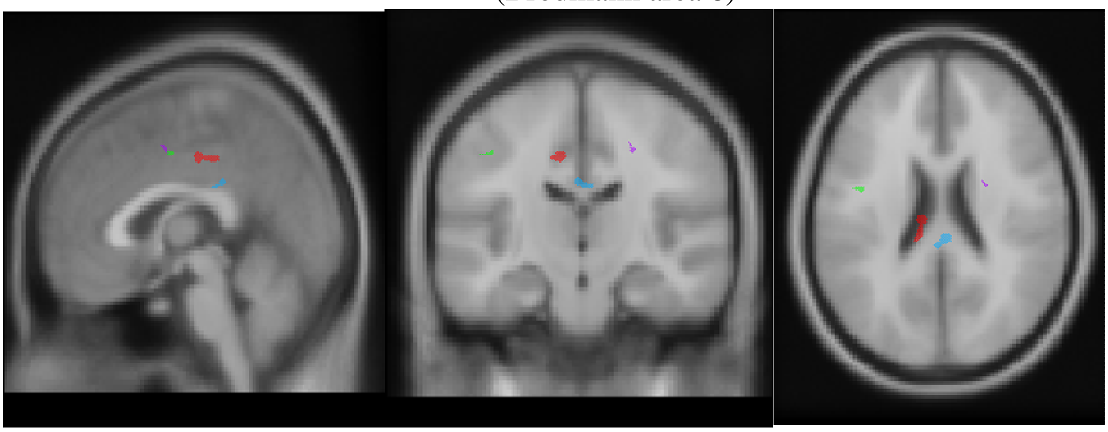
Note: Values are in mm. Total variance= the percentage of variability explained by the model

Components	Total variance	Dipoles	X	Y	Z
P200 (150-290ms)	86.4%	Dipole 1 (Red) Left Cerebrum Frontal Lobe Medial Frontal Gyrus	-6	-5	50
		Dipole 2 (Green) Left Cerebrum Frontal Lobe Middle Frontal Gyrus	-40	8	40
		Dipole 3 (Blue) Left Crebrum Frontal Lobe Paracentral Lobule (Brodmann area 5)	-3	-33	98
		Dipole 4 (Purple) Left Crebrum Frontal Lobe Paracentral Lobule (Brodmann area 5)	-48	38	62



Note: Values are in mm. Total variance= the percentage of variability explained by the model

Components	Total variance	Dipoles	X	Y	Z
N250 (270-400ms)	90.5%	Dipole 1 (Red) Left Cerebrum Limbic Lobe Cingulate Gyrus (Brodmann area 24)	-11	8	45
		Dipole 2 (Green) Right Cerebrum Frontal Lobe Superior Frontal Gyrus (Brodmann area 8)	24	26	45
		Dipole 3 (Blue) Left Cerebrum Limbic Lobe Cingulate Gyrus	-2	-7	38
		Dipole 4 (Purple) Left Cerebrum Frontal Lobe Middle Frontal Gyrus (Brodmann area 8)	-43	23	45



Note: Values are in mm. Total variance= the percentage of variability explained by the model

Tai-chi and non tai-chi groups on the image transformation task

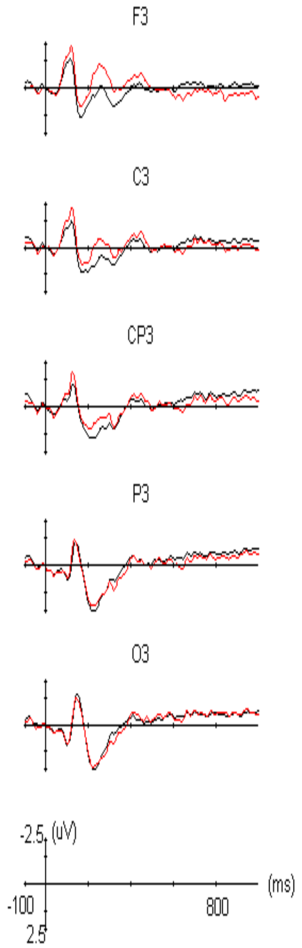
Repeated measures ANOVAs were conducted to examine the differences in amplitude and latency of N100, P200, N250, N400 and LPC between the two subject groups on the image transformation task. The first Group (tai-chi and non tai-chi) x Site (Fz, Cz, CPz, Pz and Oz) ANOVA model was conducted on the midline electrodes while the second Group x Laterality (left and right) x Site ANOVA was conducted on the left and right lateral electrodes.

<u>Overall ERP waveform</u>

The morphology of the tai-chi and non tai-chi groups is presented in Figure 5.4. In general, tai-chi group displayed more negative-going N100 than non-tai-chi group over the anterior regions. Tai-chi group had less positive-going P200 over the fronto-central regions than the non-tai-chi group. The N250 was found to be more negative-going in the frontal areas for tai-chi group. Differences between groups were observed in N400 in the fronto-central regions.

Figure 5.4:

Grand-averaged ERPs of the electrical activities captured on scalp in the image transformation task for tai-chi (red line) and non tai-chi group (black line), at 15 electrodes from -100ms to 1000ms.



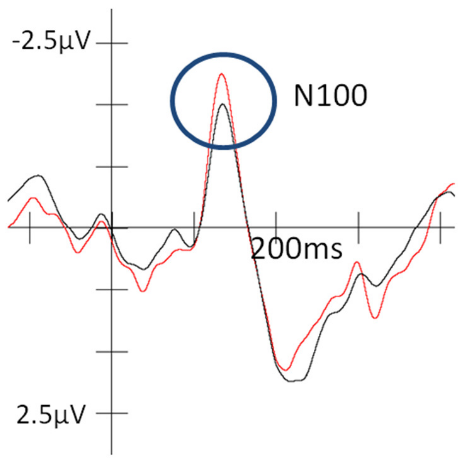
N100

For the image transformation task, only the Midline Site effect on the amplitude of N100 was statistically significant ($F(1,34)=86.97$, $p<0.001$) (Table A11 in Appendix II). The Group ($F(1,34)=2.05$, $p=0.161$) and Group x Midline Site effects ($F(1,34)=2.15$, $p<0.078$) were found statistically not significant. When testing the effects of the lateral electrodes, the Group ($F(1,34)=59.57$, $p<0.001$), Laterality ($F(4,31)=18.30$, $p<0.001$) and Site ($F(4,31)=65.01$, $p<0.001$) effects were all significant, whilst the Laterality x Group and Site x Laterality effects were statistically not significant. ($p=0.080$ to 0.404) (Table A12 in Appendix II).

The Midline Site effect on the latency of N100 was statistically significant ($F(1,34)=140.70$, $p<0.001$); whilst the Group ($F(1,34)=2.21$, $p=0.147$) and Group x Midline Site effects ($F(1,34)=1.54$, $p<0.225$) were not significant. When testing the effects of the lateral sites ob latency of N100, only the Site effect ($F(4,31)=712.23$, $p<0.001$) was statistically significant, whilst the Group ($F(1,34)=1.710$, p=0.200) and Laterality ($F(1, 34)=0.01$, $p<0.922$) were not significant. All except the Group x Laterality ($F(1,34)=6.185$, $p<0.003$) interaction effects were statistically not significant ($p=0.056$ to 0.248) (Table B8-B9 in Appendix III).

Figure 5.4a:

Grand-averaged ERPs captured on scalp in the image transformation task for tai-chi (red line) and non tai-chi group (black line), of N100 component at Cz from -100ms to 300ms.



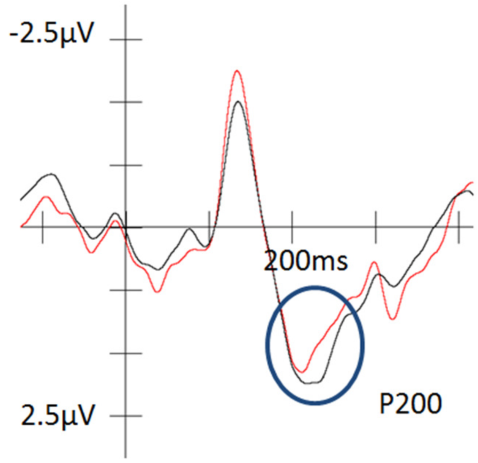
P200

For the image transformation, the Group effect on the amplitude of P200 was not statistically significant ($F(1,34)=1.52$, $p=0.227$), but the Midline Site ($F(1,34)=49.98$, $p<0.001$) and the Group x Midline Site effects were found significant ($F(1,34)=13.32$, $p<0.001$) (Table A13 in Appendix II). Post-hoc comparisons indicated tai-chi subjects had significant less positive in amplitude of P200 at Fz and Cz sites ($p<0.001$) (Table A14 in Appendix II). When testing the effect of the lateral electrodes, the Lateral Site ($F(4,31)=43.25$, $p<0.001$), the Group ($F(1,34)=5.83$, $p=0.021$) and the Laterality ($F(1, 34)=44.68$, $p<0.001$) main effects were found statistically significant. The Group x Laterality x Lateral Site ($F(4,31)=10.42$, $p<0.001$) and all interaction ($F=23.43$-27.78, $p<0.001$), except the Laterality x Group interaction effect ($F(1,34)=3.63$, $p=0.065$) were found statistically significant. Post-hoc comparisons indicated tai-chi subjects had significant less positive in amplitude of P200 than non tai-chi subjects at F3, F4, C3, C4, CP3 and CP4 ($p\leq0.001$)(Table A15-A16 in Appendix II).

The Group effect ($F(1,34)=109.28$, $p<0.001$) and Midline Site effect ($F(1,34)=419.77$, $p<0.001$), and Group x Midline Site effects on the P200 latency were all significant ($F(1,34)=5.87$, $p=0.003$). Post hoc analyses revealed that the latency for tai-chi group was significantly shorter than non tai-chi group at CPz, Pz and Oz sites ($p\leq0.011$) (Table B10-B11 in Appendix III). In contrast, the test of lateral electrode indicated that the Group ($F(1,34)=12.89$, $p=0.001$), Lateral Site effects ($F(4,31)=835.54$, $p<0.001$) and Laterality ($F(1,34)=6.44$, $p=0.016$) effects were significant, but the Group x Laterality x Lateral Site effect was found not significant ($F(4,31)=3.53$, $p=0.041$). Other significant interaction effects were found in Group x Laterality ($F(1, 34)=25.96$, $p<0.001$) and Laterality x Lateral Site ($F(4,31)=10.24$, $p<0.001$), but the Group x Lateral Site ($F(4, 31)=2.73$, $p=0.071$). Post hoc analyses revealed that the latency for tai-chi subjects had significantly shorter than non tai-chi subjects at P3, P4, O3 and O4 sites ($p\leq0.007$) (Table B12-B13 in Appendix III).

Figure 5.4b:

Grand-averaged ERPs captured on scalp in the image transformation task for tai-chi (red line) and non tai-chi group (black line), of P200 component at Cz from -100ms to 400ms.



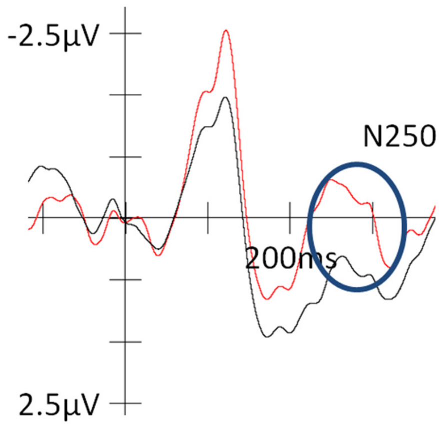
N250

For the image transformation, the Group (F(1, 34)=28.12, *p*<0.001) and the Midline Site (F(1,34)=18.10, *p*<0.001) and the Group x Midline Site effects were found statistically significant (F(1,34)=19.92, *p*<0.001) (Table A17 in Appendix II). Post-hoc comparison indicated significant more negative-going N250 in the tai-chi subjects than non tai-chi subjects at Fz, Cz and Oz sites (*p*≤0.008) (Table A18 in Appendix II). When testing the effects of the lateral electrodes, the Group (F(1,34)=64.84, *p*<0.001) and Lateral Site (F(4,31)=35.67, *p*<0.001) effects were statistically significant, but the Laterality effect (*p*=0.305) was not significant..The Group x Laterality x Lateral Site (F(4,31)=8.97, *p*<0.001), the Group x Lateral Site (F(4,31)=28.56, *p*<0.001), Laterality x Site (F(4,31)= 5.69, *p*<0.001) but not in the Group x Laterality (*p*=0.519) effects were found statistically significant. Post-hoc comparison indicated significant tai-chi subjects had more negative-going amplitude than non tai-chi subjects at F3, F4, C3, C4, P3 and O3 sites (*p*≤0.039) (Table A19-A20 in Appendix II).

When testing the effects of the lateral electrodes, the Midline Site (F(1,34)=571.60, *p*<0.001) and Group x Midline Site (F(1,34)=14.89, *p*<0.001) effects were statistically significant, but the Group effect was not significant (F(1,34)=0.93, *p*=0.341). Post-hoc analyses revealed that the latency for tai-chi subjects was significantly shorter than non tai-chi subjects at Fz and Cz sites (*p*≤0.001) (Table B14-B15 in Appendix III). In contrast, the test of lateral electrodes indicated that the Lateral Site (F(4,31)=259.14, *p*<0.001) but not the Group

(F(1,34)=0.24, *p*=0.625) and Laterality effects (F(1,34)=0.97, *p*=0.331) were statistically significant. The Group x Laterality x Lateral Site e (F(4,31)=7.34, *p*<0.001), the Lateral Site x Group (F(4, 31)=4.50, *p*=0.032) and Laterality x Lateral Site (F(4,31)=9.64, *p*<0.001) interaction effects were found significant but Laterality x Group interaction effects found not significant (F(1, 34)=0.34, *p*=0.564). Post-hoc analyses revealed that the latency for tai-chi subjects had significantly shorter than non tai-chi subjects at F3, F4, C3, and CP4 sites (*p*<0.01) (Table B16-B17 in Appendix III).

Figure 5.4c:
Grand-averaged ERPs captured on scalp in the image transformation task for tai-chi (red line) and non tai-chi group (black line), of N250 component at C3 from -100ms to 400ms.

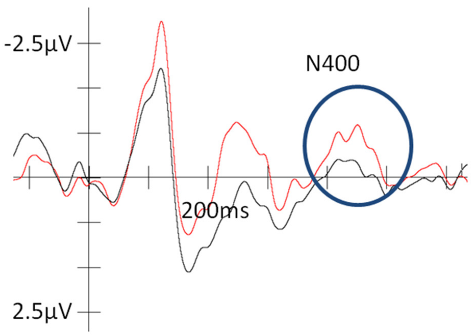


<u>N400</u>

For the image transformation task, the Group (F(1,34)=25.01, *p*<0.001) and Midline Site (F(1,34)=4.71, *p*=0.001), and the Group x Midline Site (F(1,34)=3.35, *p*=0.012) effects were found statistically significant (Table A21 in Appendix II). Post-hoc comparisons indicated that amplitudes of N400 of the tai-chi subjects had more negative-going than the non tai-chi subjects at Fz, Cz and CPz, sites (*p* ≤0.007) (Table A22 in Appendix II). In contrast, the test of lateral electrodes indicated that all the main effects were statistically significant (F=10.04 -34.38, *p*≤0.002). The Group x Laterality x Site (F(4,31)=3.36, *p*=0.012) and the Lateral Site x Laterality (F(4, 31)=3.11, *p*=0.012) interaction effects were found statistically significant. Post-hoc comparisons indicated that amplitudes of N400 of the tai-chi subjects were more negative-going than the non tai-chi subjects at C4, CP4 and O4 sites (*p* ≤0.001) (Table A24 in Appendix II).

