ANALYTICAL TAIJIQUAN

Submitted By

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This articles was originally submitted as a thesis in fulfillment of my degree in electrical engineering.

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ABSTRACT

Tai Chi Chuan, the national sport of China, is spreading like wild fire to other countries in recent years. With researchers finding many health benefits to be obtained from practicing Tai Chi Chuan, interest in Tai Chi Chuan is inevitable. This study aims to quantify Tai Chi concepts to enable practitioners to be able to have a more efficient learning. Also, the quantifying of Tai Chi would enable it to be used in software applications. The study involves 3 main areas, stability, power of waist and hips and lastly, sinking the shoulders and dropping the elbows. In each experiment, the following process is undertaken. 1. Identify the relevant properties to be quantified. 2. Design experiments to obtain data from an experienced and inexperienced practitioner. 3. Analyse the data and verify the hypothesis. The equipment used in the experiments are the gypsy motion capture and myotrace electromyography unit. For stability, it was found that using gait angle and base of gait to explain stability is not conclusive. A better way is to plot the position of the left feet, right feet and sacrum and observe the position of the sacrum with respect to both feet. Muscle activity of the agonist muscle compared to the antagonist muscle is also conclusive. For power of hip and waist, the hypothesis of using the hip angle as a potential quantifier for proper use of hip and the use of the elbow angle with respect to the waist as well as the electromyography readings of the shoulder muscle have been verified. Lastly, for sinking of the shoulders and dropping of the elbows, the angle between the shoulder and the elbow as well as the height of the elbow relative to the shoulder

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Tai Chi Chuan, the national sport of China, is spreading like wild fire to other countries in recent years. With researchers finding many health benefits to be obtained from practicing Tai Chi Chuan, interest in Tai Chi Chuan is inevitable. This study aims to quantify Tai Chi concepts to enable practitioners to be able to have a more efficient learning. Also, the quantifying of Tai Chi would enable it to be used in software applications. The study involves 3 main areas, stability, power of waist and hips and lastly, sinking the shoulders and dropping the elbows. In each experiment, the following process is undertaken. 1. Identify the relevant properties to be quantified. 2. Design experiments to obtain data from an experienced and inexperienced practitioner. 3. Analyse the data and verify the hypothesis. The equipment used in the experiments are the gypsy motion capture and myotrace electromyography unit. For stability, it was found that using gait angle and base of gait to explain stability is not conclusive. A better way is to plot the position of the left feet, right feet and sacrum and observe the position of the sacrum with respect to both feet. Muscle activity of the agonist muscle compared to the antagonist muscle is also conclusive. For power of hip and waist, the hypothesis of using the hip angle as a potential quantifier for proper use of hip and the use of the elbow angle with respect to the waist as well as the electromyography readings of the shoulder muscle have been verified. Lastly, for sinking of the shoulders and dropping of the elbows, the angle between the shoulder and the elbow as well as the height of the elbow relative to the shoulder

have proved to be possible quantifiers

ACKNOWLEDGEMENTS

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CHAPTER 1

Introduction

1.1. Tai Chi Chuan

Tai Chi Chuan is a form of martial arts originating from China. This is generally recognized by its slow flowing moves, circular movements and the emphasis on inner cultivation of 'chi' and not the use of external force. Tai Chi Chuan has two main uses. Firstly, improve health through the increase circulation of 'Chi' through the 12 major meridians of the body. The Chinese believe that these are major vessels that deliver 'chi' to the various organs thus revitalizing the internal organs. Secondly, it is a form of self defense where an effective use of force is taught. Tai Chi Chuan is hugely influenced by Taoist philosophies which is concerned with the laws of nature, such as Yield and overcome; Bend and be straight. -- *Tao Te Ching* (22). The martial art is also named and represented by the Taoist image of the supreme pole.

1.2. Origins of Tai Chi Chuan

There are differing views regarding the origins of Tai Chi Chuan. One of the common view is that the 14th Century Taoist Master Chang San Feng created the forms after watching a fight between a snake and a crane. The snake responds to the stabbing action of the crane by agile and relaxed movements. Others believe that the original creator stems from Chen Wang Ting, a military leader of the 17th century.

1.3. Current Situation

Tai Chi Chuan is not only China's national sport, it is also has a huge following in many parts of the world. This is due to the accessibility of the exercise as well as the health benefits that are achieved. The slow movements have much less impact on the joints then many other type of exercise. This meant that elderly or even disabled people could practice Tai Chi Chuan. Some of the most common benefits enjoyed are better flexibility and agility, improvement in digestive system, lymphatic fluid circulation and increased metabolism. Recently, experiments have focused on the effectiveness of Tai Chi to help the elderly have a better balance control thus a reduced in fall rates.

1.4. Objectives

The gain in popularity of Tai Chi Chuan around the world means that the quality of teaching will vary significantly. Also as Tai Chi Chuan classics are written in classical Chinese with mystic terminology, the understanding of Tai Chi Chuan may not be complete. Without proper understanding of the correct Tai Chi movements, students may not be able to reap the benefits.

This project aims to quantify the concepts central to Tai Chi Chuan so that learners can learn at a faster rate and increase the quality of their learning. It can also standardize how Tai Chi masters teach across the board. The quantification of Tai Chi can also be used in applications such as robotics or software applications. Specifically, the following objectives are to be met.

1. Identify the key concepts

2. Design an experiment to observe the manifestation of these concepts, come up with hypothesis

3. Compare the results for an experienced vs a non experience Tai Chi practitioner to verify hypothesis

4. Analyze data obtained.

1.5. Approach

First literature research is done to identify the concepts central to Tai Chi. Books, magazines and opinions of experienced Tai Chi practitioners are sought. The author also attended forums on Tai Chi, the most significant one by Tai Chi Master Chen Zhen Lei. To broaden one's knowledge on Tai Chi and to gather in-depth knowledge and information on the subject matter, the author took up a Tai Chi course. This provided one with ample opportunity to have personal interaction with the Tai Chi masters and fellow practitioners. This would also enable identification of the areas one would like to know more about.

3 areas have been chosen from the many Tai Chi Chuan principles. Experiments to quantify these 3 areas will be proposed. The equipment and facility needed will be identified and the experiments will then be carried out. Measurements are carried out and analysis of data will be undertaken.

1.6. Project Flowchart

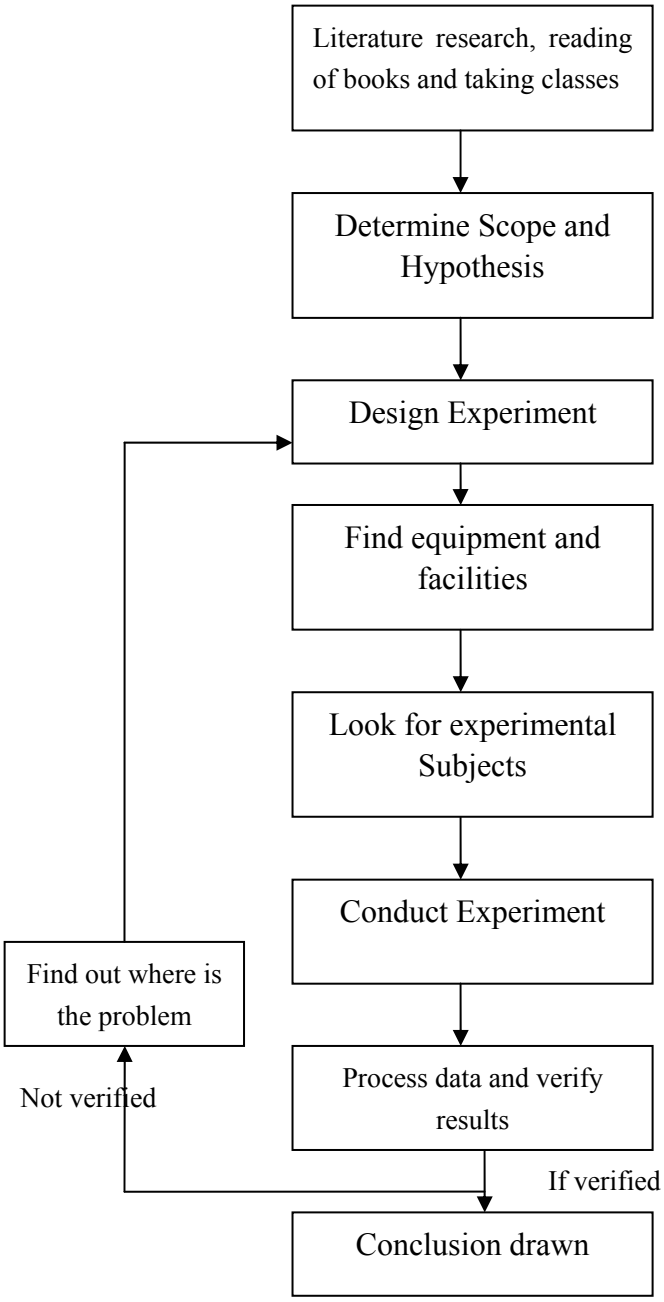

Figure 1. Flowchart of Approach to project

1.7. Scope

From extensive literature research, the following 3 principles are identified for the study.

1. Stability

2. Hip and Waist power

3. Sinking of shoulders and dropping of elbows

CHAPTER 2

Equipment

A brief discussion on the equipment required for the experiments is undertaken below.

2.1. Electromyography

Electromyography(EMG) involves testing the electrical activity of muscles. Muscle movements involves electrifying nerve cells. Thus, it can positively identify if a certain part of muscle is used during a period of motion. A portable electromyography system is used in the experiment. The values obtained will be displayed as voltage level. Myotrace 200 is used in this study. (Pls see Figure 2.) It is a hand-held, lightweight and portable two-channel audio and visual biofeedback instrument that can be used in homes. It is easy to use and only requires normal ECG electrodes.

Figure 2. Myotrace 200

2.2. Motion Capture System

Since it is difficult to track motions of a Tai Chi master with only the human eye, there is a need to use a good motion capture system for this purpose. Joint centres of the limbs are calculated thus giving more accurate results. Two types of motion capture were evaluated, namely, the Vicon Peak optical system and the Gypsy 4 system. Practice was done on both systems to determine which was more suitable.

2.2.1. Gypsy 4 motion capture system

The gypsy suit, as seen in Figure 3, uses 37 potentiometer sensors and 2 inertial gyroscopes placed around 17 human joints. The rotational angles of the different joints are captured. The main advantage of the gypsy motion capture system is that since it is based on mechanical movements of the suit, it is very portable and convenient. All it requires for data capture is the suit and a laptop. The file is in BVH format which means that long sequences of data could be stored taking up very little memory. On the flipside, the calibration of the suit is very tedious and inaccurate. As the suit is of standard size, there are physical limitations, one of which is the extension length of the various parts may restrict the movement in certain positions by the wearer. Trials with the gypsy suit unearthed many problems with the upper body. The hands of the wearer are unable to go above the shoulder in many cases.

Figure 3. Gypsy motion suit

2.2.2. Vicon Peak Optical capture system

The Vicon motion system (Motion Analysis Lab, Department of Orthopaedic Surgery) uses 6 optical cameras to capture the movements of individual reflective markers placed on the subject. In Figure 4, the optical cameras at the back and left side of the practitioner are visible. The reflective markers are the white spheres on various positions on the practitioner's clothing.

Figure 4. Vicon mo-cap setup

Vicon offers a better accuracy. However, on the downside, the C3D files it generates takes up much more memory space than that of the Gypsy system.

Hence, long sequence of motion is not advisable. Post processing of data is also very tedious as each marker has to be identified in as many frames as possible. This is because unlike gypsy, the software has no way of knowing which marker reference which part of the body.

Having tried both systems, I have chosen to use Vicon Peak as the Gypsy motion capture data has significant errors in the data.

CHAPTER 3

Stability

3.1. Understanding Stability

Stability is obtained through a large part by rooting. In Tai Chi Chuan, the stability of the lower body is very important. Rooting has been described in classics as feeling the muscles of the upper body relax and the centre of gravity sinking down to the feet. This vague instruction could lead to different interpretations, with many Tai Chi practitioners simply thinking that the lower the stance, the better the stability. Although lowering of the centre of gravity is also a part of rooting, other factors also play a big part in stability. Rooting is central to Tai Chi as it connects all parts of the body to the ground. This is important since force is directed to the arm from the ground and an attacking force is deflected into the ground. Rooting encompasses more than stability, however, in this paper, it shall be taken interchangeably with stability.