The Midline Site (F(1,34)=29.68, *p*<0.001) and Group x Midline Site (F(1,34)=9.28, *p*=0.001) effects on the N400 latency were statistically significant., but the Group effect (F(1,34)=0.48, *p*=0.492) was not significant.. Post-hoc analyses revealed that the latency of N400 for tai-chi subjects had significantly longer than non tai-chi subjects at CPz site (*p*<0.001) (Table B18-B19 in Appendix III). In contrast, the test of lateral electrode indicated that the Laterality (F(1,34)=455.63, *p*<0.001) and Lateral Site (F(4,31)=178.51, p<0.001) but not Group (F(1,34)=2.47, *p*=0.125) effects were statistically significant. The Group x Laterality x Site interaction effect was found statistically significant (F(4,31)=18.88, *p*<0.001). All other two-factor interaction effects were significant (F=21.26-215.93, *p*<0.001). Post-hoc analyses revealed that the latency of N400 for tai-chi subjects had significantly longer than non tai-chi subjects at C4, P4 and O4 sites (*p*<0.001) (Table B20-B21 in Appendix III).

Figure 5.4d:
Grand-averaged ERPs captured on scalp in the image transformation task for tai-chi (red line) and non tai-chi group (black line), of N400 component at Fz from -100ms to 600ms.

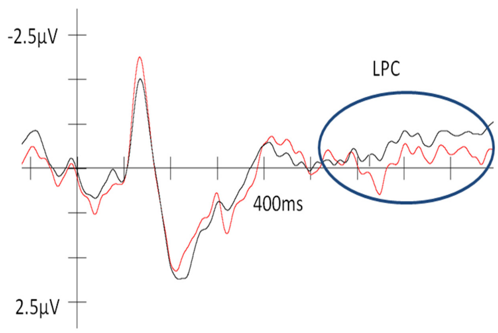


<u>Late positive component (LPC)</u>

For the statically analysis within the data captured in time window (520-800ms), the Midline Site effect (F(1,34)=4.33, p=0.002) was significant, but the Group (F(1,34)=0.05, p=0.957) and Group x Midline Site (F(1,34)=1.57, p=0.185) effects were not statistically significant (Table A25 in Appendix II). In contrast, when testing the effects of the lateral electrodes, the Lateral Site (F(1, 34)=58.95, p<0.001) and Laterality (F(1, 34)=17.43, p<0.001) effects were significant, but the Group effect (F(4,31)=58.95, p<0.001) was not statistically significant. The Group x Laterality x Site effect was found not statistically significant (F(4,31)=2.24, p=0.053) (Table A26 in Appendix II).

The Group ($F(1,34)=19.33$, $p<0.001$), Midline Site ($F(1,34)=57.41$, $p<0.001$) and Group x Midline Site ($F(1,34)=67.77$, $p<0.001$) effects on latency of LPC were found statistically significant. Post-hoc analyses revealed that the latency for tai-chi subjects had significantly longer than non tai-chi subjects at Cz site ($p<0.001$). In contrast, the testing of lateral electrodes indicated the Laterality ($F(1,34)=144.70$, $p<0.001$) and Lateral Site ($F(4,31)=107.91$, $p<0.001$) but not Group ($F(1,34)=1.95$, $p=0.172$) effects were statistically significant. The Group x Laterality x Site effect was found statistically significant ($F(4,31)=4.57$, $p=0.021$). The Group x Laterality ($F(1,34)=4.58$, $p=0.040$) and the Laterality x Lateral Site effect ($F(4,31)=246.41$, $p<0.001$) interaction effects were significant, but the Group x Lateral Site ($F(4, 31)=0.54$, $p=0.710$) was not significant. Post-hoc analyses revealed that the latency for tai-chi subjects had significantly longer than non tai-chi subjects at P3 site ($p=0.008$).

Figure 5.4e:
Grand-averaged ERPs captured on scalp in the image transformation task for tai-chi (red line) and non tai-chi group (black line), of LPC component at Cz from -100ms to 800ms.



In summary, between-group differences were revealed in the amplitude, latency and the significant post hoc sites comparison (with Bonferroni adjustments) respectively of specific ERP components when subjects performed on the image transformation task. Significant differences in amplitudes of P200, N250 and N400 among the midline sites (Table 5.16a). Similarly, the differences in amplitudes among the lateral sites were found for the P200, N250 and N400, but not in the LPC (Table 5.16a). Significant between-group differences in latency were revealed among the midline sites for P200, N250, N400 and LPC, and lateral sites for the N100, N250 and N400 but not the P200 and LPC (Table 5.16b).

Table 5.16a.

Statistically significant interaction effects of the amplitude of Group x Midline Site repeated measure ANOVA and Group x Laterality x Site repeated measure ANOVA on the image transformation task

	Interaction Effects	df	F	p	Post hoc comparisons
P200	Gp x Midline Site	1, 34	13.32	<0.001	Fz, Cz
N250	Gp x Midline Site	1, 34	19.92	<0.001	Fz, Cz, Oz
N400	Gp x Midline Site	1, 34	3.35	0.012	Fz, Cz, CPz
P200	Gp x Laterality x Site	4, 31	10.42	<0.001	F3, F4, C3, C4, CP3, CP$
N250	Gp x Laterality x Site	4, 31	8.97	<0.001	F3, F4, C3, C4, P3, O3
N400	Gp x Laterality x Site	4, 31	3.36	0.012	C4, CP4, O4

Note: Gp=Group (tai-chi and non tai-chi), Site=Site (Fz, Cz, CPz, Pz and Oz), Laterality=Laterality (left and right), Post hoc comparison=significant sites with p≤0.01(Bonferroni adjustments)

Table 5.16b.

Statistically significant interaction effects of the latency of Group x Midline Site repeated measure ANOVA and Group x Laterality x Site repeated measure ANOVA on the image transformation task

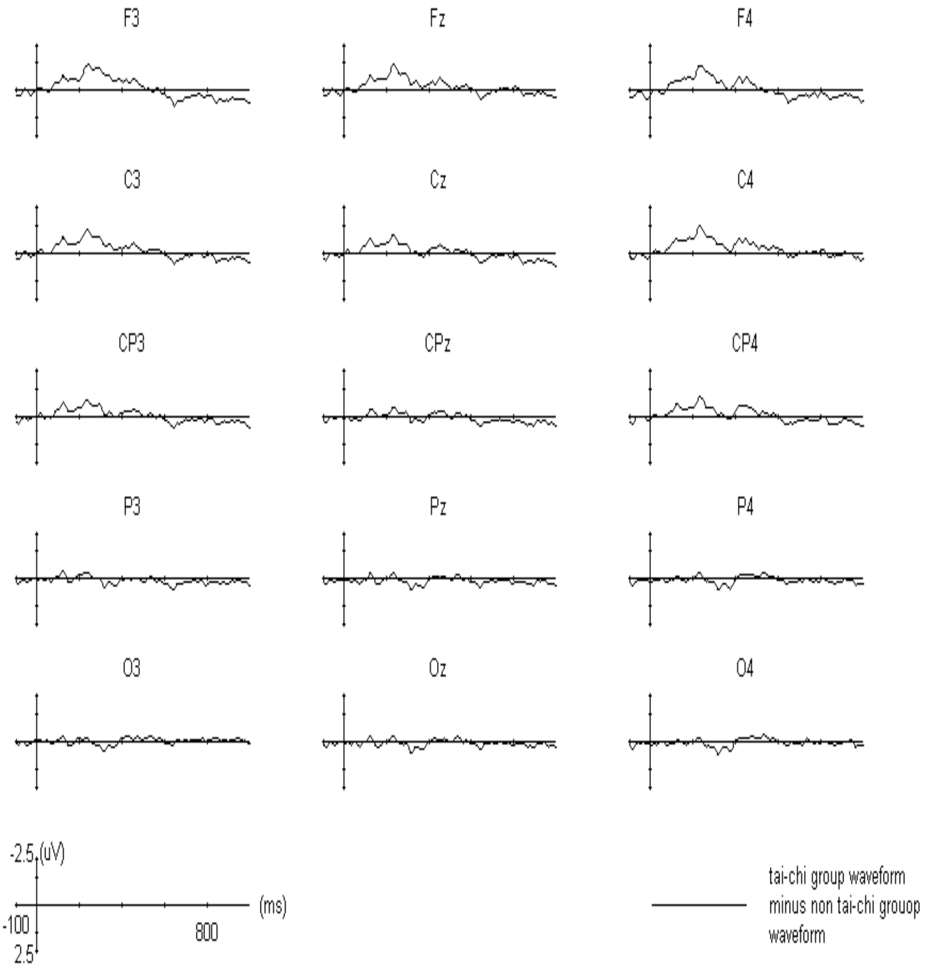
	Interaction Effects	df	F	p	Post hoc comparisons
P200	Gp x Midline Site	1, 34	5.87	0.003	CPz, Pz, Oz
N250	Gp x Midline Site	1, 34	14.89	<0.001	Fz, Cz
N400	Gp x Midline Site	1, 34	9.28	<0.001	CPZ
LPC	Gp x Midline Site	1, 34	67.77	<0.001	Cz
P200	Gp x Laterality x Site	4, 31	3.53	0.041	P3, P4, O3, O4
N250	Gp x Laterality x Site	4, 31	7.34	<0.001	F3, F4, C3, CP$
N400	Gp x Laterality x Site	4, 31	18.88	<0.001	C4, P4, O4
LPC	Gp x Laterality x Site	4, 31	4.57	0.021	P3

Note: Gp=Group (tai-chi and non tai-chi), Site=Site (F, C, CP, P and O), Laterality=Laterality (left and right), Post hoc comparison=significant sites with $p \leq 0.01$(Bonferroni adjustments)

To further illustrate the differences in the electrical activities over the scalp between tai-chi and non tai-chi groups in the image transformation task, the subtracted waveform in tai-chi group minus non tai-chi group was obtained (Figure 5.5). The topography of the subtracted waveform is presented in Figure 5.6. The results indicated that the largest between-group differences were around the 130ms to 390ms in particular N100 and N250 which was primarily generation of images on tai-chi forms. The differences were relatively smaller in the N400 and LPC which were the primary components for transformation of images on tai-chi forms.

Figure 5.5.

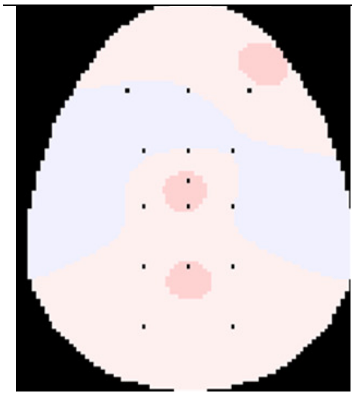
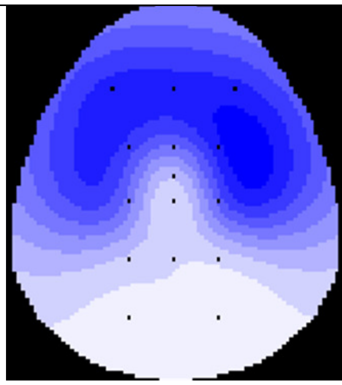
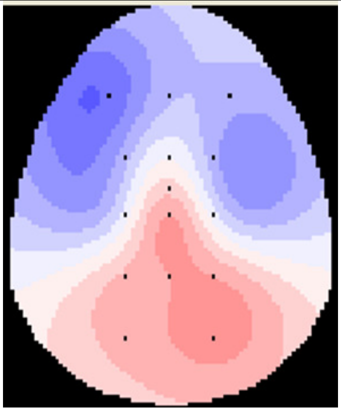
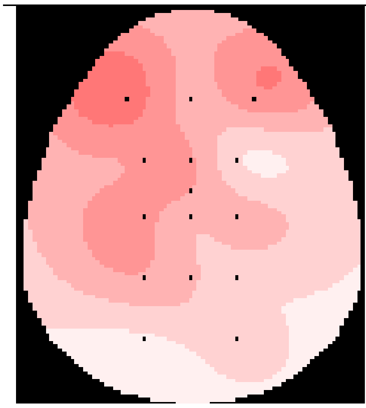
Grand-averaged ERPs of subtracted waveform on the image transformation task (tai-hi minus non tai-chi group), at 15 electrodes from -100ms to 1000ms.

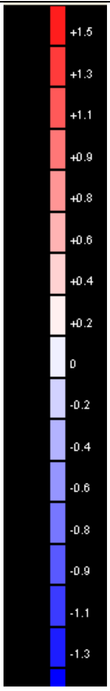


F3
Fz
F4
C3
Cz
C4
CP3
CPz
CP4
P3
Pz
P4
O3
Oz
O4
-2.5
(uV)
(ms)
-100
800
2.5
tai-chi group waveform minus non tai-chi grouop waveform

Figure 5.6.

Topography of grand-averaged ERPs of subtracted waveform (tai-chi Minus non tai-chi) for the image transformation task

N100 component (70-150ms)	P200 component (160-300ms)
	
N250 component (300-400ms)	**N400 component (375-520ms)**
	
Late positive component (520-800ms)	
	



Note:

Voltage = -2.5 -2.5µV

Red color = positive

Blue color = negative

Dipole sourcing of the image transformation task in tai-chi and non tai-chi group

The transformation task of the two subject groups (tai-chi and non tai-chi) were further used for the source localization respectively. The six components were acquired by obtaining the Maps of scale voltage. The ERP components data was used for estimating dipole sources by CURRY 5 (NeuroScan Inc., Herndon, VA, USA). The residual variance (RV) between the model and the observed spatial-temporal component distribution was minimized by the iterative changes in the location and orientation of the dipole sources (Scherg, 1990).

<u>Source localization of image transformation task in tai-chi group</u>

For the N100 component, two distinct dipoles were identified. The multiple model derived with best SNR of 10.9 and the residual variance is equal to 9.2% account for within the 90.8%. The results suggest parietal region could be regarded as the origin for the N100 component.

For the P200 component, two distinct dipoles were identified. The multiple model derived with best SNR of 8.7 and the residual variance is equal to 21.4% account for within the 78.6%. The results suggest middle frontal gyrus and precentral gyrus in the frontal regions could be regarded as the origins for the P200 component.

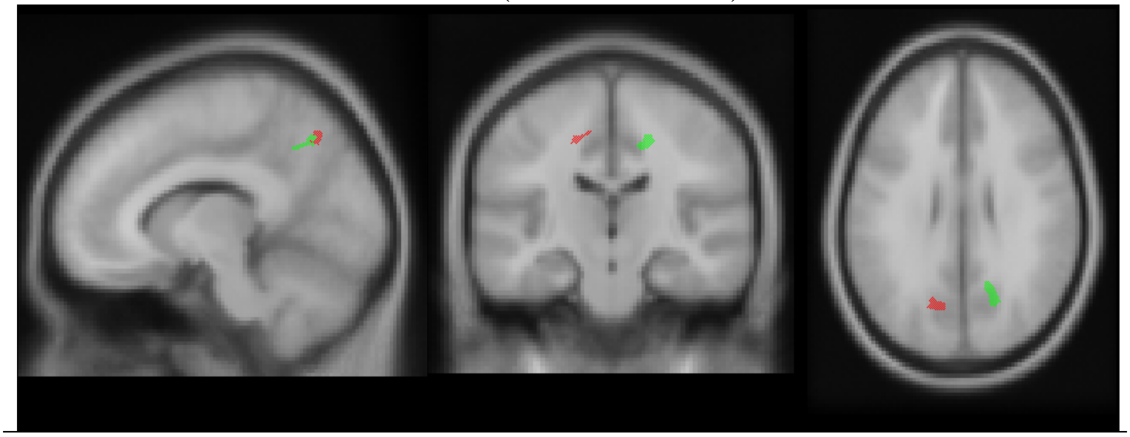
For the N250 component, two distinct dipoles were identified. The multiple model derived with best SNR of 14.7 and the residual variance is equal to 6.4% account for within the 93.6%. The results suggest middle fronal cingulated gyrus and precentral gyrus in the frontal region could be regarded as the origins for the N250 component

For the N400 component, three distinct dipoles were identified. The multiple model derived with best SNR of 3.5 and the residual variance is equal to 23.4% account for within the 76.6%. The results suggest paracentral gyrus, postcentral gyrus and the middle frontal gyrus in the frontal region could be regarded as the origins for the N400 component.

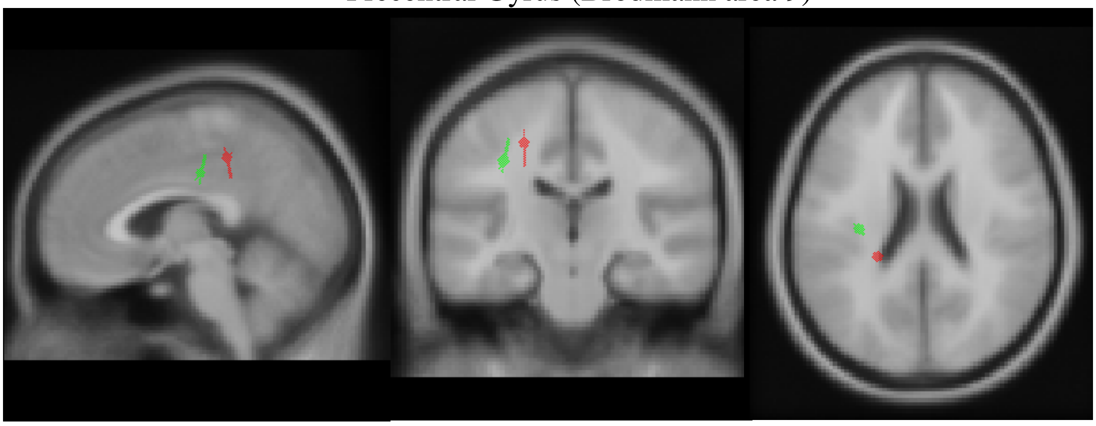
For the LPC component, three distinct dipoles were identified. The multiple model derived with best SNR of 3.8 and the residual variance is equal to 18.7% account for within the 81.3%. The results suggest Cingulate gyrus in the Limbic lobe, caudate and inferior parietal gyrus in the parietal region could be regarded as the origins for the P600 component.

Table 5.7. Location an orientation of CURRY 5 fitted dipoles of grand averaged ERP expressed in Talairach cooidnates

Components	Total variance	Dipoles	X	Y	Z
N100 (70-150ms)	90.8%	Dipole 1 (Red) Left cerebrum, Parietal lobe, Precuneus (Brodmann area 7)	-12	--43	48
		Dipole 2 (Green) Right cerebrum, Parietal lobe, Precuneus (Brodmann area 7)	12	-43	48

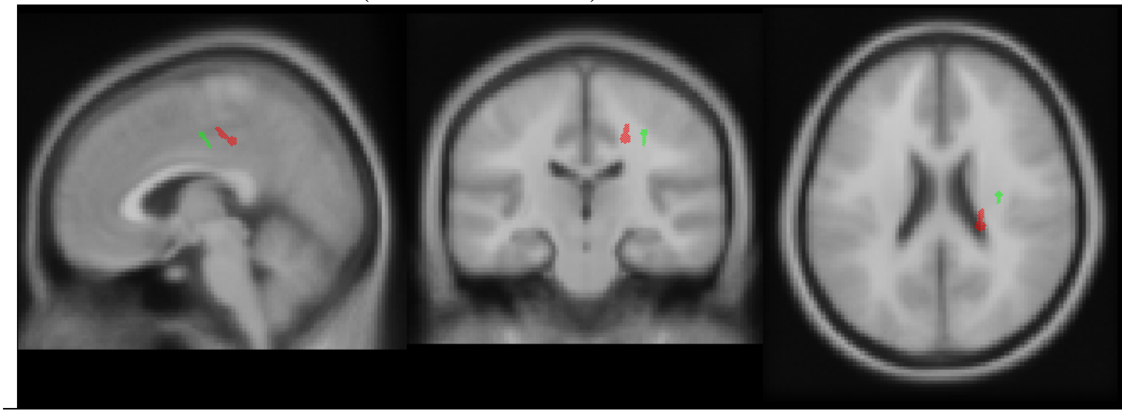


Components	Total variance	Dipoles	X	Y	Z
P200 (160-300ms)	78.6%	Dipole 1 (Red) Left cerebrum, Frontal lobe, Middle Frontal Gyrus (Brodmann area 6)	-24	-6	39
		Dipole 2 (Green) Left cerebrum, Frontal lobe, Precentral Gyrus (Brodmann area 9)	-34	7	35



Note: Values are in mm. Total variance= the percentage of variability explained by the model

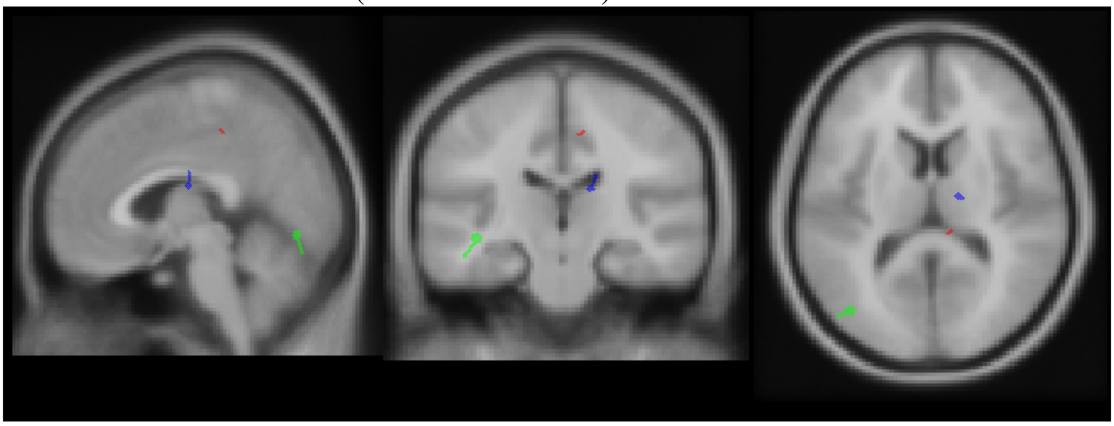
Components	Total variance	Dipoles	X	Y	Z
N250 (300-400ms)	93.6%	Dipole 1 (Red) Right cerebrum, Limbic lobe, Middle Frontal Cingulate Gyrus (Brodmann area 24)	20	-14	40
		Dipole 2 (Green) Right cerebrum, Frontal lobe, Precentral Gyrus (Brodmann area 9)	35	15	39



Components	Total variance	Dipoles	X	Y	Z
N400 (375-400ms)	76.6%	Dipole 1 (Red) Left cerebrum, Frontal lobe, Paracentral Gyrus (Brodmann area 6)	-15	-29	49
		Dipole 2 (Green) Left cerebrum, Frontal lobe, Postcentral Gyrus (Brodmann area 3)	20	-29	55
		Dipole 3 (Blue) Left cerebrum, Frontal lobe, Middle Frontal Gyrus (Brodmann area 6)	27	-2	48

Note: Values are in mm. Total variance= the percentage of variability explained by the model

Components	Total variance	Dipoles	X	Y	Z
LPC (520-800ms)	81.3%	Dipole 1 (Red) Right cerebrum, Limbic lobe, Cingulate Gyrus (Brodmann area 24)	10	-3	50
		Dipole 2 (Green) Right cerebrum, Sub-lobar, Caudate, Caudate body	14	13	12
		Dipole 3 (Blue) Left cerebrum, Parietal lobe, Inferior Parietal Gyrus (Brodmann area 40)	-42	-54	40



Note: Values are in mm. Total variance= the percentage of variability explained by the model

Source localization of image transformation task in non tai-chi group

For the N100 component, two distinct dipoles were identified. The multiple model derived with best SNR of 6.4 and the residual variance is equal to 1.4% account for within the 98.6%. The results suggest precuneus in the occipital region could be regarded as the origin for the N100 component.

For the P200 component, two distinct dipoles were identified. The multiple model derived with best SNR of 7.5 and the residual variance is equal to 18.4% account for within the 81.6%. The results suggest middle temporal gyrus and inferior parietal lobule in the temporal region could be regarded as the origins for the P200 component.

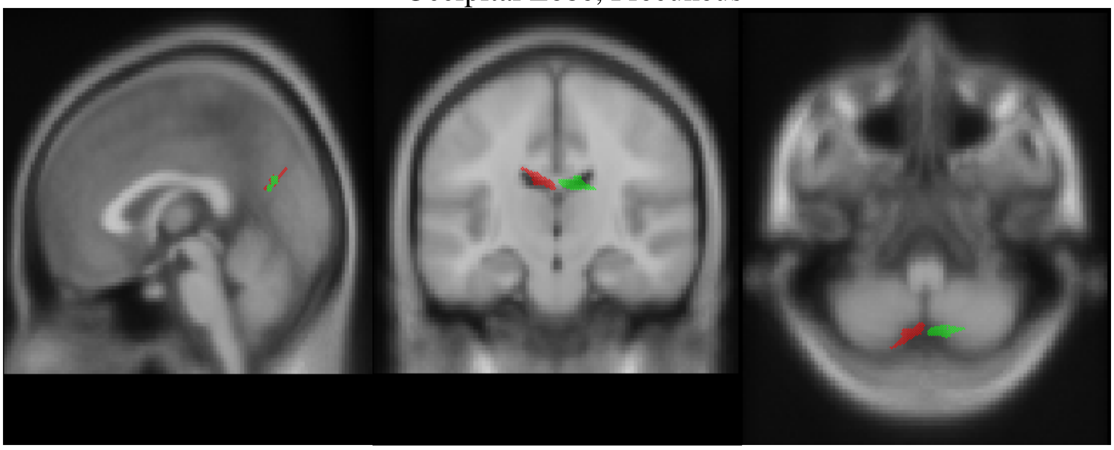
For the N250 component, three distinct dipoles were identified. The multiple model derived with best SNR of 5.6 and the residual variance is equal to 14.9% account for within the 85.1%. The results suggest middle frontal gyrus and precentral gyrus in the frontal region could be regarded as the origins for the N250 component.

For the N400 component, two distinct dipoles were identified. The multiple model derived with best SNR of 3.6 and the residual variance is equal to 25.7% account for within the 74.3%. The results suggest precentral gyrus and middle frontal gyrus in the frontal region could be regarded as the origins for the N400 component.

For the LPC, three distinct dipoles were identified. The multiple model derived with best SNR of 1.5 and the residual variance is equal to 22.7% account for within the 67.3%. The results suggest superior frontal gyrus in the frontal region, posterior cingulated in limbic lobe and thalamus could be regarded as the origins for the P600 component.

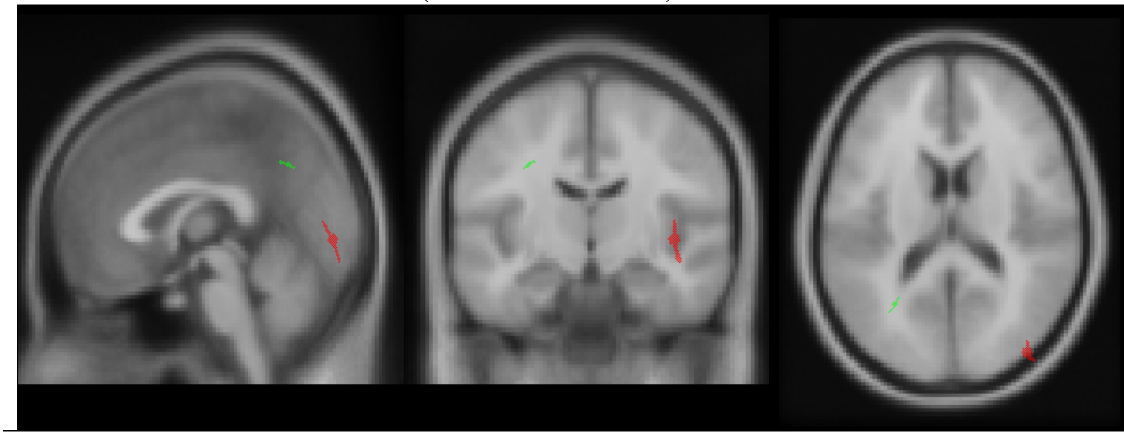
Table 5.8. Location an orientation of CURRY 5 fitted dipoles of grand averaged ERP expressed in Talairach coordinate.