3.2. Scientific Research

Rooting has been interpreted in scientific research as a good balance control. Much research has been done on the balancing prowess of the elderly after taking up Tai Chi Chuan. These articles focus on proving that Tai Chi Chuan is good for balance however, little details are given regarding the principles that indirectly lead to better control of lower body.

Some articles on the behaviour of the lower limbs include “The Kinematical characteristics of the lower extremities during Tai Chi Chuan” (Mao, Hong and Li) focused on the base which centre of mass acts through. Parameters that contribute to the stability includes a large gait angle and a long distance base of gait. “Plantar Pressure Distribution During Tai Chi Exercise” (Mao, Hong and Li, 2006) on the other hand measures the force distribution of the foot during the Tai Chi stance. It is found that the big toe exerted the most pressure.

Other useful materials include biomechanics text such as “The Thinking Body” which suggests how the mechanical alignment of the trunk, hips and legs would allow the transference of body weight to the bones instead of the muscle.

In a Final Year Project covered previously, rooting was proved through a constant exertion of force in the X, Y and Z planes exerted by an experienced pracitioner compared to varying force exerted by a non-tai chi practitioner. (Appendix A.)

3.3. Potential Quantifiers – Muscle Activation

From literature review, it can be seen that elderly who learn Tai Chi have better lower limb muscle control. One could infer that rooting is directly affected by the lower limb muscles. It is not possible to use brute force in maintaining rooting as tied in to the concept of rooting is ‘Song’, which would enable the transverse of force from the lower body to the upper body and vice versa. Therefore, efficient use of muscle force is implied and will be examined in this paper.

There are several steps in considering muscle activation. Firstly, the Tai Chi

Chuan step cycle is identified. Secondly, a detailed analysis of the muscles used in the Tai Chi step is undertaken. The Tai Chi step consists of a cycle of flexion and extension of the leg. Please See Figure 5.

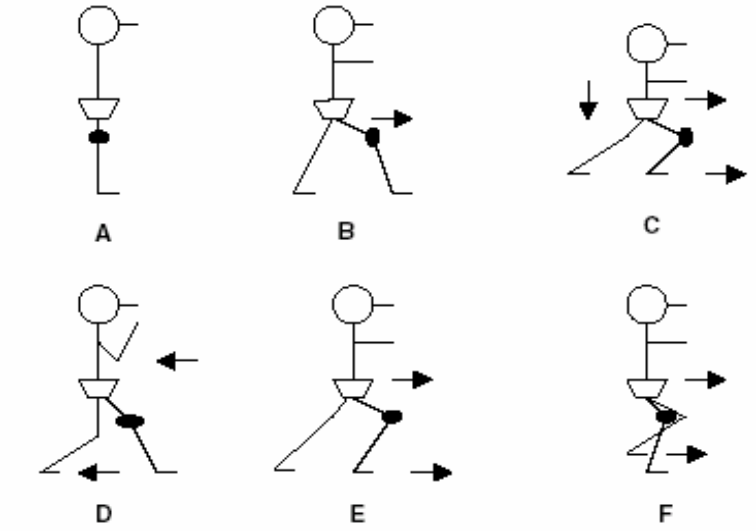

Figure 5. Tai Chi Step[1]

The flexing of knee in the Tai Chi Step would involve muscles controlling the knee joint.

Muscles can be classified as agonist or antagonist. An agonist muscle is capable of creating a torque in the same direction as the joint action while an antagonist creates a torque opposite the joint action. In this case, Quadriceps, consisting of a group of muscles such as the Rectus Femoris and the Vastus Lateralis, are the agonist since they lie in the front part of the thigh and are extended to move the Knee Joint forward. On the other hand, muscles at the back of the thigh such as the Hamstrings are antagonist since they are contracted while the Knee joint is moved forward. Tseng, Liu and McQuarde noted that experienced Tai Chi

[1] Taken from Muscle Activation Profiles about the Knee during Tai Chi stepping movement compared to normal gait step, Tseng, Liu, McQuade, 2005

practitioners showed higher muscle activation profiles of the Quadriceps and lower activation profiles of the Hamstrings compared to non-experienced Tai Chi practitioners.

Muscle activation can be detected using electromyography (EMG). This detects the electrical potential generated by muscle cells when these cells contract.

3.3.1. Experimental Investigation – EMG of thigh muscles

The following experimental work is designed and carried out to verify if EMG of thigh muscles gives a good indication of good rooting.

Hypothesis

It is hypothesized that good rooting involves efficient use of muscles such that strength is not wasted and unused muscle remain in a relaxed state. Antagonist muscles should not be used as much as agonist muscles.

Design of Experiment

Muscle activation profiles for the upper leg obtained during the Tai Chi step cycle were to be taken from two groups of people, experienced Tai Chi practitioners and inexperienced Tai Chi practitioners. The data for the two different groups will then be compared.

Each group will consist of three people. The groups will be separated into those who have at least 5 years and above experience in Tai Chi and those who have less than 1 year experience. The basic criteria for the inexperienced Tai Chi practitioners are that they have to be able to do the Tai Chi step smoothly with no

break in between. The average age of the Tai Chi group is around 56.7 while that of the control group is around 43.

Muscular tension was measured by surface electromyography using the 2-channel MyoTrace 200 system with silver/silver chloride bipolar electrodes (Noraxon).

The muscles to be measured are the Rectus Femoris (Extensor muscle) and the Hamstring muscle.

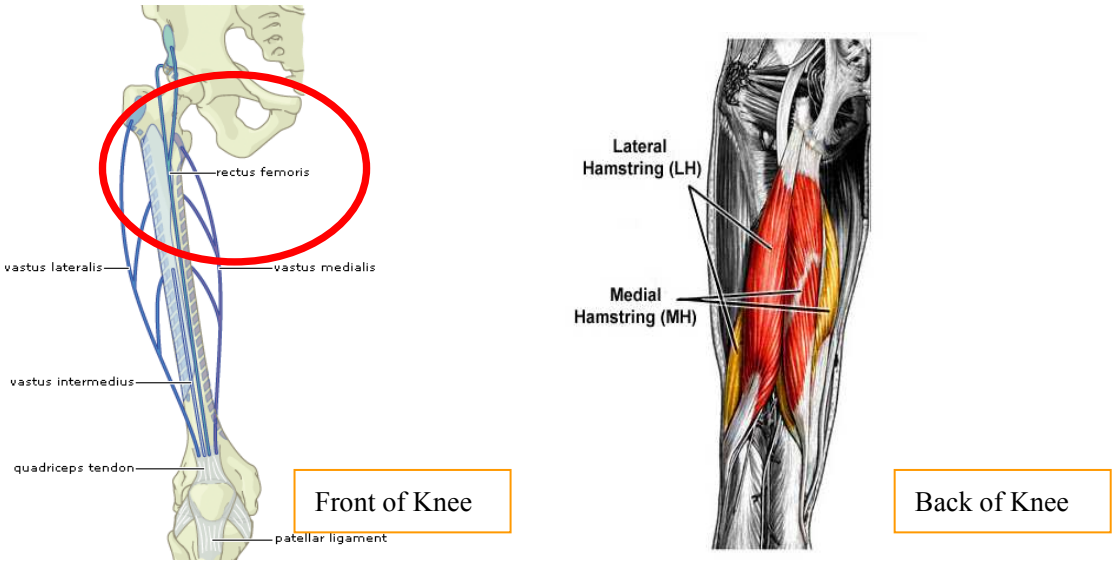

Figure 6. Rectus Femoris(Left) and Hamstring(Right)

Experimental Procedure

The following procedure is undertaken.

A Noraxon dual electrode was placed on the belly of each muscle along the muscle fibre direction of the Rectus Femoris and Hamstring muscles. Common ground electrodes (Noraxon single) were placed at the knee cap.

1. Subjects are told to stand and flex their knee as much as possible with feet shoulder width apart. Maximum voluntary contraction (MVC) of the

Rectus Femoris and Hamstring muscles are then taken and recorded.

2. Subjects are to perform a cycle of the Tai Chi step. Maximum EMG readings are noted down for each flexion of the leg as seen in Figure 7.

Figure 7. Front flex of Left Knee and Back Flex of right knee

These positions are chosen since in Front Flex and Back Flex, the knee is to be controlled by the muscles around it. This will be done twice to get accurate readings. The data obtained is normalised with the MVC values.

3.3.2. Results

The following results were obtained for EMG readings of Rectus Femoris and Hamstrings during the Tai Chi step for experienced and inexperienced practitioners.

Table 1. EMG readings during Front Flex

	EMG Readings (μV)	
	Experienced Practitioner	Inexperienced Practitioner
Rectus Femoris	2.33	1.33
Hamstrings	1.2	3

Table 2. EMG readings during Back Flex

	EMG Readings (μV)	
	Experienced Practitioner	Inexperienced Practitioner
Rectus Femoris	2	0.33
Hamstrings	0.83	3

3.3.3. Discussion

The experienced practitioners were shown to have 1.94 to 2.4 times use of their agonist muscles to antagonist muscles during flexing of the knee. This is comparable to the result in a case study by Chan, Luk and Hong(2003) which showed the EMG of rectus femoris to be 3 times that of the Hamstring muscles. On the other hand, the inexperienced practitioner was shown to have opposing results, with the muscle activity of the Hamstrings much larger than the Rectus Femoris. Although it was expected that the agonist and antagonist muscles may show both show a similar activity rate in an inexperienced practitioner, the results obtained may hint to the fact that the inexperienced practitioners may not only be using muscle inefficiently, the stance may also be incorrectly done. A possible reason could be incorrect alignment of body. If the upper body is not upright but leaning slightly forward, the practitioner may exert additional force in the hamstring to maintain balance.

3.4. Potential Quantifier - Biomechanical analysis of centre of gravity

Apart from muscle activation profiles, it was assumed that general physics and biomechanical concepts applying to general stability of objects should be observed to take place during proper rooting. These include a wider base area with

the centre of gravity within the base area.

Centre of gravity and its position in relation to the body affects stability. Therefore it is important to analyse how proper Tai Chi step ensures that the centre of gravity is within the support area. The centre of gravity is the central point where the entire mass of a body could be balanced upon.

Two different concepts will be considered. Firstly, the base support and secondly whether the line of action of the centre of gravity falls within the base area.

Base of Support

The base of support is the area within the lines connecting the perimeter of each point of support. The area of the base of support will affect stability as shown in Figure 8.

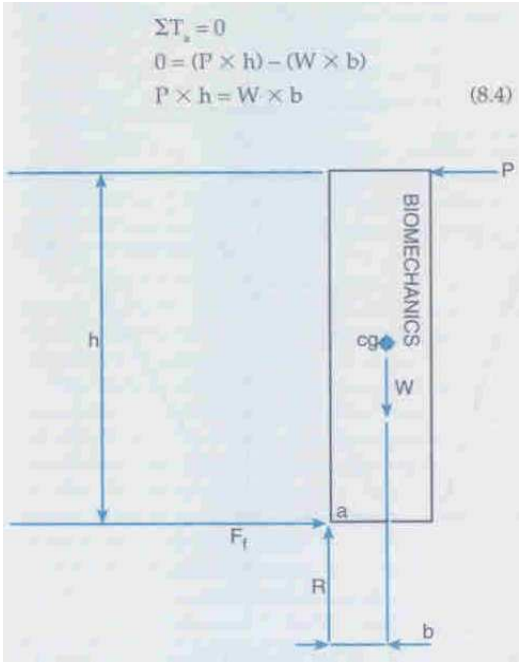

Figure 8. Base area and stability

An object is placed on a table with b is a dimension that is related to the base area

and will depend on the direction of force p. It can be seen that for the object to be stable, h must be small and b must be large.

In Tai Chi stance, the base of support is determined by the area between 2 feet. The Kinematical Characteristics of the Lower Extremities during Tai Chi Chuan Exercise by Mao, Hong and Li derived that the angle of gait (alpha) and base of gait (b) will determine the area of the base of support as shown in Figure 9.