Components	Total variance	Dipoles	X	Y	Z
N100 (70-150ms)	98.6%	Dipole 1 (Red) Left Cerebrum Occipital Lobe, Precuneus	-12	-66	36
		Dipole 1 (Green) Right Cerebrum Occipital Lobe, Precuneus	12	-66	36

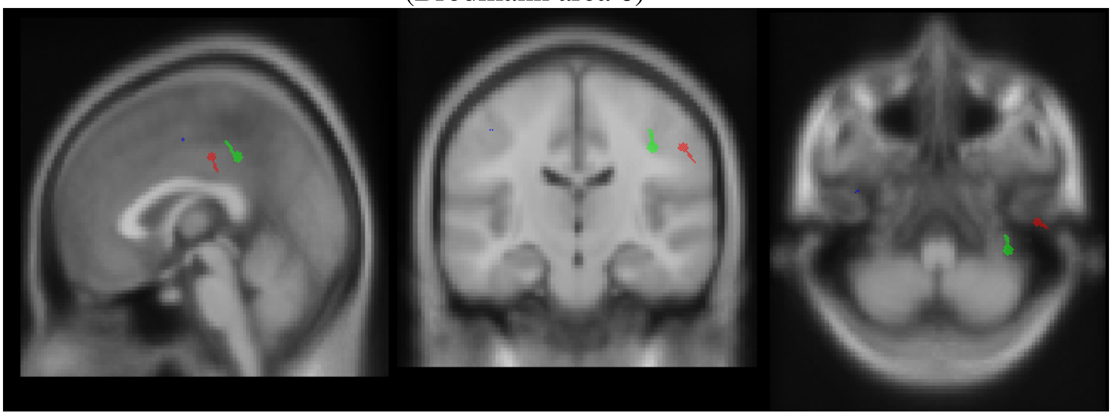


Note: Values are in mm. Total variance= the percentage of variability explained by the model

Components	Total variance	Dipoles	X	Y	Z
P200 (160-300ms)	81.6%	Dipole 1 (Red) Right Cerebrum Temporal Lobe Middle Temporal Gyrus (Brodmann area 39)	41	-64	16
		Dipole 2 (Green) Left Cerebrum Parietal Lobe Inferior Parietal Lobule (Brodmann area 40)	-30	-34	40

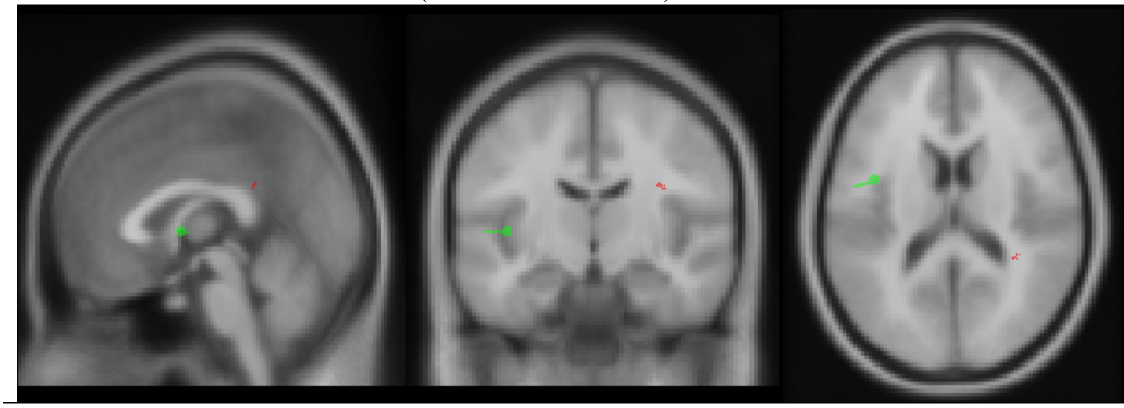


Components	Total variance	Dipoles	X	Y	Z
N250 (300-400ms)	85.1%	Dipole 1 (Red) Right Cerebrum, Frontal Lobe Middle Frontal Gyrus (Brodmann area 6)	53	5	50
		Dipole 2 (Green) Right Cerebrum, Frontal Lobe Middle Frontal Gyrus (Brodmann area 8)	-43	23	53
		Dipole 3 (Blue) Left Cerebrum, Frontal Lobe Precentral Gyrus (Brodmann area 6)	-38	-10	50

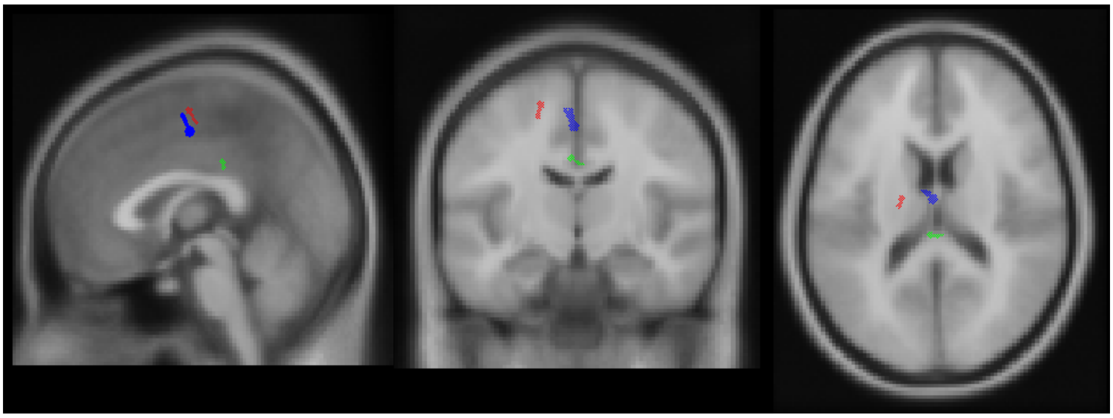


Note: Values are in mm. Total variance= the percentage of variability explained by the model

Components	Total variance	Dipoles	X	Y	Z
N400 (375-520ms)	74.3%	Dipole 1 (Red) Right Cerebrun, Frontal Lobe Precentral Gyrus (Brodmann area 4)	32	-16	45
		Dipole 2 (Green) Left Cerebrum, Frontal Lobr Middle Frontal Gyrus (Brodmann area 46)	-42	23	20



Components	Total variance	Dipoles	X	Y	Z
LPC (520-800ms)	67.3%	Dipole 1 (Red) Left Cerebrum, Frontal Lobe Superior Frontal Gyrus (Brodmann area 6)	-19	20	63
		Dipole 2 (Green) Left Cerebrum, Limbic Lobe Posterior Cingulate (Brodmann area 29)	-1	-39	16
		Dipole 3 (Blue) Left Cerebrum, Sub-lobar Thalamus	-3	-2	16



Note: Values are in mm. Total variance= the percentage of variability explained by the model

Correlation between ERP components for image generation Tai Chi experience

Statistical significant electrode sites in the post hoc comparison were further used for the correlation analysis. The score on the TCMIQ-KI was moderately correlated with the amplitude of P200 elicited at the fronto-centro-parietal region ($r=-0.52$ to -0.61, $p\leq0.05$) obtained from the image generation task. The results indicated that the more the competence of the tai-chi subjects using KI for practicing tai-chi the more positively-going was the amplitude of P200 at the fronto-centro-parietal region (Table 5.17). In contrast, the scores on the TCMIQ-KI was not found significantly correlated with the amplitude of N250 elicited at the fronto-central region ($r=-0.38$ to -0.48, $p>0.05$) (Table 5.17). This suggested that the competency on using KI in tai-chi practice was correlate to the P200 component in the image generation task

The years of tai-chi experience was found to moderately correlated with the amplitude of P200 elicited at the frontal-central region ($r=-0.43$ to 0.66, $p<0.01$) in the generation task. The more the years of experience which subjects in the tai-chi group practiced tai-chi the less positively-going was the amplitude of P200 at the frontal central region (Table 5.17). In contrast, the scores on the years of tai-chi experience was found to moderately correlated with the amplitude of N250 elicited at the frontal-central region ($r=-0.33$ to -0.54, $p<0.05$) in the generation task. The more the years of experience which subjects in the tai-chi group practiced tai-chi the less positively-going was the amplitude of N250 at the frontal-central and parietal-occipital region (Table 5.17).

Table5.17: Spearman's correlation coefficients between year of tai-chi experience, scores on TCMIQ among subjects in the tai-chi group and amplitude of P200 and N250 in image generation tasks

Component	P200					
Channels	F3	Fz	C4	CP3	CPz	P4
Year of experience	-0.43**	-0.55**	-0.51**	-0.58**	-0.57**	0.66**
TCMIQ-KI	-0.61**	-0.13	-0.56*	-0.52*	0.11	-0.07
TCMIQ-VMI	-0.13	-0.11	-0.07	-0.11	-0.02	-0.13
Component	N250					
Channels	F3	C4	P3	Oz		
Year of experience	-0.48**	-0.45**	0.33*	-0.54**		
TCMIQ-KI	-0.38	--0.30	-0.44	-0.48		
TCMIQ-VMI	-0.16	-0.01	-0.03	-0.05		

* p-value = 0.05, ** p-value = 0.01

Correlation between ERP components for image transformation and Tai Chi experience

Statistical significant electrode sites in the post hoc comparison were further used for the correlation analysis. The score of TCMIQ-KI was moderately correlated with the amplitude of P200 elicited at the frontal and central region ($r=-0.56$ to -0.61, $p<0.05$) obtained from the image transformation task. The results indicated that the more the competence of tai-chi using KI for practicing tai-chi the less positively-going was the amplitude of P200 at the fronto-centro-parietal region (Table 5.18). The score of TCMIQ-KI was moderately correlated with the amplitude of N250 elicited at the fronto-central region ($r=-0.56$ to -0.64, $p<0.05$)(Table 5.18). The more the competence of tai-chi using KI for practicing tai-chi the more negatively-going was the amplitude of N250 at the fronto-central region. The score of TCMIQ-KI was moderately correlated with the amplitude of N400 elicited at the fronto-central region ($r=-0.65$ to -0.81, $p<0.01$) (Table 5.18). this result indicated that the more the competence of tai-chi using KI for practicing tai-chi the more negatively-going was the amplitude of N400 at the fronto-central region.

The years of tai-chi experience was found to moderately correlated with the amplitude of P200 elicited at the frontal-central region ($r=-0.53$ to -0.89, $p<0.01$) in the transformation task. The more year of experience which subjects in the tai-chi group practiced tai-chi the less positively-going was the amplitude of P200 at the frontal central region (Table 5.18). The years of tai-chi experience was found to moderately correlated with the amplitude of N250 elicited at the frontal-central-parietal region ($r=-0.52$ to -0.79, $p<0.01$) in the transformation task. The more year of experience which subjects in the tai-chi group practiced tai-chi the less positively-going was the amplitude of P200 at the frontal-central-parietal region (Table 5.18). The years of tai-chi experience was found to moderately correlated with the amplitude of N400 elicited at the frontal-central-parietal region ($r=-0.44$ to -0.64, $p<0.05$) in the transformation task. The more year of experience which subjects in the tai-chi group practiced tai-chi the less positively-going was the amplitude of P200 at the frontal-central-parietal region (Table 5.18).

Table5.18: Spearman's correlation coefficients between year of tai-chi experience, score of TCMIQ among subjects in the tai-chi group and amplitude of P200, N250 and N400 in image transformation tasks

Component					P200				
Channels	F3	Fz	F4	C3	Cz	C4	CP3	CP4	
Year of experience	-0.83**	-0.80**	-0.53**	-0.83**	-0.59**	-0.78**	-0.89**	-0.87**	
TCMIQ-KI	-0.61*	0.13	-0.37	-0.13	-0.39	-0.56*	-0.07	-0.06	
TCMIQ-VMI	-0.13	-0.04	-0.25	-0.11	0.06	-0.06	-0.07	-0.07	
Component					N250				
Channels	F3	Fz	F4	C3	Cz	C4	CP4	P3	O3
Year of experience	-0.78**	-0.68**	-0.79**	-0.66**	-0.68**	-0.52**	-0.75**	-0.68**	-0.73**
TCMIQ-KI	-0.56*	0.02	-0.57**	-0.64**	-0.12	0.57**	0.58**	-0.38	-0.27
TCMIQ-VMI	0.16	0.21	-0.18	0.12	0.02	0.18	-0.03	-0.16	-0.22
Component					N400				
Channels	Fz	Cz	C4	CPz	P4	O4			
Year of experience	-0.64**	-0.58**	-0.48**	-0.44*	-0.45**	-0.46**			
TCMIQ-KI	-0.81**	-0.68**	-0.65**	-0.20	-0.13	-0.09			
TCMIQ-VMI	-0.32	0.01	-0.12	-0.16	-0.08	-0.06			

* p-value = 0.05, ** p-value = 0.01

CHAPTER VI

DISCUSSION

This chapter begins with presenting overall finding of the behavioral and ERP studies. This is to be followed by interpretations of the neural processes underlying generation and transformation of tai-chi related kinesthetic images by subjects with experience in practicing tai-chi. The implications on potential application of tai-chi as an intervention in cognitive rehabilitation will also be discussed.

Overall findings

Results indicated that subjects in the tai-chi and non tai-chi groups were not differed in scores on VVIQ (p=0.149), MIQ-KI (p=0.550) and MIQ-VMI (p=0.355) suggesting that both groups had similar visual and motor imagery abilities. The non significant differences in the scores on the TCQ and TCMIQ among subjects within the tai-chi group further suggested that the homogeneity of subjects in the tai-chi group in terms of their experiences and perhaps competence in practicing tai-chi. Behavioral result from the ERP main study indicated that the tai-chi group was more accurate than the control group in both the generation (p=0.006) and transformation (p=0.004) tasks. In contrast, the tai-chi group performed significantly slower than the control group on both tasks (generation: p<0.001; transformation: p=0.02). This might be due to the characteristic of practicing Tai Chi. Tai Chi practitioner usually plays Tai Chi in a calmness mind activity with a slow pacing practice (Li et al, 2003).

In generating images of tai-chi forms, subjects in the tai-chi group were found to elicit more positive going P200 fronto-central regions and more negative going N250 in extensive anterior to posterior regions than those in the non tai-chi group. The only difference in N100 was in latency elicited in the posterior regions of which tai-chi group had shorter latency than non tai-chi group. When compared with the control group, the ERPs elicited by subjects in tai-chi group when transforming images of tai-chi forms were found to be different from those elicited when the images were generated. Subjects in tai-chi group were revealed to have shorter latency than non tai-chi group in most of the ERP components, except the N400. The P200 elicited by the tai-chi group during the transformation of images were less-positive than the non tai-chi group and its topography covered extensive anterior to posterior regions. The N250 elicited was also more negative-going over an extensive anterior region and less negative-going over the posterior region. Different from P200, the N400 elicited by the tai-chi group was more negative-going than the non tai-chi group over fronto-central and occipital areas. While the between-group differences in the LPC were less obvious, which was supported the non-significant results obtained from the independent component analysis.

Tai-chi effects on generation of kinesthetic images

The rate limit steps of the image generation task used in this study were attending to the single-Chinese-character prompts and then retrieved images of the tai-chi form learnt prior to the experiment. These processes were proposed to associate with early event-related components of N100, P200 and N250. The ERP morphology suggested that subjects in the tai-chi and non tai-chi groups showed differences in the amplitude of P200 and N250. Such differences were not observed in the N100, however. The P200 and N250 components were largely associated with processes involved in the "imagery network" proposed by Kosslyn and Thompson (2003).

N100 was previously found to associate with allocation of attentional resources such as visualizing stimuli (Fort et al., 2005; Lick et al., 2000; Rugg et al., 1987;

Vogel & Luck, 2000; Wascher et al., 2009). Cebrian and Janata (2010) found that less negative-going N100 at the parieto-occipital regions was associated with increased experience in generating accurate images after receiving appropriate auditory information. The non-significant between-group differences in amplitudes of N100 suggested that the attentional resources allocated by subjects when engaging in generating the images of tai-chi forms were rather similar between tai-chi and non tai-chi groups. The implications of the findings were that subjects in both groups were not differed in the competence in associating the single-Chinese-character prompts with specific tai-chi forms when performing the image generation task. In the training session, subjects with tai-chi background would need to relearn the single-Chinese-characters which were different from what they had been used to. Recruiting tai-chi subjects who did not had prior experience practicing *Yang* style would be useful for reducing the pre-training biases against familiarization of the tai-chi forms between the two groups. N100 was also revealed to associate with discrimination processes after detection of the stimuli (Vogel & Luck, 2000; Vogel, Woodman & Luck, 2001). The shorter latency (mean difference ranged from -25.28ms to 25.86ms) in this early component (over parieto-occipital regions) elicited among the tai-chi subjects probably suggested that these subjects might have reacted more readily to the visual prompt than their non tai-chi counterpart. To what extent the shorter latency N100 would contribute to between-group differences in the subsequent processing was not clear.

The component following N100 was P200. Previous studies on rotation of mental images revealed that P200 elicited over frontal and parietal areas were associated with retrieval of motor related images (mental rotation of the hand) from the long term memory (Thayer & Johnson, 2006). Annett (1995) suggested that positive-going P200 elicited in the anterior (or centro-parietal) regions was associated with retrieval of motor-related information from long term memory. The information was further proposed to be used for motor preprogramming (Fattapposta et al., 1996; Thayer &Johnson, 2006). The results of this study revealed that subjects with tai-chi experience elicited more positive-going P200 than those without tai-chi experience over F3, Fz, C4, CP3, CPz and P4. The non-significant differences in the P200 latency supported that the mental processes undergone were similar between the two groups. Putting them together, subjects with tai-chi experience when generating images of tai-chi forms would have involved more effective retrieval from long term memory processes than those without tai-chi experience. With more effective retrieval, subjects with tai-chi experience were likely to have better motor preprogramming in actual execution of the tai-chi forms. This proposition was supported by a study conducted on gun shooting athletes revealing their more superior preprogramming than novelist (Fattapposta et al, 1996). It was noteworthy that the amplitudes of the significant P200 was found negatively correlated with subjects' years of experience practicing tai-chi (r=0.43-0.66, p=0.01). In other words, those who were with less experience practicing tai-chi (fewer years) would elicit more positive amplitude of P200, suggesting that they would be less effective on retrieving bodily images. This concurs with the findings of significant correlations found between the TCMIW-KI scores and the amplitude of P200 elicited at the central sites (r= -0.51 to -0.56, p=0.05). The significant correlations suggest that for tai-chi subjects who expressed using KI more would facilitate the retrieval of motor-related images. These findings further substantiated the validity of the Tai Chi Questionnaire (TCQ) and Tai Chi Motor Imagery Questionnaire (TCMIQ). Subjects with fewer years of experience tended to rate lower on items of both questionnaires. The examples are: #Q3 of TCQ: When I performed the forms, I am always certain about whether the postures I displayed were correct or not (每次耍太極時我都清楚知道是否打出正確姿勢).

#Q1 of TCMIQ: When performing on the forms, I am used to display a step-by-step series of posture/limb actions in my mind (打太極的時候，我習慣在腦海中呈現一個接一個的動作). Previous studies attributed in smaller amplitudes of P200 to neural efficiency at the central region (Di Russo et al., 2005; Haufler et al, 2000; Kita, Mori & Nara, 2001). The neural efficiency suggested more efficient cortical function. In the context of this study, tai-chi subjects who obtained higher scores on the TCMIQ would have higher performances on generating the tai-chi images.

N250 elicited within the 270 - 400 ms time window in the premotor region was revealed to associate with motor-related working memory (Yammamoto & Mukai, 1998) and preparation for motor execution (Romero et al., 2000). When elicited from contralateral posterior sites, the component was functionally related to spatial discrimination of visual or auditory stimuli (Eimer & Schroger, 1998; Luck & Vogel, 1997). In this study, the image generation task required the subjects to visualize positions of various body parts of the human-model practicing tai-chi forms. The subjects would need to attend and visualize the posture and limb positions of the human-model which tapped on visuo-spatial working memory functions. Our findings indicated that the N250 elicited by tai-chi subjects were significantly more negative-going than non tai-chi subjects at the F3, C4, P3 and Oz sites. The subtracted waveform further suggested that the anterior regions were more negative-going than the posterior regions. The tai-chi subjects would be more readily generating the images of the tai-chi forms in the motor-related working memory than those in the control group. The tai-chi subjects would tend to rely more on their visuo-spatial discrimination (less negative-going in posterior regions) to identify the target displayed in the image of the tai-chi form, such as the left hand, and differentiate whether it would have been pointing to the “right” (requirement of making the response in the task). This would also account for their higher accuracy rate on identifying the posture and limb positions of the generated tai-chi images than those in the control group on the image generation task.

Tai-chi effects on transformation of kinesthetic images

The rate limiting step in the image transformation task was on the manipulation of sequential motor-related images corresponding to specific instances within the six four-second tai-chi form clips. Its processing would be subsequent to generation of the image of the human-model assuming the start posture of a tai-chi form. Results indicated that the transformation of these kinesthetic images involved six distinct components: N100, P200, N250, N400 and late positive components. The four early components N100 to N250 would have associated with primary with image generation whilst the two late components N400 and LPC would have associated with the transformation of these images. These ERP components are consistent with those revealed in imagery of vibrotactile sensation (Chow et al., 2007), visual stimuli (Thayer & Johnson, 2006) and auditory stimuli (Wu et al., 2006).

The between-group differences revealed in the early components captured during the image transformation task are largely comparable with those obtained from the image generation tasks. There are two main discrepancies. First, the latency differences observed in these early components were more obvious as majority of them reached statistical significance. In general, subjects in tai-chi group displayed a significantly shorter latency in all early components, except that of N100. Second, the between-group differences in the amplitudes were greater than those revealed in the image generation task, whilst the sites found with significant differences were more extensive. In several cases, the differences between the tai-chi and non tai-chi groups covered anterior to posterior topography. These findings supported the notion that transformation of images of tai-chi forms was likely to first involve generation of these images. More importantly, the retrieval of motor-related images and had them maintained for manipulation in the motor-related working memory (Chow et al., 2007; Fallgatter, Muelle & Strik, 1997; Kekoni et al., 1996; Romero et al., 2000) would be more intensive. Subjects in the tai-chi group were likely to undergo these processes more effectively and hence perform more superiorly in terms of accuracy rate than those in the non tai-chi group on the image transformation task. This proposition was supported by the significant between-group differences obtained for P200 and N250 elicited over fronto-central and parieto-occipital areas. It was plausible that these differences were attributable to the internalized tai-chi effects of which practicing on tai-chi forms involved heavily on visualizing kinesthetic images of forms in particular seeing self assuming posture/limb positions before actual execution of these forms. Li and colleagues (2003) commented that forming mental intention leading to physical force and actual execution was an important component in tai-chi (Li et al., 2003). For example, the internal skill could be the abilities in controlling the equilibrium of static/moving, active/passive, tension/relaxation, forceful/yielding through the integration of “意” ji3 (Cantonese)(Liang & Wu idea cited in Li et al., 2003, p.207).

The N400 belongs to one of the two late components expected to elicit in the image transformation task. Previous study suggested that N400 elicited at the posterior sites was associated with semantic processing of words (Bach et al., 2009; Sitnikova et al., 2008) and semantic priming effect (Chwilla et al., 2000; Hill et al, 2005; Kiefer et al., 2002). Semantic processing was commonly manipulated by having subjects to identify meaning of words in a sentence. With this in mind, the significant between-group differences in the amplitude of N400 elicited at the posterior sites obtained in this study might be attributable to the differences in semantic processing between the tai-chi and non tai-chi groups in the image transformation task. The non-significant correlations between the amplitudes of the posterior site N400 and scores on the TCMIQ suggest that the between-group differences in amplitudes are likely not to be tai-chi specific. Instead, these differences could be attributable to the design of the image transformation task which biased against the tai-chi but not non tai-chi subjects. For example, the tai-chi subjects would find truncating the "十字手" form into four discrete 1 s duration steps not compatible with their regular tai-chi practice. This is in discrepancy with the continuous flow of actions in tai-chi practice. The stimulus containing "十3" (means 3rd second in the form) would have special semantic meaning to the tai-chi but not non tai-chi subjects. In contrast, the significant differences in the amplitude of N400 elicited at the anterior sites would not relate to semantic processing but retrieval and integration of motor related task information between the tai-chi and non tai-chi subjects (Gunter & Bach, 2004; Reid & Striano, 2008). The significant differences in N400 also reflect differences in preparation of motor actions in the image transformation task between the tai-chi and non tai-chi subjects. The preparation of motor actions was reported in study using a congruent and incongruent motor image task (Proverbio & Riva, 2009). Gunter and Bach (2004) observed N400 elicited when meaningful and meaningless hand postures were contrasted. In this study, subjects in tai-chi group displayed more negative-going N400 than those in non tai-chi group within the 375 - 520 ms time window. . The former group had significantly shorter N400 latency than the latter group over centro-parietal sites, and higher accuracy rate in manipulation of images of tai-chi forms. The amplitudes of N400 over the Fz, Cz and C4 sites of tai-chi subjects moderately correlated with the tendency of using KI when practicing tai-chi. These correlations further support the argument that the between-group significant differences in N400 elicited in the anterior sites were motor related. The differences indicated tai-chi subjects had higher tendency and perhaps competence in retrieving, transforming and integrating tai-chi related images in the experimental task than the non tai-chi subjects. It is noteworthy that the tai-chi subjects had higher accurate rate but longer response time than the non tai-chi subjects in the behavioral task. The between-group differences seem to be attributable to the experiences gained by the tai-chi subjects particularly the slowness, sequential and continuous flow of forms when practicing the tai-chi forms.

Late positive component captured within the 520 – 800 ms time window was previously related to processing of complex information by maintaining such information in working memory (Guillen et al., 1999). Yamamoto and Mukai (1998) reported the association of more positive-going LPC elicited at fronto-cento-parietal regions with recall of kinesthetic (or motor) images. In our study, between-group differences in LTC amplitudes and latency were statistically non-significant. The reasons for explaining the counter-intuitive findings are similar to those given for N400. The rather simple four-second tai-chi form clips and training would have jeopardized the effect size for the between-group comparisons.

Comparison of waveforms associated with image generation and transformation

Attempts were made to compare the waveforms between the image generation and transformation processes. The purpose was to explore the possibility of further isolating the image transformation processes from the image generation processes by subtracting the waveforms generated from the two conditions: namely image generation and image transformation. Initial inspection of the waveforms indicated differences in the earlier components (Figures 6.1 and 6.2). The differences were observed in the P200 component of which the waveform for the image transformation condition appeared to be less positive-going in the anterior sites and more positive-going in the posterior sites than that of the image generation condition. The P200 latency also seemed to elicit earlier in the image transformation than generation condition. Similarly, the N250 elicited in the image transformation condition appeared to be less negative-going than that in the image generation condition. The differences in their peaks however were less easy to observe. In view of these findings, waveform subtraction method was not conducted as the results might not be meaningful. Nevertheless, the observable differences could not lead to conclusion that the image generation processes were not comparable between the image generation and transformation tasks used in the study. The shape of a local part of the waveform might not direct reflect the latent components underlying the mental process (Luck, 2005). The observable differences could be the results of the differences in the task demands when generating the motor-related images in the two tasks. For instance, in the image transformation task, the subject was required to generate the human figure in a specific tai-chi form and at the same time visualize the details of the figure and prepare for a mental rotation process. In contrast, in the image generation task, mental rotation was not part of the task and henceforth the subject could attend to the image generated and conduct the visualization.

Figure 6.1

Grand-averaged ERPs of the electrical activities captured on scalp in the image generation and transformation conditions for tai-chi group at 15 electrodes from -200 ms to 1000 ms.

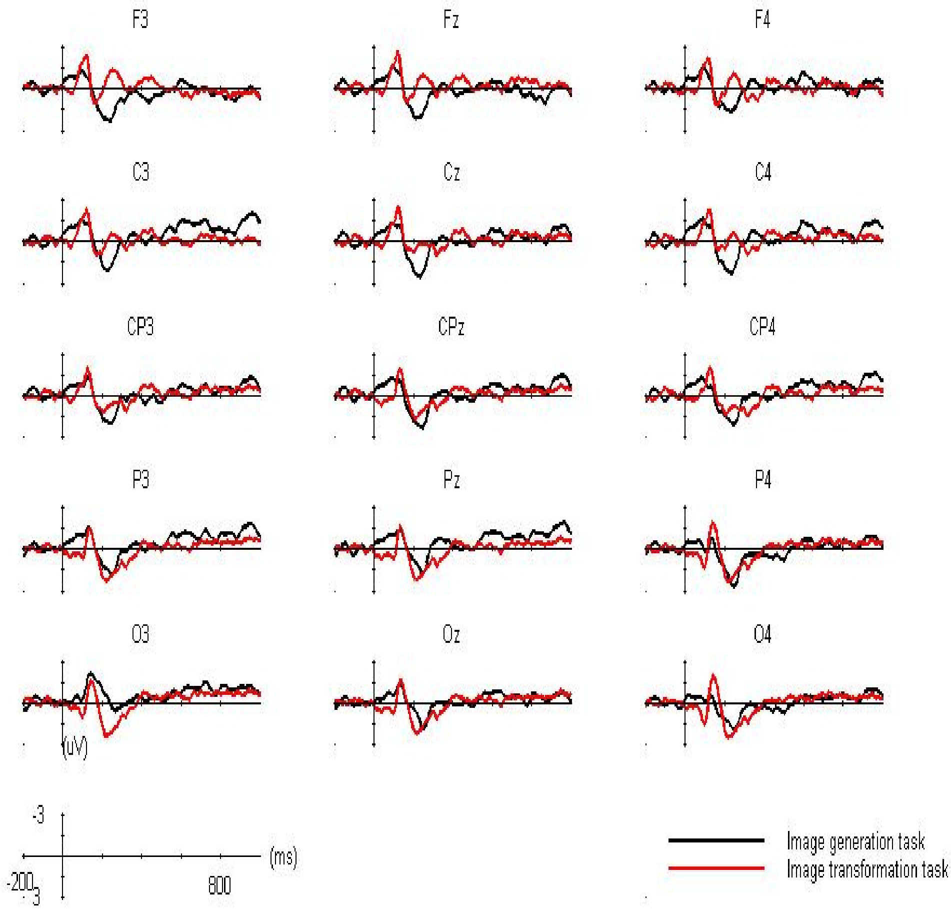
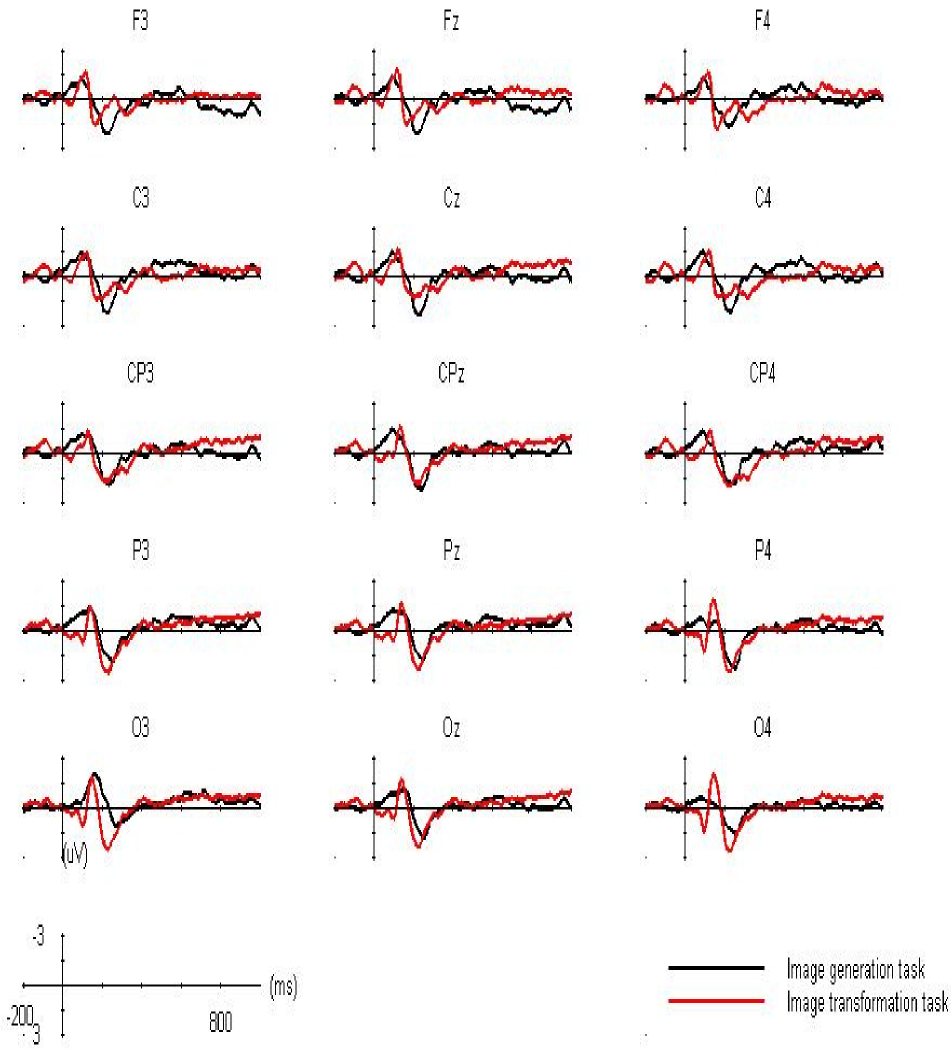