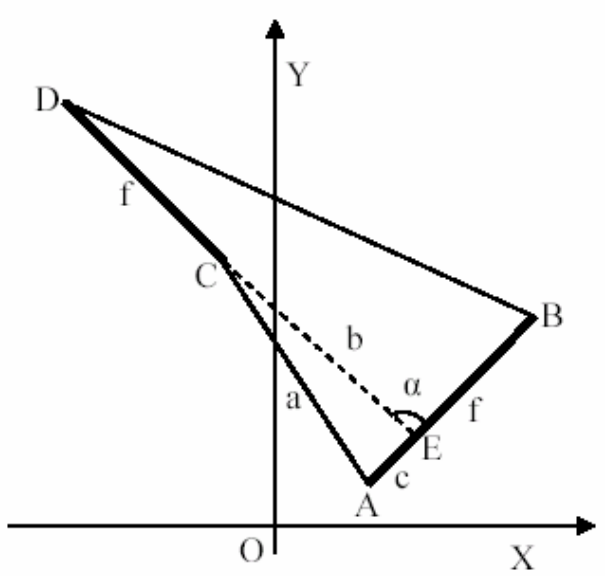

Figure 9. Base area enclosed by 2 feet

In this figure, DC and AB represent the position of the feet while alpha is the gait angle and b is the base of gait. They have derived the formula of the base area to be:

$$S=\frac{1}{2}\times(f-c)\times(f+b)\times\sin\alpha+\frac{1}{2}\times b\times c\times\sin(180-\alpha)$$

$$=\frac{1}{2}\times\sin\alpha\times(f^2+f\times(b-c))$$

Consider the case where the size of foot, f and c are constant, the base area would be dependant on the gait angle alpha and the base of gait. The base area would be

a maximum nearing 90 degrees. Hence, these can be used as a potential quantifier for stability.

3.4.2. Experimental Investigation – Gait angle

The following experimental work is designed and carried out to verify if the gait angle and base of gait during the Tai Chi step gives a good indication of good rooting.

Hypothesis

It is hypothesized that a large gait angle and base of gait is needed for maximum base support area and hence increases stability.

Design of Experiment

Motion capture is used to obtain the gait angle and base of gait needed. An experienced Tai Chi practitioner and an inexperienced Tai Chi practitioner will each perform a specified sequence of the Tai Chi forms. The data obtained is used to calculate the gait angle.

Experimental Procedures

Subject A is a male Tai Chi master (height 163cm, weight 60kg) who has been teaching Tai Chi for many years while the Subject B is a female student (height 174cm, weight 61kg) who has only learnt Tai Chi for 2 months. The procedures are as follows.

1. Set up of Vicon motion capture system with 6 optical cameras. Ensure subjects

are within capture range of the system. Spherical markers are placed as shown in Figure 10.

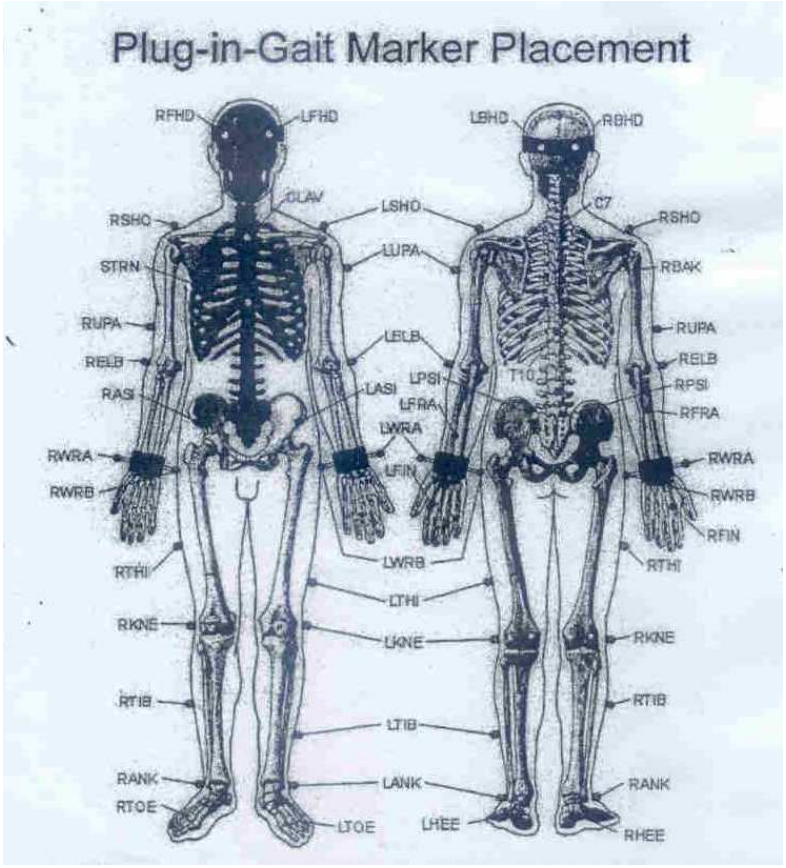

Figure 10. Gait Marker Placement

Subjects should wear skin tight clothes for more accurate results.

2. Do the following Tai Chi forms.

a. Brush Knee (Lou Xi Ou Bu)

b. Grasp the Sparrow's Tail (Lan Que Wei)

They will be further described in the following section.

3. The forms are captured twice and the more accurate trial is then processed.

Background Tai Chi forms

A brief background on the "Brush Knee" and "Grasp the Sparrow's Tail" will be given for a better understanding of the purpose and movements the forms involve.

Brush Knee, (Lou Xi Ou Bu)

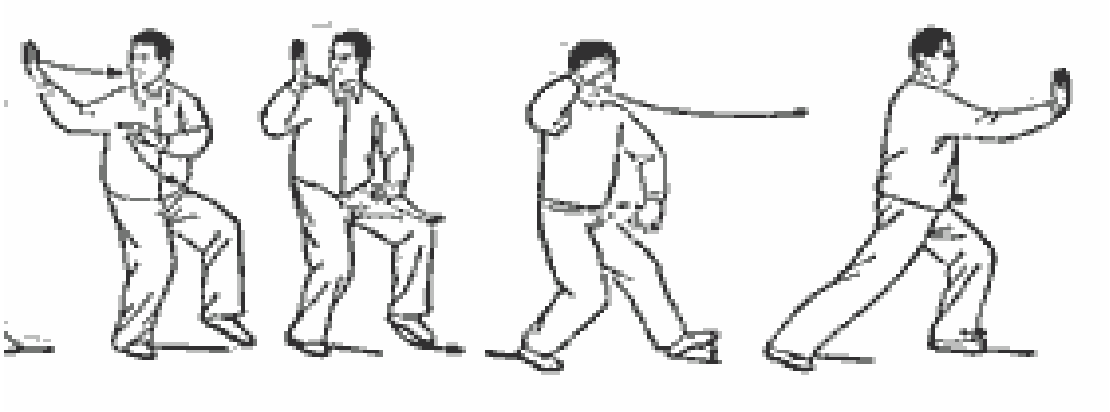

Figure 11. Brush Knee[2]

1. Put weight on right foot, both arms back on the right side, right palm facing up, left facing down.

2. Lift right foot off the ground and step forward.

3. Move left arm forward and 'brush' above the knee in a sweeping arc. At the same time, push right hand forward.

This can be applied as shown in Figure 12.

Figure 12. Application of Brush Knee[3]

[2] Brush knee and Step Forward, Taken from the World Wide Web, http://www.ocregister.com/ocr/2004/06/27/sections/health_family/health_family/article_144815.php

The Tai Chi practitioner on the left is using "Brush Knee" with the practitioner on the right trying to attack him. The left arm is uses the momentum from the turning of the body to parry away the attack and the right hand uses the force generated to push the attacker away.

Grasping the Sparrow's Tail, (Lan Que Wei)

"Grasping the Sparrow's Tail" actually consists of a series of four steps. Ward (Peng), Roll back (Lu), Press (Ji) and Push (An). In this paper, the focus is on Press (Ji).

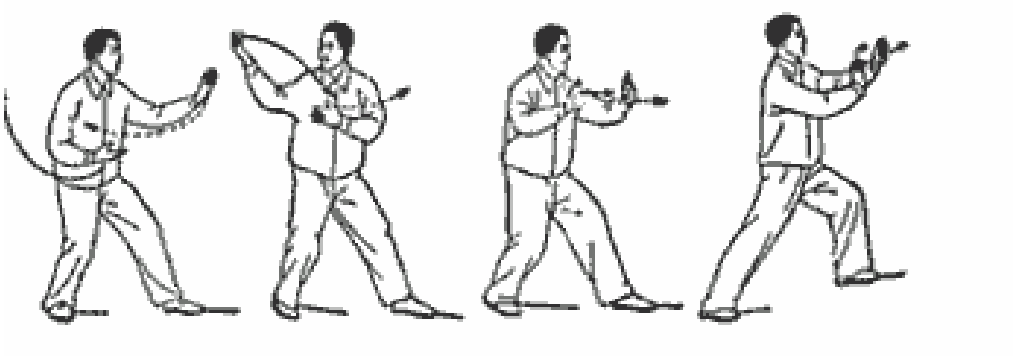

Figure 13. Grasping the Sparrow's Tail[4]

Data Processing

The data captured is processed using the Vicon software provided. All the markers have to be labelled with the correct anatomy. For example, the right elbow has to be labelled as such. This has to be done for as many frames as possible. The missing trajectories will be added in by the software during export. Thus, if the

[3] Martial Applications of Tai Chi Chuan, Taken from World Wide Web, http://www.patiencetaichi.com/brushkne.htm

[4] http://www.geocities.com/ottawakungfu/200TaiChi004D.htm

number of frames filled is not enough, the data may be inaccurate. The completed motion capture is shown below.

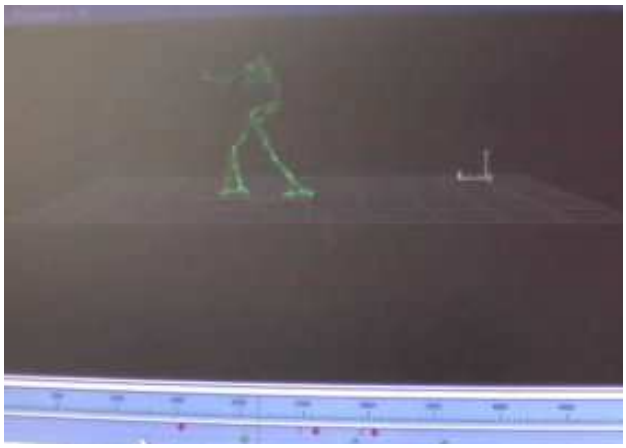

Figure 14. Motion Capture

For each subject, the beginning and ending frame number of the targeted form is recorded down. Data from the vicon motion capture system is exported in the form of a .CSV file. This file can be opened in excel and will list down the X,Y,Z coordinates of the different markers for all the frames. An example of the file is shown in Figure 15.

Frame number

Left Knee Coordinate

	A	B	C	D	E	F	G	H	I	J	K	L
1	Trial02											
2	Date:	##########										
3	Time:	17:13:23										
4	Type:											
5	Description:											
6	Notes:	Imported from: D:\Gait\Gait\Taiji\Rennie\Session 1\T4										
7												
8	TRAJECTORIES											
9	100	Hz										
10		Rennie:LTHI			Rennie:LKNE			Rennie:LANK			Rennie:SACR	
11	Field #	X	Y	Z	X	Y	Z	X	Y	Z	X	Y
12	1	-74.7573	300.2076	587.381								
13	2	-74.7011	300.2593	587.4439								
14	3	-74.6456	300.3084	587.5036								
15	4	-74.5908	300.3549	587.5601	-133.27	295.9493	459.2139					
16	5	-74.5367	300.3989	587.6135	-133.226	295.9505	459.213					
17	6	-74.4833	300.4402	587.6637	-133.183	295.9517	459.2125	-128.844	360.7821	63.03509		
18	7	-74.4306	300.479	587.7108	-133.141	295.9529	459.2125	-128.753	360.8954	63.13485		
19	8	-74.3787	300.5152	587.7547	-133.1	295.9541	459.2129	-128.669	361.0003	63.22719		
20	9	-74.3274	300.5488	587.7954	-133.059	295.9553	459.2139	-128.591	361.0965	63.31211		
21	10	-74.2769	300.5799	587.833	-133.02	295.9565	459.2153	-128.521	361.1844	63.38971		
22	11	-74.2271	300.6084	587.8674	-132.982	295.9577	459.2172	-128.458	361.2639	63.46008		
23	12	-74.178	300.6343	587.8986	-132.944	295.9589	459.2196	-128.402	361.3352	63.52341		
24	13	-74.1296	300.6576	587.9266	-132.908	295.9602	459.2225	-128.352	361.3987	63.5799		
25	14	-74.082	300.6784	587.9513	-132.872	295.9614	459.2259	-128.308	361.4546	63.62983		

Figure 15. Example of .CSV file

The relevant data is then extracted for the specified frame and processed in excel.