Figure 6.2:

Grand-averaged ERPs of the electrical activities captured on scalp in the image generation and transformation conditions for non tai-chi group, at 15 electrodes from -200 ms to 1000 ms.



<u>Dipole sources identified for image generation and transformation processes</u>

Significant differences were revealed in the amplitudes and latency of the ERP components elicited in the image transformation processes between the tai-chi and non tai-chi group. The dipole sources estimated based on the data of the two groups provide additional information to support these findings. In the generation task, the tai-chi group dipole identified for the N100 and P200 components were around the frontal region included medial frontal gyrus (for N100 only), superior frontal and precentral gyrus and cingulated gyrus in the limic region (for P200 only), whilst for the non tai-chi group was around medial frontal gyrus, cingulated gyrus in the limbic lobe, postcentral gyrus (for N100 only) and paracentral lobule in the frontal region (for P200 only). The main differences were in the posterior shift in the non tai-chi group suggesting that subjects in the non tai-chi group could use more attentional, semantic on the somato-sensory than their tai-chi counterpart when generating visualizing images of tai-chi form. For the N250 component, dipole identified in both tai-chi group and non tai-chi group was around middle frontal gyrus and cingulated gyrus in the limbic region suggest both group undergo the cognitive and attention process when generate and hold the image of the tai-chi form.

In the transformation task, the tai-chi group, dipole identified for the P200 and N250 component was around the middle frontal gyrus (BA6) (for P200 only), precentral gyrus (BA9), and middle frontal cingulate gyrus (for N250 only), whilst that for the non tai-chi group was around the middle temporal gyrus (BA39) and inferior parietal lobule (BA40) for P200 and middle frontal gyrus (BA6 and BA8) and precentral gyrus (BA6) for N250. The main differences were in the posterior shift in the non tai-chi group suggesting that subjects in the non tai-chi group could use more phonology and semantics than their tai-chi counterpart when generating and visualizing images of tai-chi forms (Stoekel, et al., 2009). In contrast, the differences in the dipole sources identified for the N400 were less obvious between the two groups. For the P600 component, despite the cingulate was identified as the dipole source but it was the cingulate gyrus (BA24) identified for the tai-chi group and posterior cingulate (BA29) identified for the non tai-chi group. Their locations and functional roles are rather different that the former is related to error and conflict detection whilst the latter is related to prioception and visuospatial processing. The other dipole sources identified for the tai-chi group were the caudate body and the inferior parietal gyrus when compared with the superior frontal gyrus and thalamus for the non tai-chi group. The caudate nucles is associated with learning and memory and the inferior parietal region is concerned with interpretation of sensory information and body image (Peeter et al., 2009). The thalamus is related to sensation, spatial sense and motor signals and the superior frontal gyrus is sensori-motor system coordination (Goldberg, Harel & Malach, 2006).

Implications for better understanding of tai-chi practice

Tai-chi is a low to moderate intensity activity which emphasizes slow pace, body flexibility and mind-body integration. Tai-chi is composed of sequential series of physical forms of which their execution tap heavily on motor preparation and motor planning (Chen, 2002; Wolf et al., 1997; Yan & Downing, 1998). The importance of preparation and planning prior to execution of tai-chi forms is further supported by Li (2003). First, a crucial component of tai-chi practice is “using mental focus instead of physical force” (Li et al., 2003, p.207). In other words, tai-chi practitioners have been reminded to undergo mental imagery and in particular kinesthetic imagery (visualize self performing the form) before and during execution of the forms. These mental imagery processes were given the term “mental intention” (Li, 2003). Outside the context of tai-chi, making decision on initiating specific voluntary movements at a specific moment was previously defined as motor planning (Deeke, 1996). The processes were further differentiated into decision making mediated by frontal lobe and updating of sensori-motor information mediated by the parietal lobe. It is plausible that kinesthetic imagery or mental intention processes would play an important role in enhancing smooth and continuous transition across sequential tai-chi forms. Other crucial elements proposed by Li (2003) were related to the complex coordinated movements in tai-chi forms. For instance, "coordinating upper and lower body movements" and "distinguishing solid (weight bearing) and empty (non-weight bearing)" (Li et al., 2003, p.207) are useful for raising the awareness of sensori-motor inputs and integration during the preparedness and practice of tai-chi forms. Maintaining steady and slow pace is another feature of tai-chi. Lotze and Halsband (2006) suggested that speedy motor execution would hamper quality of motor imagery.

Findings of this study revealed differences in the neural processes between subjects with experience of practicing tai-chi and those who did not possess such experience. Majority of these differences were found in the generation of images of tai-chi forms but less in transformation of these images. In general, subjects with tai-chi experience allocated less attentional resources (denoted by N100) than the controls relating and retrieving static images of tai-chi forms from memory (by P200). They were found to be more readily to generate the tai-chi form images (denoted by N250), and maintain them in the motor-related working memory for manipulation (N400). These processes probably define the activities involved in "mental intention" in tai-chi (Li, 2003). Tai-chi practitioners commonly learnt series of forms which compose a style. The number of forms ranges from 8 to 128 in the simplified Ng and Yang styles respectively. The learning of the forms requires practitioners to vividly store each of the forms in the long term memory. Before execution of these forms such as in an actual practice, a practitioner would require to recall these forms in sequence and visualize them in the instance when the forms are executed. The recall (P200), generation (N250), and maintenance (N400) of tai-chi forms would be comparable to those processes elicited in the image generation task and beginning of the image transformation task. As the mental processes in the image generation task shared similarities with those in motor planning prior to execution of tai-chi forms, the readiness and higher intensity of neural processes elicited when generating tai-chi images is likely to be attributable to the experiences of tai-chi practice. However, the manipulation of the images subsequent to maintenance of these images (denoted by P600) did not reach a significant between-group difference in the transformation task. This perhaps was due to the constraints of the task design (without a motor component) of which the tai-chi forms used were much shorter in duration than the actual forms (only four-second clips versus 30 to 40 seconds) and the posture and limb positions displayed were relatively simple. Any privileges as results of gaining tai-chi experience would have become less effective. The argument that the between-group differences were likely to be due to familiarity with tai-chi biased against the non tai-chi practitioners could not be established as training was provided to both tai-chi and non tai-chi groups prior to the experiment.

Our findings on tai-chi practitioners concur with those revealed by other studies on experienced pianists (Bangert & Altenmüller, 2003), dancers (Sacco et al, 2006), golfer (Brouziyne & Molinaro, 2005). These studies indicated that experts, when compared with novelists, showed significantly stronger or higher level of neural processes such as BOLD responses in areas of the brain which mediated the learning and practices of these skills. These studies further explained that differences in the neural processes between experts and novelists perhaps were attributable to the possible plastic changes in the neural system as results of learning through training and practice.

Tai-chi and implication to rehabilitation

The findings of this study support the notion that tai-chi practitioners would be readily to undergo intense kinesthetic imagery of tai-chi forms. Previous studies reported the usefulness of employing mental training for complementing performance-based training on improving isometric muscle strengths (Yue & Cole, 1992), dynamics motor performance (Grandevia, 1999), and lower limb function (Lafleur et al., 2002). Jackson and colleagues (2001) concluded that, when compared with novel and external motor-related images, internal driven images were useful for maximizing gains in combining motor imagery and performance-based training. These principles were found to equally apply to training of athletes (Cumming & Hall, 2002; Roure et al., 1999) and musicians (Langheim et al., 2002). Tai-chi practice as shown in this study would involve kinesthetic imagery of which the images generated are from the first-person perspective. Its practice would enhance kinesthetic imagery and hence producing internal driven images which is useful for motor functional retraining. Liu et al. (2004a) demonstrated that imagery training on execution of complex daily tasks could enhance their actual performance among post-stroke patients. The ultimate outcome was to use imagery training to enhance functional regain of brain injury patients (Liu et al., 2004b). There is potential for tai-chi to be used as a rehabilitation strategy for promoting motor function recovery of patients suffered from brain injuries.

CHAPTER VII

CONCLUSION

The present study using event-related potential to investigate the potential differences in neural processes associated with kinesthetic imagery of tai-chi forms between those with or without experience in practicing tai-chi. The results would enable us to understand the mental component of tai-chi and at the same time explore how practice and experience could modulate kinesthetic imagery process.

The ERP components found associated with the tai-chi image generation included P200 and N250. The P200 was found associated with the beginning of the imagery processes to retrieval motor related images from the long term memory (Thayer & Johnson, 2006). N250 component associated with spatial working memory and motor related manipulation in the senori-buffer. The ERP components found to be associated with the image transformation task included P200, N250 and N400. The P200 component played an important role for generating motor information and then maintained the information for next step (manipulation) in the imagery network. N250 component was associated with manipulation in working memory and The N400 was suggested to associate with the retrieval of context-specific stimuli with effort required, and to associate with retrieval and integration of motor related task information. Result suggested that subjects with tai-chi experience could generate tai-chi images and transform the movement sequences embedded in the tai-chi forms more effectively than those without tai-chi experience. The intensity of activities associated with most of these processes was found to positively correlate with the years of practicing tai-chi. Experiences in practicing of tai-chi could modulate kinesthetic imagery of images of tai-chi forms. The results obtained are consistent with other studies on motor imagery or execution between experts and novices. The results of this study may not readily be generalized to other activities or sports as tai-chi has its unique ingredients and practices. The fact that tai-chi emphasizes slowness and smoothness in planning and execution largely different from common sport activities. Generalization of our findings to execution of tai-chi forms would also pose problem. The reason is that the experimental tasks used in this study did not involve execution but planning and mental rehearsal of tai-chi forms.

This study provides the opportunity for researchers to better understand the mental component of tai-chi. The allocation of less attentional resources, more effective retrieval from long term memory on tai-chi images, and maintenance and manipulation of these images in motor-related working memory are likely to be brought about by practice of tai-chi by the practitioners. The specific neural processes might be useful for designing rehabilitative interventions using tai-chi as a training media for patients with brain injury.

Limitation of this study

The researcher believes that this study is the first of its kind on benefits brought by practice of tai-chi. There are however a few limitations which might confound the finding and have rooms for improvement in future study.

First, event-related potential has a low signal-to-noise ratio. To maximize the signal strength, this study employed two strategies: one was to design simple kinesthetic imagery tasks and the other one was to use more trials in each task task. As a result, a control task which originally planned to elicit kinesthetic imagery of non tai-chi forms such as physical movements or sports had been excluded from the task design. With a control task, the between-group differences due to familiarity of tai-chi forms biased against the non tai-chi group could be eliminated. The lack of a control task would weaken the conclusions to be drawn on the between-group differences, i.e. the tai-chi effects on specific neural processes associated with kinesthetic imagery. Nevertheless, the differentiation of the tai-chi effects on fronto-central but not parieto-occipital region topography of tai-chi minus non tai-chi group elicited by the image generation task is the counter-argument of potential familiarity biases confounded in the experimental tasks.

Second, the image generation and transformation tasks were custom-designed for this study (new tasks). Its validation has not been published. The mental processes undergone in each of the tasks were based on review of previous literature and verification of the event-related potentials elicited from performing on the tasks. It would have been desirable if both image generation and transformation could be validated on control subjects and both tai-chi and non tai-chi tasks beforehand. As a result, the conclusions made based on the results were limited to the characteristics of the tasks and background of the subjects. The attribution of practice of tai-chi and superiority of tai-chi practitioners than the novices was less emphasized.

Third, in order to control for potential Type I errors, we adopted a conservative approach to set statistical significance for all comparisons. Bonferroni adjustments were applied to all repeated measures ANOVAs such as $p \leq 0.010$ instead of 0.050. This procedure would largely reduce the chance to reject null hypotheses in testing the main and interaction effects in particular the Group effect. The results obtained from this study should be interpreted with caution.

Implications for future study

This is the first ERP study on tai-chi practice and kinesthetic imagery of tai-chi forms. Future study should incorporate a control task which requires both tai-chi and non tai-chi subjects generate and transform non tai-chi form images. This would further minimize the biases which would have brought by the task content. Neuroimaging study can shed light on the spatial resolution of the neural processes which compliments the results of this study. The effect of using tai-chi form practice for training of patients with neurological impairments or brain damage can use event-related potentials for informing how the practice might modulate the related neural processes in motor planning and preparation.