3.4.3. Results

Firstly, the left heel and toe, right heel and toe coordinates are obtained for the targeted frame sequence. Next, the angle is obtained from the using the following formula.

$$\text{Gait angle} = \arccos(a.b/|a||b|)$$

Where a = (Left Heel- Left Toe) coordinates and b = (Right Heel – Right Toe) coordinates. The position of both feet during a pushing stance in Lou Xi Ou Bu for both experienced and inexperienced practitioners are obtained by plotting the coordinates of the right and left foot on a graph. The base of gait is then obtained by arithmetic manipulation from the graph.

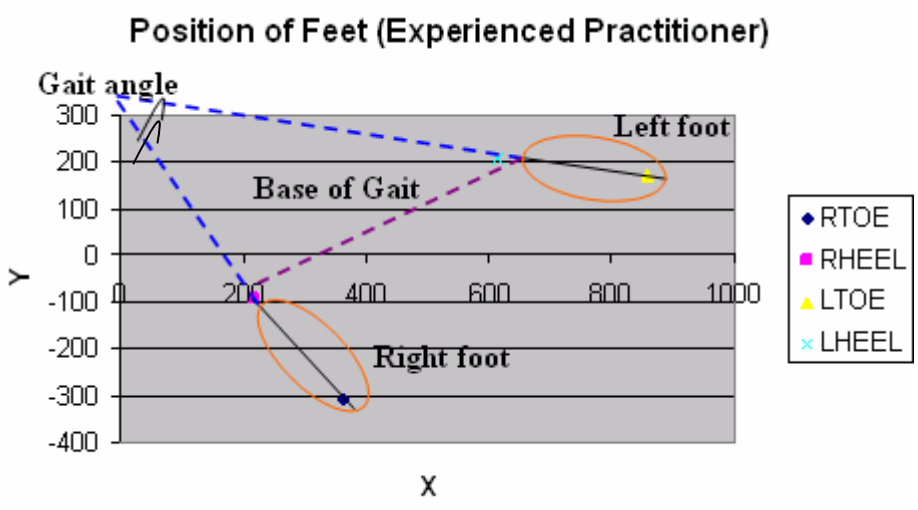

Figure 16. Base of Gait and gait angle of experienced practitioner

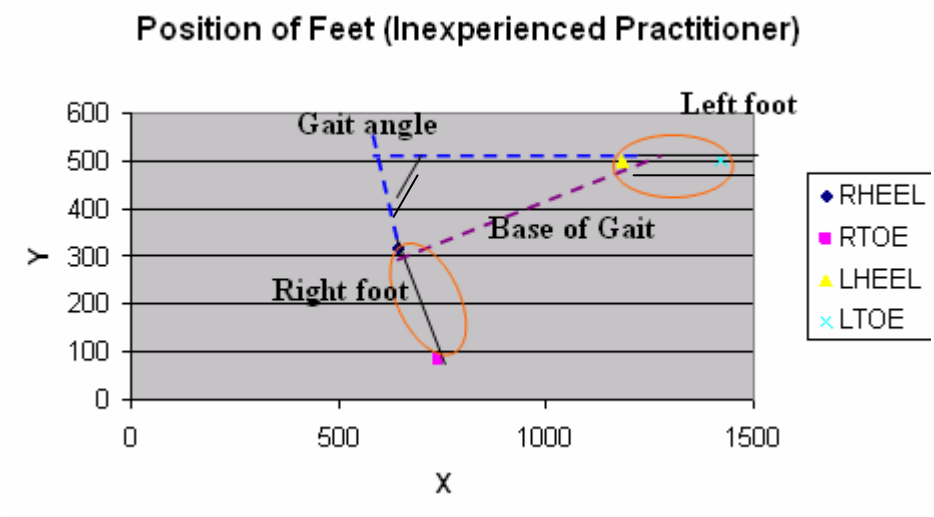

Figure 17. Base of Gait and Gait angle of inexperienced practitioner

Table 3. Gait Angle of Experienced Practitioner vs Inexperienced Practitioner

	Experienced Practitioner	Inexperienced practitioner
Gait angle (degrees)	48.02	67.64

Table 4. Distance between heel of both feet

	Experienced Practitioner	Inexperienced practitioner
Feet distance (cm)	49.62	68

3.4.4. Discussion

It can be seen that the results are not conclusive. The experienced practitioner turns out to have a smaller gait angle then the inexperienced practitioner and a shorter distance between both feet. Hence, the gait angle and distance is not enough to determine who was more stable. An additional condition is the height of the centre of gravity of the respective practitioners.

In many books, the sacrum (Figure 18) is used as an estimation of the centre of

gravity when the body is upright. Thus, the height of the sacrum is taken for the respective practitioner. The z- coordinate of the sacrum at the end of the movement of "Brush Knee" was taken from the data and shown below.

Figure 18. Position of sacrum

Table 5. Sacrum Height of Experienced Practitioner vs Inexperienced Practitioner

	Experienced Practitioner	Inexperienced practitioner
Sacrum Height(cm)	79.512	94.23

The experienced practitioner has an obvious lower centre of gravity compared to the inexperienced practitioner. It can be seen that this would be dependent on the height of the practitioner too. Naturally, a taller person has a higher centre of gravity. On the other hand, he/she may also have a larger stride.

3.5. Line of Centre of Gravity within Base Area

Basis of stability is that the centre of gravity must be within the base area. In normal standing position, this would mean the centre of gravity falling evenly between both feet. In Tai Chi, this basis must be kept. Apart from this, Tai Chi

emphasize that to maintain agility and hence to be able to shift the weight of the body quickly to respond to attacks, the body should not be double rooted. The weight should be distributed unequally between both feet depending on whether the foot is active or passive.

3.5.1. Experimental Investigation

As the centre of gravity acts through the sacrum, the following experimental work is designed and carried out to verify if the position of the sacrum with respect to the heels of the feet gives a good indication of rooting.

Experimental Design

Motion capture is used to obtain the position of the heels and the sacrum. An experienced Tai Chi practitioner and an inexperienced Tai Chi practitioner will each perform “Brush Knee”. The position of heels and sacrum are plotted in excel and analysed.

Procedure

Subject A is a male practitioner who has been learning Tai Chi for 10 years while the Subject B is a female student who has only learnt Tai Chi for 2 months. Vicon will be used to capture the motions of subject A and B.

1. Both will perform “Brush Knee”

2. Data will be used from the start of the pushing movement to the end.

3.5.2. Results

The X and Y coordinates of the left heel, right heel and the sacrum were obtained and plotted throughout the movement. Figure 19, 20 and 21 show the results for the experienced practitioner and Figure 22, 23 and 24 show the results for the inexperienced practitioner.

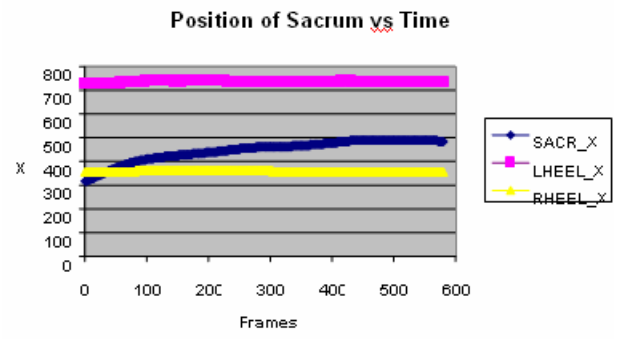

Figure 19. Graph of movements in the X direction against Time(Experienced Practitioner)

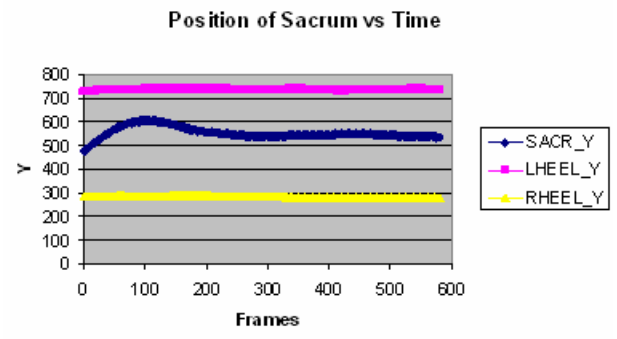

Figure 20. Graph of movements in the Y direction against Time (Experienced Practitioner)

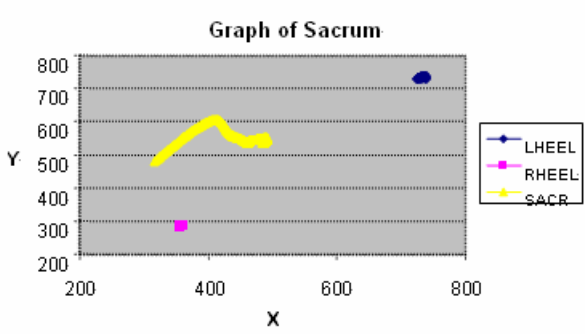

Figure 21. Graph of Overall movement over Time(Experienced Practitioner)

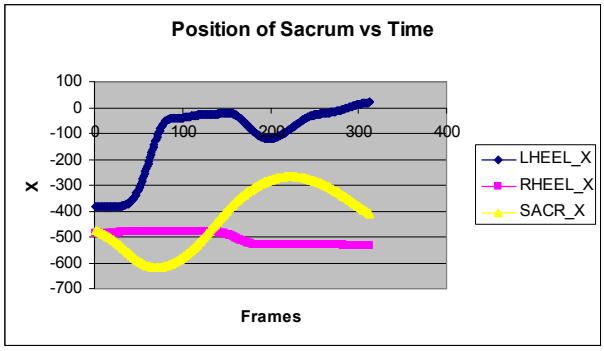

Figure 21. Graph of movements in the X direction against Time (Inexperienced Practitioner)

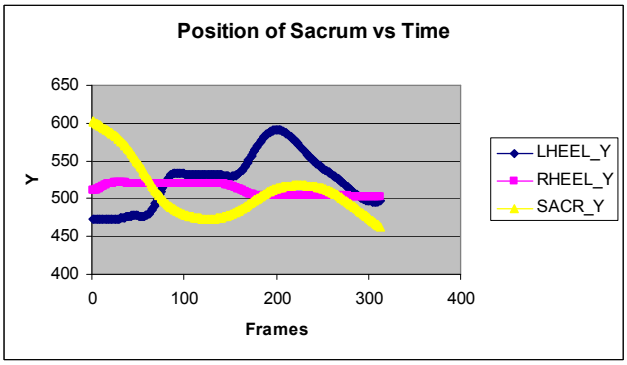

Figure 22. Graph of movements in the Y direction against Time (Inexperienced Practitioner)

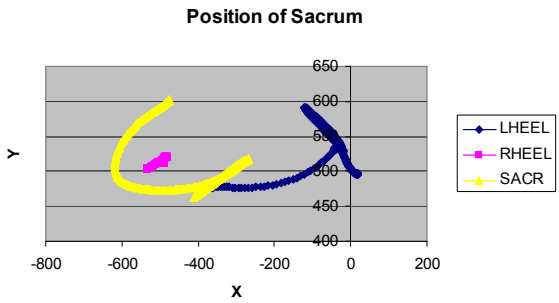

Figure 24. Graph of Overall movement over Time (Inexperienced Practitioner)

3.5.3. Discussion

From the graph of the overall movements, it can be seen that the sacrum of the experienced practitioner is at all times within both heels and thus, within the base area of the body. For the inexperienced practitioner, the sacrum appears to be outside the base area at times. Looking at the individual X and Y motions, for the experienced practitioner, since the push is in the X direction, there is a gradual and consistent increase of the sacrum in the X direction and almost constant in the Y direction. However, for the inexperienced practitioner, the increase of the sacrum in the X direction is not smooth. Also, at the same time as the practitioner is

pushing in the X direction, the Y direction moves up initially then down. Hence, this shows instability in the movement.

The graphs may also shed some light on double rooting. It is observed from Figure 19 of the experienced practitioner that the weight is more on the right foot than the left foot in the X direction. However, in the Y direction, the weight is towards the left foot. Overall movement in Figure 21 shows that double rooting may be present. As the inexperienced practitioner's data is erratic, it cannot be a good comparison.

Further verification

To verify, data from a Tai Chi master with 50 years experience is used to investigate if the sacrum's position can be used to determine double rootedness.

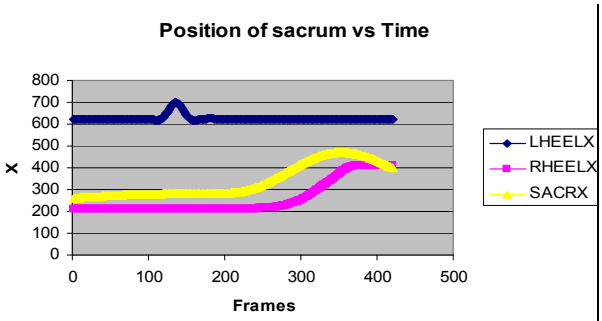

Figure 23. Graph of movements in the X direction against Time (Tai Chi Master)

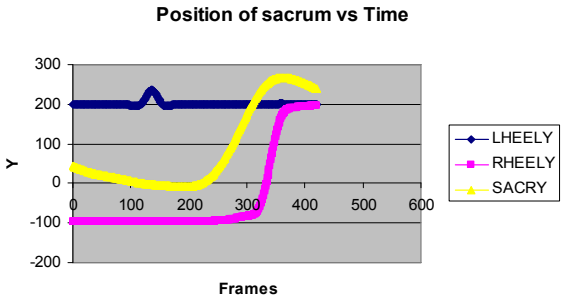

Figure 26. Graph of movements in the Y direction against Time(Tai Chi Master)

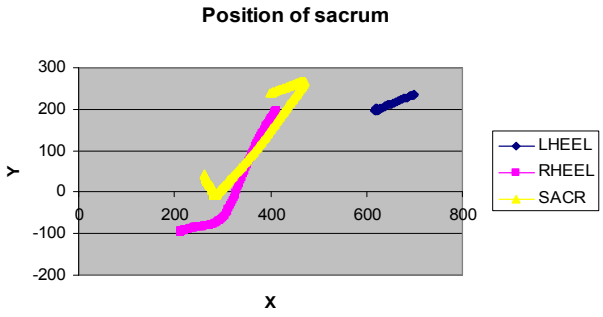

Figure 27. Graph of Overall movement over Time (Tai Chi Master)

It can be observed that the Tai Chi master has an obvious inclination of the sacrum towards the right foot. Therefore, the sacrum's position with respect to both feet can be a potential quantifier of good rooting.

3.6. Conclusion of Experiment

The EMG value for thigh muscle showed conclusively the usage pattern of the lower limbs can be used as a potential quantifier for proper rooting. When the muscle is used efficiently, the antagonist muscle did less work than the agonist muscle.

Using general biomechanics principle to explain rooting turned out to be more cumbersome. Initially, the gait angle and base of gait were thought to be potential quantifiers. However, after experimental investigations, it was found that these two quantifiers were not conclusive on their own. While it is good to have a large base area and gait, this would also depend on the height of the practitioner. This package of stability is still incomplete. The area in which the line of action of the centre of gravity acts has to be examined to give a complete picture. The sacrum is used as the point in which the centre of gravity of the body acts through. A graph is plotted of the position of the sacrum with respect to both feet. With this data, it can be concluded that the inexperienced practitioner have an incorrect posture with the centre of gravity acting outside the base area. Double rootedness can also be verified using the same graph.

It should also be noted that there are many different schools of Tai Chi, for

example, Chen, Yang and Wu. For each different schools, the required Tai Chi stance varies. For example, for Chen style Tai Chi Chuan, the stance is usually lower while for Wu style the stance is narrower.

CHAPTER 4

Waist and Hip Power

4.1 Understanding Waist and Hip Power

Chang San Feng in “太极 拳 论”, a Tai Chi manual wrote that “the root occurs at the foot .. controlled by the waist, and applied at the fingers.” Without learning how to use the waist to control all movements, it is not possible to achieve much in Tai Chi. It is even suggested that the waist itself is a “supreme pole” as Yin and Yang movements originate from it. In the “十 三 势 歌”,Song of 13 postures, it is written that the source of movements should start at the waist, always be aware of the waist. A common mistake during Tai Chi Chuan is the movement of arms independent to the waist. In this way, the arms are not controlled by movement of the waist. The whole form therefore is not a connected one from head to toe. The ‘waist’ in the old manuals also included the ‘kua’, the joint between the thigh and the pelvis. It is also known as ‘hip crease’. This concept is central to Tai Chi as Tai Chi Chuan does not generate force by muscles and speed but by channeling of force starting at the feet, directed by the waist.

4.2. Scientific Research

Almost no scientific research was found regarding the use of the waist in Tai Chi. However the importance of hip power is also stressed in other sports such as Karate

and Taekwondo. In an article on Taekwondo[1] it was emphasized that in a fore fist punch, when pushing of the rear leg, if the abdominal muscles rotate about the hips around the centerline of the body, more power is applied in the direction of the rotation. This results in the transference of the force from the linear motion of the leg into the rotational motion of the hips. The rotation of the hips does not end there. It also leads to rotation of the torso and shoulders which contribute to the overall power of the punch. The function of the hip and waist in Tai Chi should be examined in detail to reveal potential quantifiers to use in the experiments.

4.3. Potential Quantifier – Hip

The hip is a joint connecting the thigh to the pelvic region. It is through the hip that the weight of the upper body passes down. Improper hip alignment will result in unequal weight distribution to different muscles creating unnecessary tension. On the other hand, during Tai Chi step, the upper body is translated smoothly with respect to any shift in position of the base due to the rotation of the hip. The force from the driving leg causes the hip to rotate and align the upper body. Therefore the hip ensures stability and mobility as well as a means to transfer power. As shown in Figure 21, during a Tai Chi form, the driving leg exerts a force which is transferred to the hip. At the same time, the passive receiving leg steps out with the knee aligned with the toe.

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[1] Taken from the world wide web 10/1/2007 Hip Snap/Winding TKD tutor, Knowledge for Teakwondo professionals
http://tkdtutor.com/06Concepts/Power/HipSnapWindingSineWave/HipSnapWindingSineWave01.htm

The force is then transferred from one hip to another to align the upper body. For hip, a potential quantifier could be the angle of rotation of the passive hip during a Tai Chi bow stance after the heel of the passive foot touches the ground.

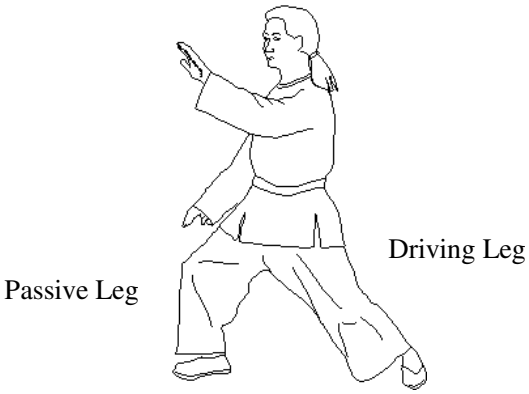

Figure 1. Tai Chi stance

Incorrect form will see Practitioners trying to twist the knee hinge joint or ankle joint instead. Also, some may turn the passive leg from the hip in mid movement when the feet have not touched the ground. Thus, transfer of force is limited.

4.3.1. Experimental Investigation – Rotation Angle of Hip

The following experimental work is designed and carried out to verify if the amount of rotation angle of the hip during the Tai Chi bow stance could be used to identify the proper use of hip in Tai Chi.

Hypothesis

It is hypothesized that if the hip is used correctly in transferring force from the ground to the upper body, the angle of rotation of the hip should be quite pronounced.

Design of Experiment

Vicon Peak optical Motion capture system is used to obtain the hip rotation angle needed. An experienced Tai Chi practitioner and an inexperienced Tai Chi practitioner will each perform a specified sequence of the Tai Chi forms. The data obtained is used to calculate the hip rotation angle.

Experimental Procedures

Previously, we have already used Vicon to capture the motions of Subject A and Subject B, the motion capture data will be recycled for use in this case. The angle of rotation of the hip during "Knee Brush" will be extracted from the data.

4.3.2. Results

The Z coordinates of the hip angles for the length of the motion were extracted from the .csv file. The results are shown in Figure 25.

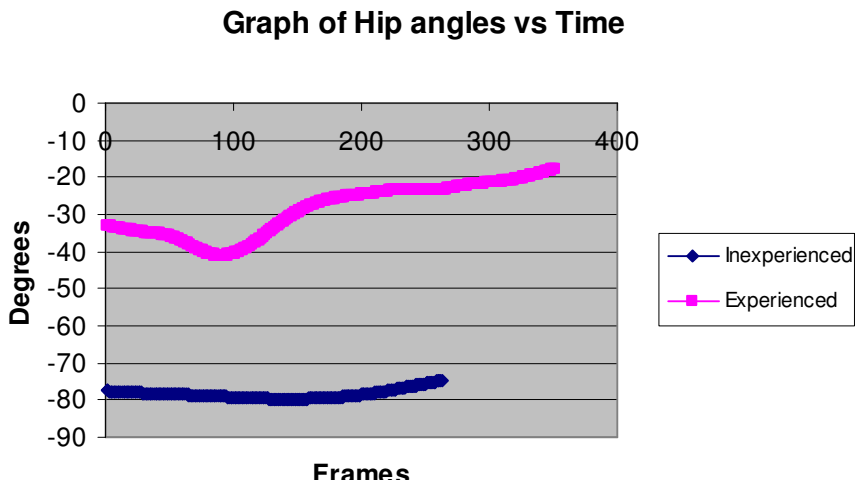

Figure 2. Graph of hip rotation

4.3.3. Discussion

From the graph, it can be seen that for the experienced practitioner, the turning angle

of the waist is about 20 degrees. However, for the inexperienced practitioner, the turning angle is only 5 degrees. Since the data is taken only from the start of the pushing movement when both feet are on the ground, this could mean that the inexperienced practitioner has already twisted the torso when moving the leg to change the direction.

A look into the slow motion frames of both practitioners may confirm this. The tai chi master moves the knee straight ahead and turns the upper body forward using the hips. For the inexperienced practitioner, the foot is extended with the knee facing inwards, Hence, in order to push forward, it was necessary to turn the foot forward which lead to turning of the knee and hip. Even before pushing, the hips are already facing the forward direction.

Figure 3. Slow Motion Capture of Experienced Practitioner

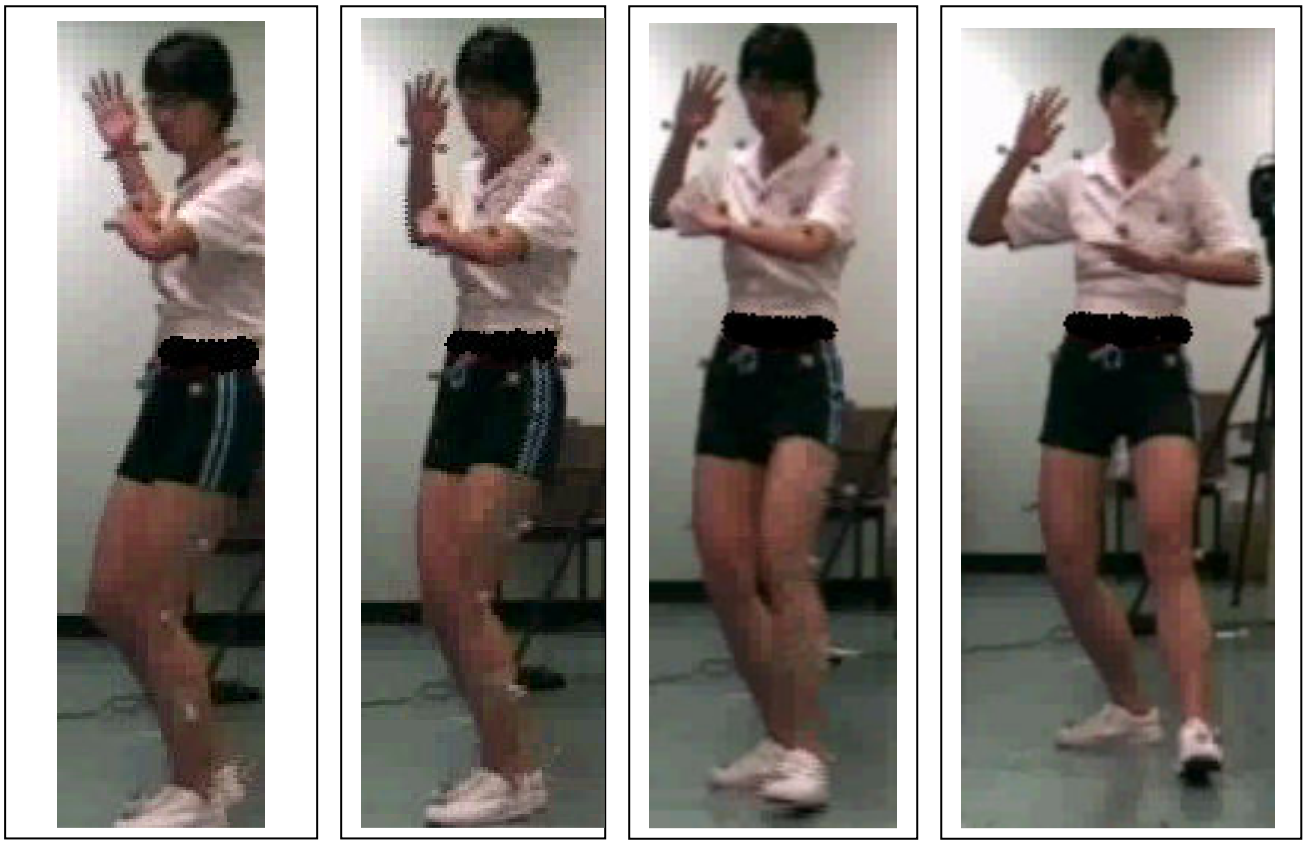

Figure 4. Slow Motion Capture of Inexperienced Practitioner

4.4. Potential Quantifier -Waist

The waist functions like an axle for the upper body. Hand movements originate from it and are a result of it. They should not move independently of the waist. This could be easily explained. If the hands move from the shoulder joint, the moments is proportional to the distance between the wrist and the shoulder joint this is much lesser than the moment obtained from turning from the waist. For the waist, a potential quantifier could be the angle of rotation of the elbow compared to the waist. This is because if the waist is the source of the movement, the angle of rotation of both should be similar. Muscle activation level of the shoulder muscle can also be

taken. If the shoulder muscle is relaxed during the movement, little tension should exist.