CHAPTER IX

APPENDICES

Appendix I – Item Modification of Tai Chi Questionnaire

Table 1:

Item Modification of Tai Chi Questionnaire

Old sentence	Modified sentence
Item 1	
我能夠清楚了解太極拳中各式的要求。	我能夠清楚了解太極拳中各式的動作及外形的要求。
Item 2	
打太極的時候，我能做到手腳協調，連綿不斷。	打太極的時候，我能做到全身放鬆，上下相隨。
Item 5	
耍太極時，我會感覺到用意不用力。	耍太極時，我會能用意念帶動身體的動作。
Item 7	
我正在改善一些招式細微動作的要求。	我正在改善一些招式的細微動作，如身體各部份之間的距離及彎曲的角度。

Table 2:

Item Modification of Tai Chi Motor Imagery Questionnaire

Old sentence	Modified sentence
Item 9	
我有時會在腦海中不自覺地呈現出在打太極時的情況。	我能在腦海中不自覺地呈現出自己在打太極時的情況。
Item 10	
當我要太極的時候，我會先感覺該姿勢或動作到達的位置，然後手腳才打到該位置。	我能很容易地想像打某一招式時，身體動作的感覺。
Item 11	
我會很容易地想像太極招式的要求。	我能很容易地想像太極招式的要求。(如動作是否到位)
Item 14	
當我看到或聽到一個太極的式名時 (如「野馬分鬃」)，我會很容易地呈現有關於該式的動作。	當我看到一個太極的式名時 (如「野馬分鬃」)，腦海能不自覺地呈現自己在要該動作。

Appendix II - Tables of Statistical Results on amplitude comparison between tai-chi and non tai-chi groups

Table A1: Detail of site (midline) comparisons of the N100 component amplitude between Tai Chi and non-Tai Chi groups in image generation task

Effect	*df*	*F*-value	*p*-value
Group	1,34	0.36	0.554
Site	1, 34	0.08	0.775
Group x site	1, 34	0.81	0.373

Table A2: Detail of laterality x site (lateral) comparisons of the N100 component amplitude between Tai Chi and non-Tai Chi groups in image generation task

Effect	df	F-value	p-value
Group	1, 34	0.28	0.601
Site	4, 31	73.55	<0.001
Site x group	4, 31	0.35	0.687
Laterality	1, 34	0.18	0.673
Laterality x group	1, 34	12.20	0.001
Site x laterality	4, 31	71.24	<0.001
Laterality x site x group	4, 31	2.42	0.052

Table A3: Detail of site (midline) comparisons of the P200 component amplitude between Tai Chi and non-Tai Chi groups in image generation task

Effect	*df*	*F*-value	*p*-value
Group	1, 34	5.73	0.022
Site	1, 34	74.45	<0.001
Group x site	1, 34	5.73	0.003

Table A4: Details of the pair-wise post hoc analysis of the site (midline) comparison at P200 component amplitude between Tai Chi and non-Tai Chi groups in image generation task

CH name	CH number		df	*t*-value	*p*-value	Mean Difference
Fz	61	TC> nTC	1, 34	3.25	0.003	0.20
CPz	64	TC> nTC	1, 34	5.74	<0.001	0.34

Adjusted significant p-level at $p \leq 0.01$

Table A5: Detail of laterality x site (lateral) comparisons of the P200 component amplitude between Tai Chi and non-Tai Chi groups in image generation task

Effect	*df*	*F*-value	*p*-value
Group	1, 34	12.40	<0.001
Site	4, 31	50.33	<0.001
Site x group	4, 31	0.56	0.592
Laterality	1, 34	47.78	<0.001
Laterality x group	1, 34	11.97	0.001
Site x laterality	4, 31	23.97	<0.001
Laterality x site x group	4, 31	26.61	<0.001

Table A6: Details of the pair-wise post hoc analysis of the laterality x site(lateral) comparisons of the P200 component amplitude between Tai Chi and non-Tai Chi groups in image generation task

CH name	CH number		df	*t*-value	*p*-value	Mean Difference
F3	33	TC> nTC	1, 34	3.15	0.003	0.27
C4	90	TC> nTC	1, 34	3.56	0.001	0.30
CP3	64	TC> nTC	1, 34	5.74	<0.001	0.34
P4	94	TC> nTC	1,34	5.70	<0.001	0.42

Adjusted significant p-level at $p \leq 0.01$

Table A7: Detail of site (midline) comparisons of the N250 component amplitude between Tai Chi and non-Tai Chi groups in image generation task

Effect	*df*	*F*-value	*p*-value
Group	1, 34	0.36	0.554
Site	1, 34	8.91	<0.001
Group x site	1, 34	4.55	0.005

Table A8: Details of the pair-wise post hoc analysis of the site (midline) comparison at N250 component amplitude between Tai Chi and non-Tai Chi groups in image generation task

CH name	CH number		df	*t*-value	*p*-value	Mean Difference
Oz	67	TC < nTC	1, 34	-3.28	0.003	-0.8

Adjusted significant p-level at $p \leq 0.01$

Table A9: Detail of laterality x site (lateral) comparisons of the N250 component amplitude between Tai Chi and non-Tai Chi groups in image generation task

Effect	*df*	*F*-value	*p*-value
Group	1, 34	0.28	0.601
Site	4, 31	73.55	<0.001
Site x group	4, 31	0.35	0.690
Laterality	1, 34	0.18	0.670
Laterality x group	1, 34	12.20	0.001
Site x laterality	4, 31	71.24	<0.001
Laterality x site x group	4, 31	31.99	<0.001

Table A10: Details of the pair-wise post hoc analysis of the laterality x site(lateral) comparisons of the N250 component amplitude between Tai Chi and non-Tai Chi groups in image generation task

CH name	CH number		df	*t*-value	*p*-value	Mean Difference
F3	33	TC < nTC	1, 34	-6.29	<0.001	-0.31
C4	92	TC < nTC	1, 34	-7.38	<0.001	-0.59
P3	39	TC < nTC	1, 34	3.64	0.001	0.31

Adjusted significant p-level at $p \leq 0.01$

Table A11: Detail of site (midline) comparisons of the N100 component amplitude between Tai Chi and non-Tai Chi groups in image transformation task

Effect	*df*	*F*-value	*p*-value
Group	1,34	2.05	0.161
Site	1, 34	86.98	<0.001*
Group x site	1, 34	2.15	0.078

Table A12: Detail of laterality x site (lateral) comparisons of the N100 component amplitude between Tai Chi and non-Tai Chi groups in image transformation task

Effect	*df*	*F*-value	*p*-value
Group	1, 34	59.57	<0.001
Site	4, 31	65.01	<0.001
Site x group	4, 31	9.70	<0.001
Laterality	1, 34	18.30	<0.001
Laterality x group	1, 34	0.71	0.404
Site x laterality	4, 31	2.13	0.080
Laterality x site x group	4, 31	1.47	0.214

Table A13: Detail of site (midline) comparisons of the P200 component amplitude between Tai Chi and non-Tai Chi groups in image transformation task

Effect	*df*	*F*-value	*p*-value
Group	1, 34	1.52	0.227
Site	1, 34	49.98	<0.001
Group x site	1, 34	13.32	<0.001

Table A14: Details of the pair-wise post hoc analysis of the site (midline) comparison at P200 component amplitude between Tai Chi and non-Tai Chi groups in image transformation task

CH name	CH number		df	t-value	p-value	Mean Difference
Fz	61	TC < nTC	1, 34	-14.42	<0.001	-0.89
Cz	63	TC < nTC	1,34	-5.12	<0.001	-0.67

Adjusted significant p-level at $p \leq 0.01$

Table A15: Detail of laterality x site (lateral) comparisons of the P200 component amplitude between Tai Chi and non-Tai Chi groups in image transformation task

Effect	*df*	*F*-value	*p*-value
Group	1, 34	5.83	0.021
Site	4, 31	43.25	<0.001
Site x group	4, 31	27.78	<0.001
Laterality	1, 34	44.68	<0.001
Laterality x group	1, 34	3.63	0.065
Site x laterality	4, 31	23.43	<0.001
Laterality x site x group	4, 31	10.42	<0.001

Table A16: Details of the pair-wise post hoc analysis of the laterality x site(lateral) comparisons of the P200 component amplitude between Tai Chi and non-Tai Chi groups in image transformation task

CH name	CH number		df	t-value	p-value	Mean Difference
F3	33	TC < nTC	1, 34	-10.92	<0.001	-0.95
F4	88	TC < nTC	1, 34	-9.57	<0.001	-0.89
C3	35	TC < nTC	1, 34	-13.48	<0.001	-0.78
C4	90	TC < nTC	1, 34	-10.61	<0.001	-0.90
CP3	37	TC < nTC	1,34	-3.71	0.001	-0.34
CP4	92	TC < nTC	1, 34	-5.97	<0.001	-0.72

Adjusted significant p-level at $p \leq 0.01$

Table A17: Detail of site (midline) comparisons of the N250 component amplitude between Tai Chi and non-Tai Chi groups in image transformation task

Effect	*df*	*F*-value	*p*-value
Group	1, 34	28.12	<0.001
Site	1, 34	18.10	<0.001
Group x site	1, 34	19.92	<0.001

Table A18: Details of the pair-wise post hoc analysis of the site (midline) comparison at N250 component amplitude between Tai Chi and non-Tai Chi groups in image transformation task

CH name	CH number		df	t-value	p-value	Mean Difference
Fz	61	TC > nTC	1, 34	-9.36	<0.001	-0.63
Cz	63	TC > nTC	1, 34	-3.86	0.008	-0.35
Oz	67	TC > nTC	1, 34	4.76	<0.001	0.38

Adjusted significant p-level at $p \leq 0.01$

Table A19: Detail of laterality x site (lateral) comparisons of the N250 component amplitude between Tai Chi and non-Tai Chi groups in image transformation task

Effect	*df*	*F*-value	*p*-value
Group	1, 34	64.84	<0.001
Site	4, 31	35.67	<0.001
Site x group	4, 31	28.56	<0.001
Laterality	1, 34	1.09	0.305
Laterality x group	1, 34	0.43	0.519
Site x laterality	4, 31	5.69	<0.001
Laterality x site x group	4, 31	8.97	<0.001

Table A20: Details of the pair-wise post hoc analysis of the laterality x site(lateral) comparisons of the N250 component amplitude between Tai Chi and non-Tai Chi groups in image transformation task

CH name	CH number		df	t-value	p-value	Mean Difference
F3	33	TC > nTC	1, 34	-10.57	<0.001	-0.92
F4	88	TC > nTC	1, 34	-8.08	<0.001	-0.58
C3	35	TC > nTC	1, 34	-5.18	<0.001	-0.53
C4	90	TC > nTC	1, 34	-4.03	<0.001	-0.44
P3	39	TC > nTC	1, 34	3.25	0.003	-0.16
O3	41	TC > nTC	1, 34	3.26	0.003	0.26

Adjusted significant p-level at $p \leq 0.01$

Table A21: Detail of site (midline) comparisons of the N400 component amplitude between Tai Chi and non-Tai Chi groups in image transformation task

Effect	*df*	*F*-value	*p*-value
Group	1, 34	25.01	<0.001
Site	1, 34	4.71	0.001
Group x site	1, 34	3.35	0.012

Table A22: Details of the pair-wise post hoc analysis of the site (midline) comparison at the N400 component amplitude between Tai Chi and non-Tai Chi groups in image transformation task

CH name	CH number		df	t-value	p-value	Mean Difference
Fz	61	TC > nTC	1, 34	-2.86	0.007	-1.65
Cz	63	TC > nTC	1, 34	-3.40	0.002	-2.17
CPz	64	TC > nTC	1, 34	-2.89	0.007	-1.56

Adjusted significant p-level at $p \leq 0.01$

Table A23: Detail of laterality x site (lateral) comparisons of the N400 component amplitude between Tai Chi and non-Tai Chi groups in image transformation task

Effect	*df*	*F*-value	*p*-value
Group	1, 34	34.38	<0.001
Site	4, 31	10.04	<0.001
Site x group	4, 31	0.93	0.451
Laterality	1, 34	11.38	0.002
Laterality x group	1, 34	1.74	0.196
Site x laterality	4, 31	3.11	0.017
Laterality x site x group	4, 31	3.36	0.012

Table A24: Details of the pair-wise post hoc analysis of the lateral x site (lateral) comparison at the N400 component amplitude between Tai Chi and non-Tai Chi groups in image transformation task

CH name	CH number		df	t-value	p-value	Mean Difference
C4	90	TC > nTC	1, 34	-4.49	<0.001	-0.36
CP4	92	TC > nTC	1, 34	-3.49	0.001	-2.42
O4	96	TC > nTC	1, 34	-2.80	0.001	-0.50

Adjusted significant p-level at $p \leq 0.01$

Table A25: Detail of site (midline) comparisons of the late positive component amplitude between Tai Chi and non-Tai Chi groups in image transformation task

Effect	*df*	*F*-value	*p*-value
Group	1, 34	0.05	0.957
Site	1, 34	4.33	0.002
Group x site	1, 34	1.57	0.185

Table A26: Detail of laterality x site (lateral) comparisons of the late positive component amplitude between Tai Chi and non-Tai Chi groups in image transformation task

Effect	*df*	*F*-value	*p*-value
Group	1, 34	1.19	0.283
Site	4, 31	58.95	<0.001
Site x group	4, 31	2.28	0.064
Laterality	1, 34	17.43	<0.001
Laterality x group	1, 34	1.72	0.199
Site x laterality	4, 31	3.60	0.008
Laterality x site x group	4, 31	2.24	0.053

Appendix III- Tables of Statistical Results on latency comparison between tai-chi and non tai-chi groups

Table B1: Detail of site (midline) comparisons of the N100 component latency between Tai Chi and non-Tai Chi groups in image generation task

Effect	*df*	*F*-value	*p*-value
Group	1,34	88.37	<0.001
Site	1, 34	141.21	<0.001
Group x site	1, 34	14.14	<0.001

Table B2: Detail of laterality x site (lateral) comparisons of the N100 component latency between Tai Chi and non-Tai Chi groups in image generation task

Effect	df	F-value	p-value
Group	1, 34	0.67	0.418
Site	4, 31	23.97	<0.001
Site x group	4, 31	3.87	0.027
Laterality	1, 34	177.69	<0.001
Laterality x group	1, 34	10.64	0.003
Site x laterality	4, 31	78.86	<0.001
Laterality x site x group	4, 31	11.19	<0.001

Table B3: Details of the pair-wise post hoc analysis of the site (midline) comparison at the N100 component latency between Tai Chi and non-Tai Chi groups in image transformation task

CH name	CH number	df	t-value	p-value	Mean Difference
P4	94	1, 34	2.77	0.009	-25.29
O3	41	1, 34	2.74	0.010	25.86

Adjusted significant p-level at $p \leq 0.01$

Table B4: Detail of site (midline) comparisons of the P200 component latency between Tai Chi and non-Tai Chi groups in image generation task

Effect	*df*	*F*-value	*p*-value
Group	1, 34	3.69	0.063
Site	1, 34	21.70	<0.001
Group x site	1, 34	1.34	0.259

Table B5: Detail of laterality x site (lateral) comparisons of the P200 component latency between Tai Chi and non-Tai Chi groups in image generation task

Effect	*df*	*F*-value	*p*-value
Group	1, 34	2.86	0.100
Site	4, 31	238.43	<0.001
Site x group	4, 31	5.13	0.025
Laterality	1, 34	0.03	0.858
Laterality x group	1, 34	1.31	0.260
Site x laterality	4, 31	111.43	<0.001
Laterality x site x group	4, 31	1.44	0.224

Table B6: Detail of site (midline) comparisons of the N250 component latency between Tai Chi and non-Tai Chi groups in image generation task

Effect	*df*	*F*-value	*p*-value
Group	1, 34	0.85	0.364
Site	1, 34	66.61	<0.001
Group x site	1, 34	17.30	<0.001