4.4.1. Experimental Investigation – Rotation Angle of Waist compared to Elbow

The following experimental work is designed and carried out to verify if the rotation angle of the elbow is similar to the angle of rotation of the waist during "Brush Knee".

Hypothesis

It is hypothesized that the angle of rotation of both the elbow and waist should be very similar if not the same. The elbow should not turn faster than the waist.

Design of Experiment

Vicon Peak optical Motion capture system is used to obtain the elbow and waist rotation angle needed. An experienced Tai Chi practitioner and an inexperienced Tai Chi practitioner will each perform "Brush Knee".

Experimental Procedures

As previously, we have already used Vicon to capture the motions of Subject A and Subject B, the motion capture data will be recycled for use in this case. The angle of rotation waist and elbow during Lou Xi Ou Bu will be extracted from the data.

4.4.2. Results

In order to measure the elbow angle and the turning angle of the waist, 3 point are

used. T10, RBAK(right back) and RELB(right elbow). Since the right back cannot have turning motions on its own, it is taken as a reference point. A reference line is constructed from the RBAK to T10 and another line from the RELB to T10.

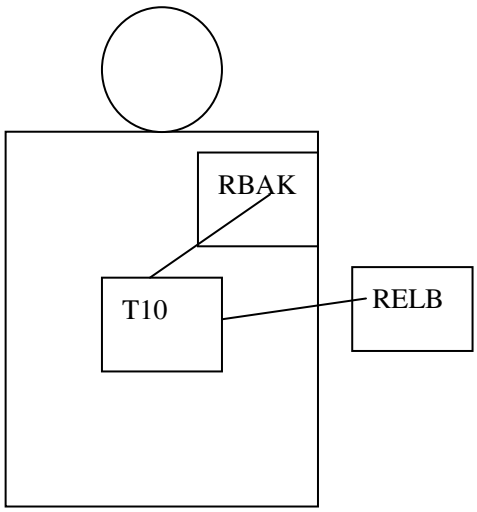

Figure 5. Markers on back of Practitioner

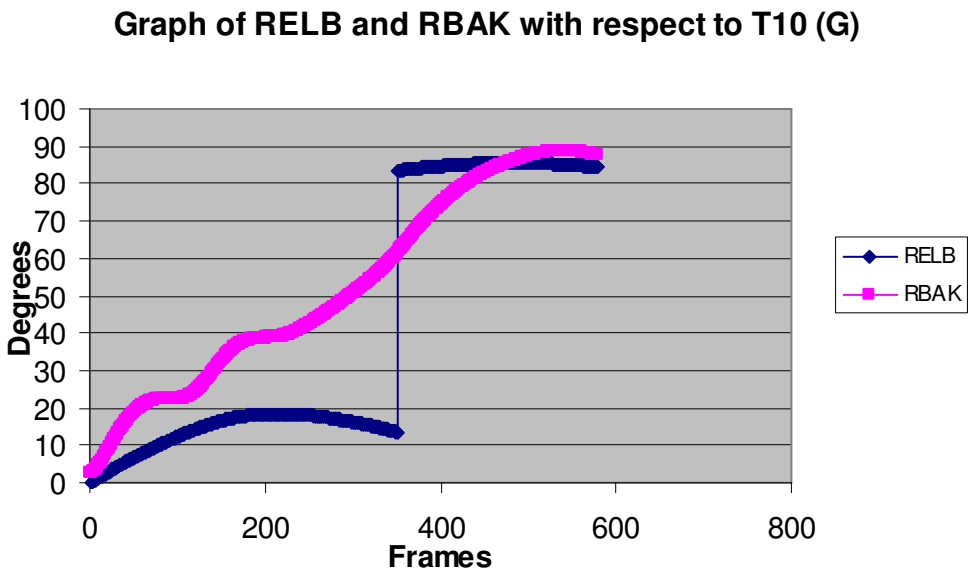

Figure 29. Angle of rotation of Elbow with respect to Waist (Experienced Practitioner)

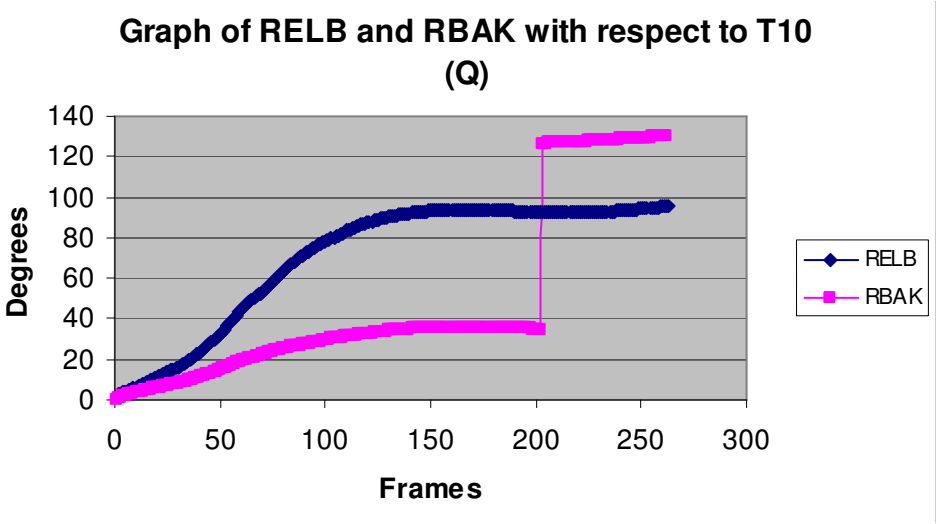

Figure 30. Inexperienced Practitioner

4.4.3. Discussion

In Figure 15, the turning angle of the elbow is less than that of the back, hence the waist. This is expected for the experienced practitioner since the turning movement of the waist should lead the elbow. The break in the curve of the elbow is due to the pushing movement. It can be seen that before the break, the curve has started to plateau. For the inexperienced practitioner, the elbow turns faster than the waist. This is incorrect practice as the turning of the hand originates from the shoulder.

4.5. Potential Quantifier – EMG of shoulder

Another way to check for incorrect use of shoulder for hand turning movements is to measure the shoulder muscle activity. If the movement originates from the shoulder, the EMG of shoulder should be large.

4.5.1. Experimental Investigation – EMG of shoulder

The following experimental work is designed and carried out to verify if the tension in the shoulder muscle is a good quantifier for the proper use of the waist to lead the hands.

It is hypothesized that the EMG levels for the shoulder should be very low for the correct use of the hands.

Design of Experiment

Muscle activation profiles for the shoulders obtained during "Brush Knee" were to be taken from two groups of people, experienced Tai Chi practitioners and inexperienced Tai Chi practitioners. The data for the two different groups will then be compared.

Experimental Procedures

The following procedure is undertaken.

A Noraxon dual electrode was placed on the belly of each muscle along the muscle fibre direction of the relevant shoulder muscle. The supraspinatus is targeted as shown in Figure 30. Common electrodes (Noraxon single) were placed at the collar bone.

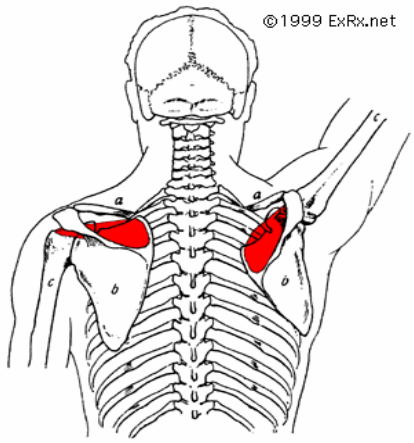

Figure 31. Supraspinatus muscle

1. Subjects are told to extend their hand backwards as far as they can. Maximum voluntary contraction (MVC) of the supraspinatus is then taken and recorded.

2. Subjects are to perform a cycle of "Brush Knee". Maximum EMG readings are noted down. This will be done twice to get accurate readings. The data obtained is normalised with the MVC values.

4.5.2. Results

	EMG Readings (µV)	
	Experienced Practitioner	Inexperienced Practitioner
Shoulder (Suprapinatus)	0.3	0.5

4.5.3. Discussion

It can be seen that the EMG reading for an experienced practitioner is lower than that of the inexperienced practitioner. Therefore it is concluded that electromyography can be used to determine if the movement of the arm originates from the waist.

CHAPTER 5

Sink the Shoulders and Drop the elbows

5.1 Understanding sinking the shoulders and dropping of elbows

In Yang's form Ten important points by Yang Cheng Fu, he emphasized on Sinking the shoulder and dropping the elbow. For the transfer of force from the feet to the hand, the muscle must be relaxed or 'Sung'. Therefore, it is important to drop the shoulder. If the shoulders are raised, tension is created in the muscles of the shoulders, upper back and neck. The position of the elbow is very significant in Tai Chi. The angle at which it is placed determine the amount of power transferred from the elbow to the hand. Hence, the elbow should be dropped below shoulder level otherwise the muscles of the shoulder will be tensed. In the point of martial arts, lifting the elbow presents an attacking opportunity to the opponent.

5.2. Scientific Research

Again, not much research has been found regarding the kinematics of the upper body. Hence, an analysis of the biomechanical importance of sinking the shoulder and dropping the elbow has to be considered below. The vague explanation given by some websites state that dropping of the elbow with respect to the shoulder will connect the elbow to the shoulder. However, Tai Chi practitioners may not

know how much should the elbow be away from the body. A rough gauge given by many websites indicates that it is adequate to have elbow away from the body to allow an egg to be held. The biomechanical analysis of this study will investigate and help clarify this required movement.

5.3 Biomechanical Analysis

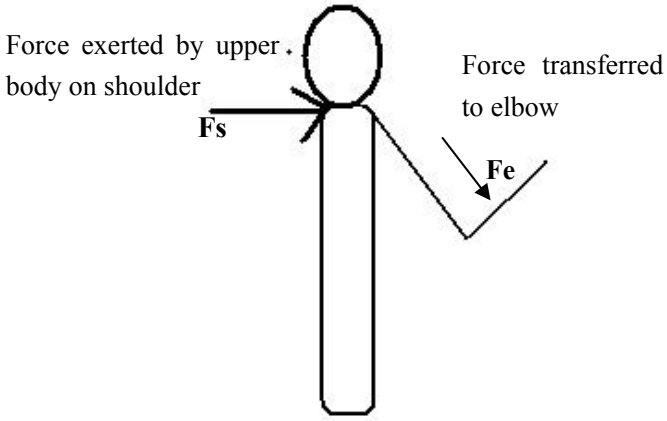

Figure 32. Force acting on elbow joint

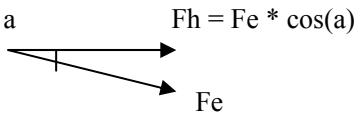

Figure 293. Static Analysis of force

Figure 26 shows a pushing movement. Only the force exerted by the upper body the elbow is considered. The force of the arm muscle itself is not considered. From the force diagram of Figure 27, with both Fe and Fh in the horizontal plane it can be seen that when angle a is 0 degrees, maximum transfer of force occurs. Fh is the force in the horizontal position, hence it is the transference of the force of the elbow in the forward direction acting on the hand. If the elbow is not dropped, the elbow will be angled outwards more and hence the force in the

horizontal direction (direction of the push) will be less. This is not entirely true for Tai Chi movement as the angle cannot be entirely zero since holding the upper arm close to the upper body will restrict movement. However, this would give a better understanding to ‘sinking the shoulders and dropping the elbows’.

5.3.1. Experimental Investigation

The following experimental work is designed and carried out to verify if the height of the elbow during a Tai Chi sequence and the angle between the upper arm to the vertical line dropping from the shoulder joint could be used to identify the correct understanding of sinking shoulders and dropping elbow.

Design of Experiment

An experienced Tai Chi practitioner and an inexperienced Tai Chi practitioner will each perform a specified sequence of the Tai Chi forms. The elbow height will be taken throughout the sequence while the angle of the upper arm to the shoulder joint will be taken during “Grasp the Sparrow’s Tail”.

Experiment Procedures

As the sequence of forms required in earlier experiments included Lan Que Wei, the data needed could be taken from the motion capture data obtained earlier. The angle is taken to be between the elbow and the vertical line from the right back. This is due to errors in the data for the shoulder joint for the experienced practitioner.

5.4.2. Results

The angle is obtained using acos(A/B) as shown in Figure 33.

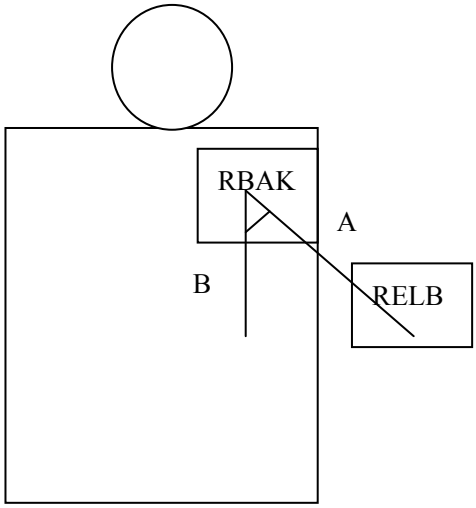

Figure 34. Angle between Elbow and Vertical line from the Right Back

Figure 35. Graph of Angle between and vertical line from right back

5.3.3. Discussion

The experienced practitioner starts with an angle of 30 degrees and at the end of the pushing movement, the maximum reached was 62 degrees. For the inexperienced practitioner, the pushing movement started at 40 degrees and the maximum is at 80 degrees. It is noted that these angles are taken using the right

back marker as reference. Hence, the angle from the shoulder to the elbow would be much smaller.

5.4 Potential Quantifiers – Height of Elbow relative to shoulder

A potential quantifier would be the height of the elbow relative to the shoulder. Using the pushing sequence in "Brush Knee", data is obtained for the Z-axis of the elbow and shoulder joint.

5.4.2. Results

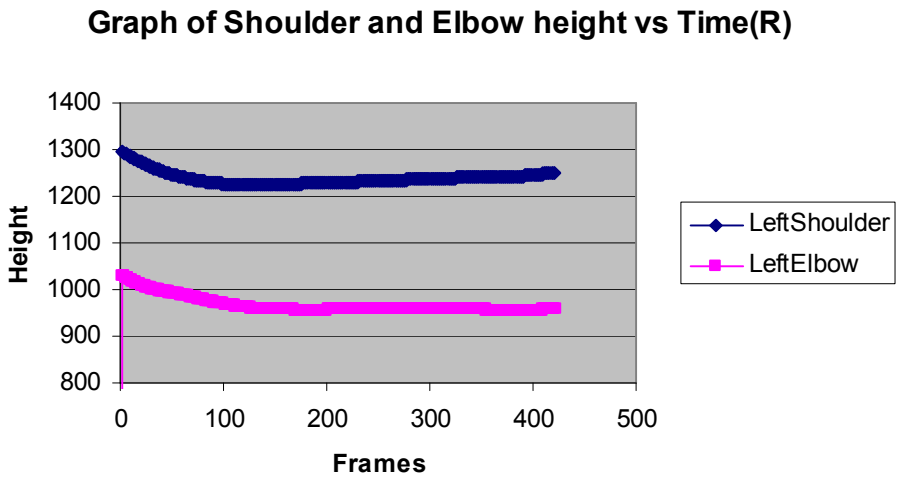

Figure 36. Graph of Shoulder and Elbow Height (Experienced practitioner)

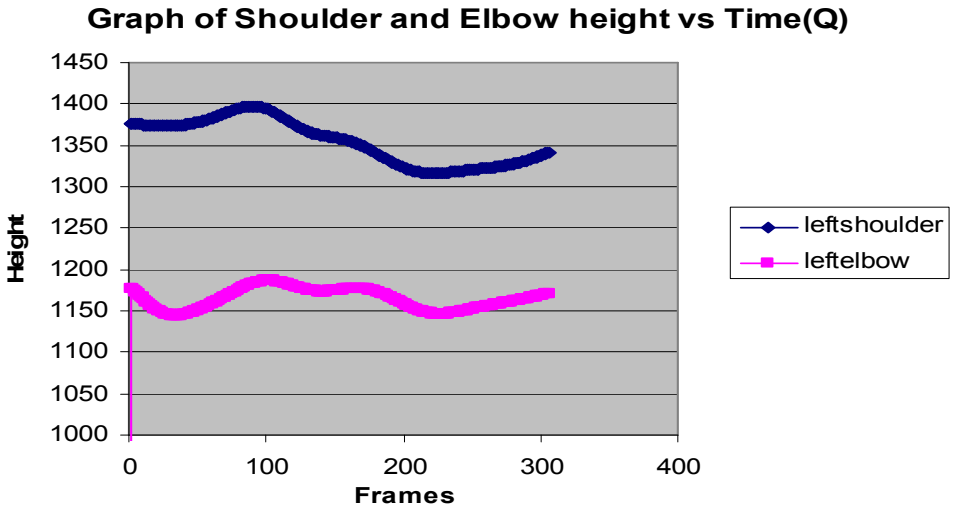

Figure 307. Graph of Shoulder and Elbow height (Inexperienced Practitioner)

Figure 38. Difference between Shoulder and Elbow Height

5.4.3. Discussion

It can be seen that for the experienced practitioner, the elbow height relative to the shoulder stayed almost constant throughout the movement. For the inexperienced practitioner, at some parts of the movement, the shoulder decreased in height, probably due to flexing of knees, however, the elbow height did not decrease. Instead, there was a slight increase. This shows that the elbow was not dropped during the form. As the data capture a pushing movement, it is inferred that the arm may be overly straightened. This would account for the increase in elbow's height. In Tai Chi, this is not advised since the straightening of the arm causes tension in the upper arm and in the shoulder. It is also observed that the push of the practitioner is smooth and consistent while that of the inexperienced practitioner is jerky.

The graph of difference between shoulder and elbow revealed more insights. The

difference should preferably be larger. The experienced practitioner had a range of values between 22.5 cm to 29.5 cm whereas the inexperienced practitioner had a range of values between 16cm to 23 cm. This means that the inexperienced practitioner did not drop the elbows much. This will lead to raised shoulders and tension in the back. It is also observed that the graphs of the two subjects are moving in different direction. While the difference between the shoulder and elbow of the experienced practitioner is increasing throughout the pushing movement, the difference is decreasing for the inexperienced practitioner. As mentioned above, this could be due to the straightening of the arm of the inexperienced practitioner.

CHAPTER 6

Conclusion

Imagine life-size robots, trained in the arts of Tai Chi. Skilled and virtually indestructible, they are hired to protect the rich and famous. The algorithm of the robots stored in their system works on data of Tai Chi principles. This is, but one application of scientific quantifying of Tai Chi. This study aims to identify quantifiers to Tai Chi principles.

From literature research and discussion with experienced Tai Chi practitioners, 3 principles are focused on. They are stability, waist and hip power and sinking of shoulders and dropping of elbows. Next, potential quantifiers are identified for each of them and experimental investigation designed. Experiments are conducted on experienced and inexperienced practitioner in order to verify the hypothesis. Then the data obtained using motion capture and electromyography are processed and analysed.

For stability, potential quantifiers are classified into two categories which are efficient use of lower limb muscles and biomechanics principles of stability. It is believed that efficient use of limb muscle results in consistent force and a stable root. Results have shown that EMG of antagonist and agonist muscle can be used to quantifier good rooting. However, due to the small number of subjects tested, statistical methods could not be carried out to achieve a level of confidence in the

results. Use of biomechanics principles of stability have turned out mixed results. The most conclusive result is to use the position of the sacrum with respect to the base area between the feet of the practitioner. This can also be used to eradicate double rooting. On the other hand, the contribution of gait angle and base of gait is relatively insignificant.

Hip and waist power is critical to Tai Chi due to the immense power to be obtained. Quite straightforwardly, possible quantifier for hip power could be the turning angle of the hip. Results show that the turning angle of the hip is indeed a good quantifier as the experienced practitioner has a turning angle 5 times that of the inexperienced practitioner. The waist can be quantified by the turning angle of the elbow should be smaller or similar to the turning angle of the waist. This hypothesis has been verified.

Lastly, sinking of the shoulders and dropping of the elbow can be quantified by the angle between the elbow and the vertical line from the shoulder joint and the height of the elbow relative to the shoulder.

The experiment has shown that Tai Chi principles can be reduced to parameters that can be measured scientifically. However, there are still some limitations to understanding Tai Chi due to its emphasis on ‘Qi’. For example, biomechanical principle of stability has been found to have little significance on rooting. In many Tai Chi books, rooting has been attributed to the channel of energy through to the acupuncture or meridian point on the sole of the foot. Thus, using biomechanics

alone is not enough. Other fields have to be brought in to give a more complete picture.

Further improvement could include having a bigger number of test subjects so that hypothesis testing can be carried out for EMG measurements. As the experiments are done in the time domain, analysis in the frequency domain could reveal insights about power of the Tai Chi practitioner.

That being said, it is believed that this paper has helped to made Tai Chi concepts clearer and increased the understanding of the principles. Particularly, to Tai Chi beginners where perfection of form is of utmost importance, it is hoped that this paper will help speed up their learning process.

Reference

[1] Alan Peck. T'ai Chi: The Essential Introductory Guide. (Vermilion, October 1996)

[2] Michael P. Garofalo. Zhang San Feng. 2007. Available from: http://www.egreenway.com/taichichuan/chang1.htm\

[3] UCT Tai Chi Club. Benefits of Tai Chi Chuan. Available from: http://sportsclubs.uct.ac.za/taichi/benefits.html

[4] Chan SP, Luk TC, Hong Y (2003). Kinematic and electromyographic analysis of the push movement in Tai Chi. Br J Sports Med 2003;37(4):339–44.

[5] Lisa Liddane. Tai Chi: Brush knee and Step Forward. Available from http://www.ocregister.com/ocr/2004/06/27/sections/health_family/health_family/article_144815.php

[6] TKD tutor. Hip Snap/Winding, Knowledge for Teakwondo professionals. Available from http://tkdtutor.com/06Concepts/Power/HipSnapWindingSineWave/HipSnapWindingSineWave01.htm

[7] Peter McGinnis, Biomechanics of sport and exercise, Champaign, Ill.: Human Kinetics, c1999.

[8] Mao DW, Hong Y, Li JX (2004). The kinematical characteristics of the lower extremities during Tai Chi Chuan exercise. In Proceedings of XXIInd International Symposium on Biomechanics in Sports (pp. 597-600).

[9] Mao DW, Li JX, Hong Y (2006). Plantar pressure distribution during Tai Chi exercise. Archives of Physical Medicine and Rehabilitation, 87(6):814-820.

Appendix A- Previous Experiment on Rooting (FYP 2006)

"Rooting"

This chapter documents the investigation that was carried out on the concept of *"rooting"*.

Understanding of *"rooting"*

"Rooting" is a concept that is closely related to stability. The Tai Chi Classics describe it as a state when "the body is like a plant or tree, rooted through the feet to the earth while the rest of the body sways and bends in accord with the elements". This metaphorical description is made more scientific by modern practitioners who understand it as the lowering of the centre of gravity (Desai 2003). While this definition may not be complete, it rightly points to the relationship between *"rooting"* and stability.