Table B7: Detail of laterality x site (lateral) comparisons of the N250 component latency between Tai Chi and non-Tai Chi groups in image generation task

Effect	*df*	*F*-value	*p*-value
Group	1, 34	1.87	0.181
Site	4, 31	25.36	<0.001
Site x group	4, 31	1.62	0.173
Laterality	1, 34	33.76	<0.001
Laterality x group	1, 34	0.82	0.371
Site x laterality	4, 31	4.59	0.036
Laterality x site x group	4, 31	0.67	0.432

Table B8: Detail of site (midline) comparisons of the N100 component latency between Tai Chi and non-Tai Chi groups in image transformation task

Effect	*df*	*F*-value	*p*-value
Group	1,34	2.21	0.147
Site	1, 34	140.70	<0.001
Group x site	1, 34	1.54	0.225

Table B9: Detail of laterality x site (lateral) comparisons of the N100 component latency between Tai Chi and non-Tai Chi groups in image transformation task

Effect	*df*	*F*-value	*p*-value
Group	1, 34	1.71	0.200
Site	4, 31	712.23	<0.001
Site x group	4, 31	1.94	0.123
Laterality	1, 34	0.01	0.922
Laterality x group	1, 34	3.90	0.056
Site x laterality	4, 31	6.19	0.003
Laterality x site x group	4, 31	1.42	0.248

Table B10: Detail of site (midline) comparisons of the P200 component latency between Tai Chi and non-Tai Chi groups in image transformation task

Effect	*df*	*F*-value	*p*-value
Group	1, 34	109.28	<0.001
Site	1, 34	416.77	<0.001
Group x site	1, 34	5.87	0.003

Table B11: Details of the pair-wise post hoc analysis of the site (midline) comparison at the P200 component latency between Tai Chi and non-Tai Chi groups in image transformation task

CH name	CH number	df	t-value	p-value	Mean Difference
CPz	64	1, 34	-2.69	0.011	-4.35
Pz	65	1,34	-4.23	<0.001	-9.45
Oz	67	1,34	-4.97	<0.001	-11.01

Adjusted significant p-level at $p \leq 0.01$

Table B12: Detail of laterality x site (lateral) comparisons of the P200 component latency between Tai Chi and non-Tai Chi groups in image transformation task

Effect	*df*	*F*-value	*p*-value
Group	1, 34	12.89	0.001
Site	4, 31	835.54	<0.001
Site x group	4, 31	2.73	0.071
Laterality	1, 34	6.44	0.016
Laterality x group	1, 34	25.96	<0.001
Site x laterality	4, 31	10.24	<0.001
Laterality x site x group	4, 31	3.53	0.041

Table B13: Details of the pair-wise post hoc analysis of laterality x site (lateral) comparisons at the P200 component amplitude between Tai Chi and non-Tai Chi groups in image transformation task

CH name	CH number	df	t-value	p-value	Mean Difference
P3	39	1, 34	-2.95	0.006	-6.00
P4	94	1, 34	-2.87	0.007	-6.65
O3	41	1,34	-3.05	0.004	-4.50
O4	96	1,34	-4.25	<0.001	-7.43

Adjusted significant p-level at $p \leq 0.01$

Table B14: Detail of site (midline) comparisons of the N250 component latency between Tai Chi and non-Tai Chi groups in image transformation task

Effect	*df*	*F*-value	*p*-value
Group	1, 34	0.93	0.341
Site	1, 34	571.60	<0.001
Group x site	1, 34	14.89	<0.001

Table B15: Details of the pair-wise post hoc analysis of the site (midline) comparison at the N250 component latency between Tai Chi and non-Tai Chi groups in image transformation task

CH name	CH number	df	t-value	p-value	Mean Difference
Fz	61	1, 34	-5.61	<0.001	-14.68
Cz	63	1, 34	-3.85	0.001	-7.60

Adjusted significant p-level at $p \leq 0.01$

Table B16: Detail of laterality x site (lateral) comparisons of the N250 component latency between Tai Chi and non-Tai Chi groups in image transformation task

Effect	*df*	*F*-value	*p*-value
Group	1, 34	0.24	0.625
Site	4, 31	259.14	<0.001
Site x group	4, 31	4.50	0.032
Laterality	1, 34	0.97	0.331
Laterality x group	1, 34	0.34	0.564
Site x laterality	4, 31	9.64	<0.001
Laterality x site x group	4, 31	7.34	<0.001

Table B17: Details of the pair-wise post hoc analysis of laterality x site (lateral) comparisons at the N250 component latency between Tai Chi and non-Tai Chi groups in image transformation task

CH name	CH number	df	t-value	p-value	Mean Difference
F3	33	1, 34	-3.46	0.001	-7.10
F4	88	1, 34	-2.96	0.006	-5.00
C3	35	1, 34	-5.61	<0.001	-14.68
CP4	94	1, 34	-2.99	0.005	-5.50

Adjusted significant p-level at $p \leq 0.01$

Table B18: Detail of site (midline) comparisons of the N400 component latency between Tai Chi and non-Tai Chi groups in image transformation task

Effect	*df*	*F*-value	*p*-value
Group	1, 34	0.48	0.492
Site	1, 34	29.68	<0.001
Group x site	1, 34	9.28	<0.001

Table B19: Details of the pair-wise post hoc analysis of the site (midline) comparison at the N400 component latency between Tai Chi and non-Tai Chi groups in image transformation task

CH name	CH number	df	t-value	p-value	Mean Difference
CPz	64	1, 34	5.81	<0.001	11.70

Adjusted significant p-level at $p \leq 0.01$

Table B20: Detail of laterality x site (lateral) comparisons of the N400 component latency between Tai Chi and non-Tai Chi groups in image transformation task.

Effect	*df*	*F*-value	*p*-value
Group	1, 34	2.47	0.125
Site	4, 31	178.51	<0.001
Site x group	4, 31	215.93	<0.001
Laterality	1, 34	455.63	<0.001
Laterality x group	1, 34	127.66	<0.001
Site x laterality	4, 31	21.26	<0.001
Laterality x site x group	4, 31	18.88	<0.001

Table B21: Details of the pair-wise post hoc analysis of laterality x site (lateral) comparisons at the N400 component latency between Tai Chi and non-Tai Chi groups in image transformation task

CH name	CH number	df	t-value	p-value	Mean Difference
C4	90	1, 34	9.06	<0.001	18.45
P4	94	1, 34	7.33	<0.001	31.71
O4	96	1, 34	6.40	<0.001	40.23

Adjusted significant p-level at $p \leq 0.01$

Table B22: Detail of site (midline) comparisons of the late positive component latency between Tai Chi and non-Tai Chi groups in image transformation task

Effect	*df*	*F*-value	*p*-value
Group	1, 34	19.33	<0.001
Site	1, 34	57.41	<0.001
Group x site	1, 34	67.77	<0.001

Table B23: Details of the pair-wise post hoc analysis of site (midline) comparisons at the late positive component (LPC) latency between Tai Chi and non-Tai Chi groups in image transformation task

CH name	CH number	df	t-value	p-value	Mean Difference
Cz	63	1, 34	7.608	<0.001	18.15

Adjusted significant p-level at $p \leq 0.01$

Table B24: Detail of laterality x site (lateral) comparisons of the late positive component latency between Tai Chi and non-Tai Chi groups in image transformation task

Effect	*df*	*F*-value	*p*-value
Group	1, 34	1.95	0.172
Site	4, 31	107.91	<0.001
Site x group	4, 31	0.54	0.548
Laterality	1, 34	144.70	<0.001
Laterality x group	1, 34	4.58	0.040
Site x laterality	4, 31	246.41	<0.001
Laterality x site x group	4, 31	4.57	0.021

Table B25: Details of the pair-wise post hoc analysis of laterality x site (lateral) comparisons at the late positive component latency between Tai Chi and non-Tai Chi groups in image transformation task

CH name	CH number	df	t-value	p-value	Mean Difference
P3	39	1, 34	-2.813	0.008	-12.10

Adjusted significant p-level at $p \leq 0.01$

Appendix IV- Consent form used in the experiment

THE HONG KONG
POLYTECHNIC UNIVERSITY
香港理工大學
Department of Rehabilitation Sciences

参與研究同意書

研究主題:
太極與意象之間的問卷調查

研究員:
陳智軒教授(正教授)，陳鵬威先生(碩士研究生)

研究資料:
由理工大學康復治療學系主理的太極與意象之間的問卷調查，目的是希望透過問卷的形式來進一步了解太極與意象的關係。參加者將會接受約 1 小時的太極及意象的問卷測試。是次研究的目的是探討學習太極之人士的進行意象的能力。研究結果將會進一步明白太極對認知康復的效果及原因。

整個研究預計需時 1 小時進行太極及意象的問卷測試。

同意書:
本人__________________同意参加太極與意象之間的問卷調查。

本人明白是次研究所得的資料將作爲日後同類研究或出版之用途。然而，我的私隱權利會被受保護，即是我的個人資料將不會被洩露。
本人清楚了解是次研究的步驟，並明白此研究不會對本人構成任何不適。本人有權在研究前或研究時放棄參與，而且不會受到任何追究。

如有任何問題，本人可致電 6080-　　聯絡碩士研究生陳先生，或致電 2766-6727 聯絡陳智軒教授。

參與者簽署:　　　　　　　　　　日期:

研究員簽署:　　　　　　　　　　日期:

THE HONG KONG
POLYTECHNIC UNIVERSITY
香港理工大學
Department of Rehabilitation Sciences

參與研究同意書

研究主題:
太極的腦神經基礎研究 －太極與意象的研究

研究員:
陳智軒教授(正教授)，陳鵬威先生(碩士研究生)

研究資料:
由理工大學康復治療學系主理的太極意象研究，目的是希望透過腦神經學的方法來進一步了解太極與意象之間的關係。參加者將會接受約4小時的太極與意象的問卷測試、太極相關題目的學習及腦電位測試。是次研究的目的是探討學習太極的人士進行意象的能力。研究結果將會進一步明白太極對認知康復的效果及原因。
整個研究預計需時4小時，我們會在香港理工大學為每位參與的人士進行太極及意象的問卷測試、太極相關題目的學習及腦電位測試。每位參與者將獲得港幣二百元作為交通津貼。

同意書:
本人＿＿＿＿＿＿＿＿同意參加太極的腦神經基礎研究 -太極與意象之間的研究。
本人明白是次研究所得的資料將作為日後同類研究或出版之用途。然而，我的私隱權利會被受保護，即是我的個人資料將不會被洩露。
本人清楚了解是次研究的步驟，並明白此研究不會對本人構成任何不適。本人有權在研究前或研究時放棄參與，而且不會受到任何追究。
如有任何問題，可致電 6080- 聯絡碩士研究生陳先生，或致電 2766-6727 聯絡陳智軒教授。

參與者簽署: 日期

研究員簽署: 日期

Appendix V- Details of TCIQ and TCMIQ

太極視覺意象及動作意象程度問卷

Subject Code: ______________

日期： ___________________________________

個人資料

姓名 ： _________________________________
聯絡電話 ： _____________________________
年齡 ： ________________
性別：___男 / 女
慣用手 ：_____左 / 右________
教育程度 ： ___________________
職業 ： _______________________

曾學習的太極派系
□ 吳家
□ 陳家
□ 楊家
□ 孫家
□ 武家
□ 吳家鄭式
□ 其他，請註明：_______________

學習太極的年數 ： ________________
練習太極的次數 ： 每週____次，每次____小時
除太極以外做的運動 ： _________________________；每週____次，每次__小時

請到下一頁作答

太極意像問卷調查

請作答以下問卷，並圈出你認爲最適合的答案。**1 爲非常不能夠，2 爲頗不能夠，3 爲中立，4 爲頗能夠，5 爲非常能夠。**

	非常不能夠				非常能夠
1. 我習慣用意象來溫習太極的招式。	1	2	3	4	5
2. 我能在腦海中轉動太極的影像。	1	2	3	4	5
3. 我能想像出太極動作中，手腳之間距離的要求。	1	2	3	4	5
4. 打太極的時候，我習慣在腦海中呈現一個接一個的動作。	1	2	3	4	5
5. 我能很容易地想到別人(如師父)在耍太極。	1	2	3	4	5
6. 平日有些時候，我會在腦海中默想自己在耍太極。	1	2	3	4	5
7. 我能很容易地想像別人耍太極的影像，而且影像清晰鮮明。	1	2	3	4	5
8. 我能很容易地想像打某一招式時，身體動作的感覺。	1	2	3	4	5
9. 我能轉動太極的影像至不同角度，從而了解姿勢之間的關係。	1	2	3	4	5
10. 我很容易地想像自己在打太極。	1	2	3	4	5
11. 當我在溫習一個新的動作或招式，我會在腦海呈現第三者(如師傅，或別人)在打該式的影像。	1	2	3	4	5
12. 我能夠在腦海裏主動地看某些動作上細緻要求。	1	2	3	4	5
13. 當看到別人在打太極的招式時，我能很容易地想像他耍出接下來的動作。	1	2	3	4	5
14. 我能在腦海中不自覺地呈現出自己在打太極時的情況。	1	2	3	4	5
15. 我能容易地呈現出別人在耍太極的清晰及鮮艷的影像。	1	2	3	4	5
16. 我能很容易地想像太極招式的要求。(如動作是否到位)	1	2	3	4	5
17. 我可以在腦海中呈現第三者(如師傅)在打太極的招式。	1	2	3	4	5
18. 我能容易地呈現自己打出一個接一個的太極動作。	1	2	3	4	5
19. 當我看到一個太極的式名時 (如「野馬分鬃」)，腦海能不自覺地呈現自己在耍該動作。	1	2	3	4	5
20. 我能輕易地想像出太極的動作，並能在腦海裡轉動該動作。	1	2	3	4	5

太極問卷調查

請作答以下問卷，並圈出你認爲最適合的答案。**1 爲非常不同意，2 爲頗不同意，3 爲中立，4 爲頗同意，5 爲非常同意。**

非常不同意　　　　非常同意

1. 我能夠清楚了解太極拳中各式的動作及外形的要求。	1	2	3	4	5
2. 打太極的時候，我能做到全身放鬆，上下相隨。	1	2	3	4	5
3. 每次耍太極時我都清楚知道是否打出正確姿勢。	1	2	3	4	5
4. 我習慣在腦海中想像師父在教授時的影像。	1	2	3	4	5
5. 打太極時，我的專注力會集中在身體內在的感覺。	1	2	3	4	5
6. 耍太極時，我會能用意念帶動身體的動作。	1	2	3	4	5
7. 我用一些方位或環境來幫助練習太極的轉向。	1	2	3	4	5
8. 我明白並能領會意念，呼吸與動作的結合及其之間有規律性的配合。	1	2	3	4	5
9. 耍太極時我未能知道自己的姿勢，需要別人從旁觀察是否正確。	1	2	3	4	5
10. 我能每次都打出相似的姿勢。	1	2	3	4	5
11. 我正在改善一些招式的細微動作，如身體各部份之間的距離及彎曲的角度。	1	2	3	4	5
12. 當打太極拳時，我的專注力會放在身體關節上，如膝蓋，手腕等。	1	2	3	4	5

~全卷完，謝謝~

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