Potential Assessment Criteria

Since *"rooting"* is primarily associated with stability, an intuitive way of assessing it would be via an examination of postural stability.

Shabana and team (2005) offered a possible method of doing this when they measured postural stability using force plates in their research.

In this experiment, postural stability was deduced from the variation in ground reaction force (F_{ground}). More specifically, a more consistent F_{ground} will imply a higher stability.

Force plates

Force plates were used to measure F_{ground}. The equipment was available at the National University Hospital's Orthopedic Diagnostic Centre. It consists of 2 force plates (50cm by 35cm) capable of detecting any downward force applied to its top surface. Figure 8.1 shows the arrangement of the plates.

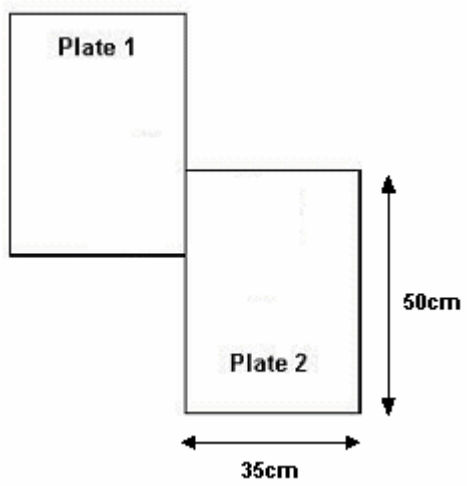

Figure 0.1 Force Plates

Experiment

The section describes the experimental work that was conducted to determine the viability of using standard deviation of ground reaction force as a parameter for assessing *"rooting"*.

Hypothesis

The hypothesis of this experiment is that success or failure at *"rooting"* can be determined from the standard deviation in the ground reaction force exerted by a person over time.

Research Methodology

To investigate the hypothesis, force plate experiments were carried out on a skilled practitioner (who represents the successful *"rooting"*) and compared against that of an untrained control (who represents no *"rooting"*).

Experimental Procedure

The subjects were (i) Subject A -- a 64-year-old Chinese male (height 166cm, weight 64kg) who has been practising Tai Chi for the past 20 years and (ii) Subject B -- a 52-year-old Chinese male (height 172cm, weight 64kg) with no prior experience of Tai Chi. Both subjects were certified to have no history of postural or proprioceptive problems.

At the start of the experiment, the subjects were asked to stand on 2 force plates with one foot on each plate. Due to the orientation of the plates, the subjects had to stand at an angle to ensure that they were able to keep their feet completely within the plates. Figure 8.2 shows the orientation of the feet with respect to the plates.

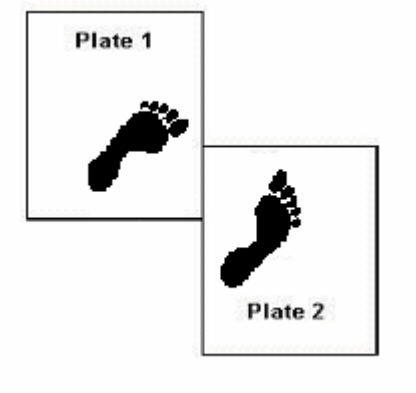

Figure 0.2 Position of feet on force plates

Subject A was asked to stand in his Tai Chi standing stance *(Zhan Zhuang*, shown in Figure 8.3) while Subject B was asked to stand in his normal standing posture. Both subjects were told to stand comfortably and not refrain from making unnecessary movements.

Figure 0.3 Standing Posture of Subject A

The subjects remained in their postures for 7 minutes and data was collected from the 2nd minute. Two sets of data were taken for each subject, with a 20 minutes break in-between.

Data Analysis

The data collected was processed using the Polygon Software. The ground reaction force (F_{ground}) was resolved into the x-, y- and z- components. Data from the 2 trials was averaged for each subject and the standard deviation was found for each subject in each direction.

Results

Figure 8.4 shows the ground reaction force patterns for the left and right foot.

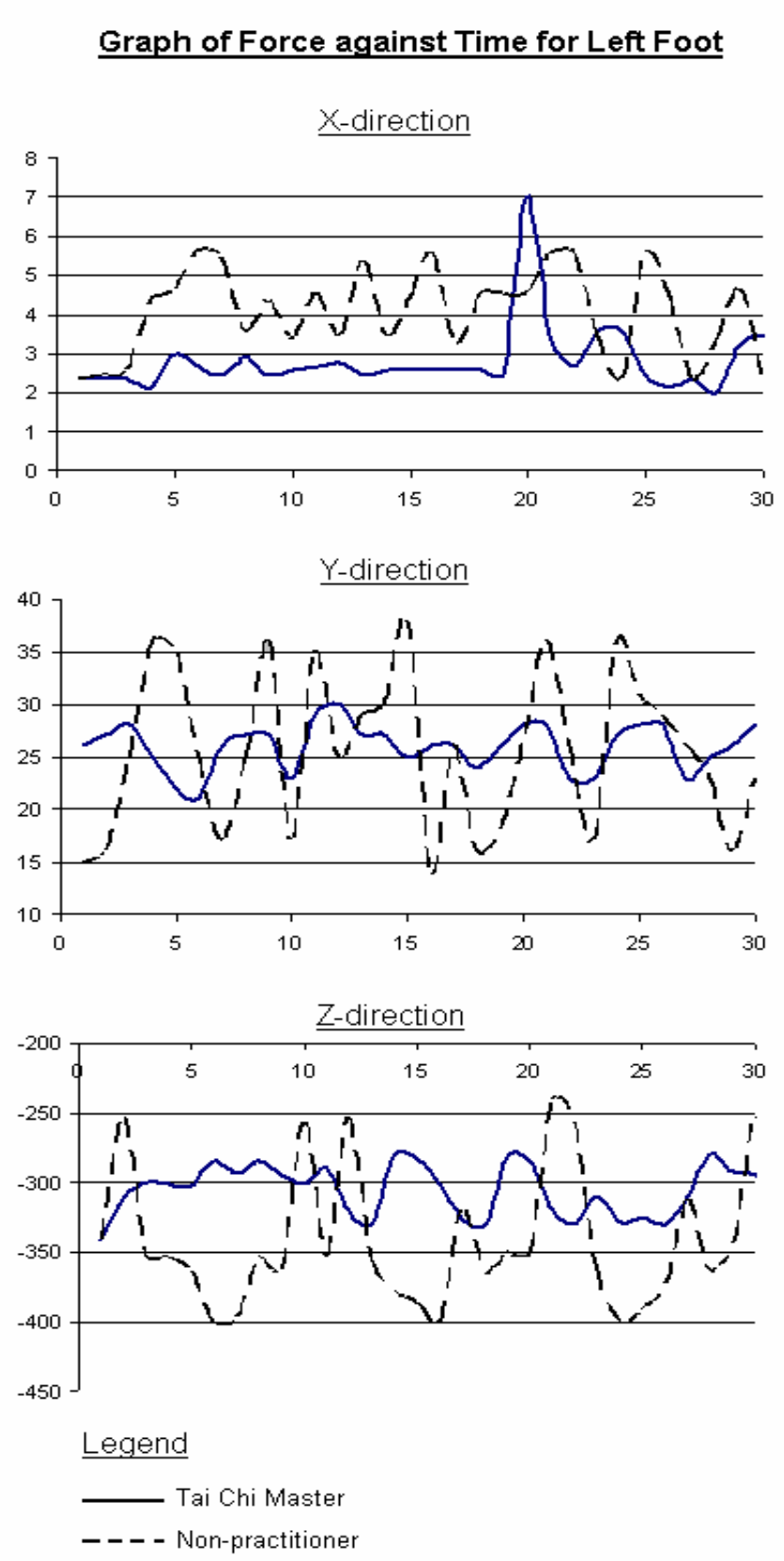

Figure 0.4(a) Left Foot Ground Force Pattern

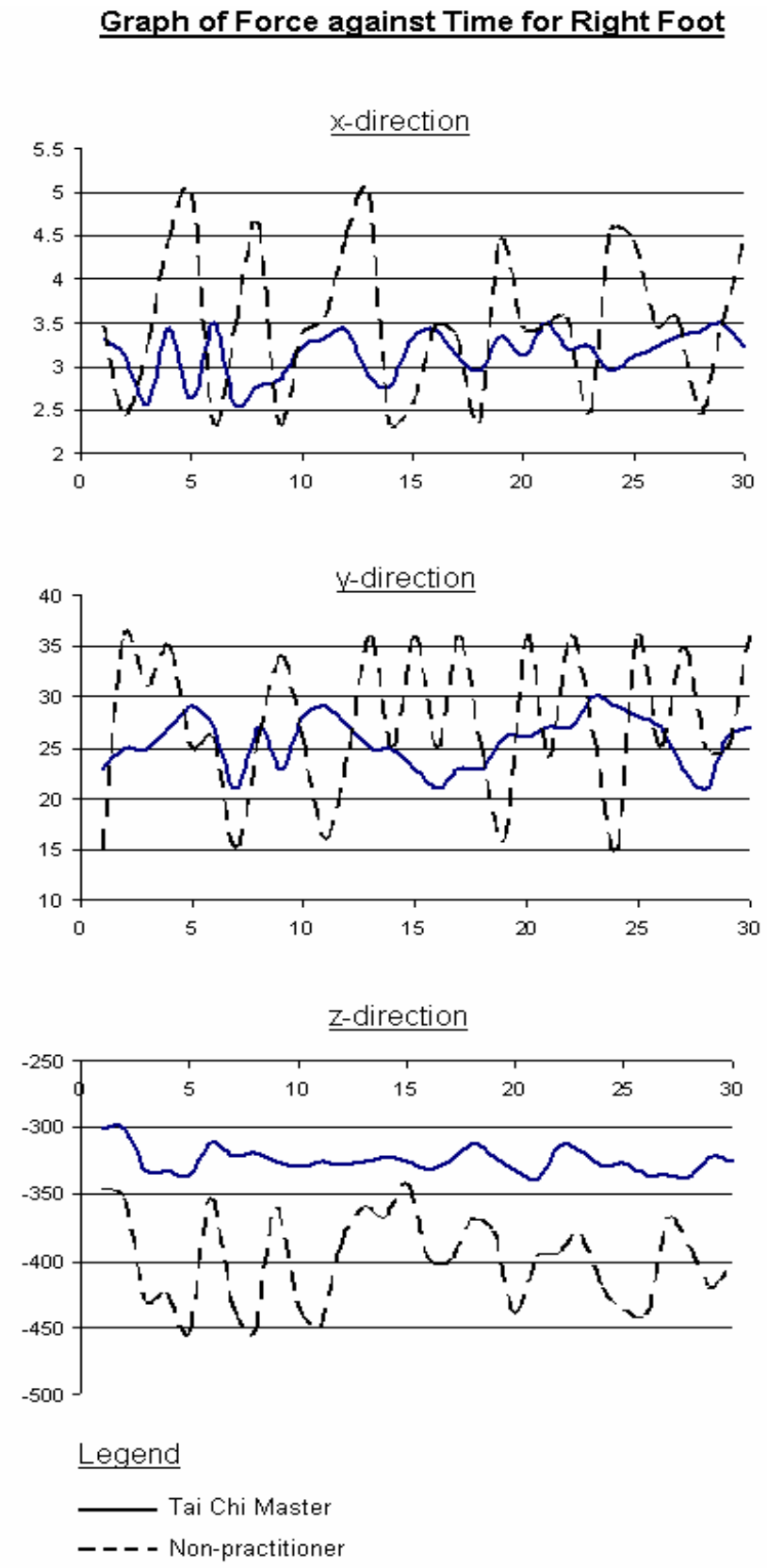

Figure 8.4(b) Right Foot Ground Force Pattern

Table 8.1 shows the standard deviations

Table 0.1 Standard Deviation of Ground Reaction Force

		Standard Deviation of Ground Force	
		Tai Chi Master	Non-practitioner
Left Foot	x	0.88	1.11
	y	2.15	7.43
	z	18.3	49.4
Right Foot	x	0.28	0.84
	y	2.50	7.19
	z	9.35	34.3

Analytically, the standard deviations in F_{ground} were 20.7%, 71.1% and 63.0% (in the x-, y-, and z- directions) lower for Subject A than Subject B for the left foot, and 66.7%, 65.2% and 72.7% lower for the right foot.

Conclusion of Experiment

The standard deviation in ground reaction force was significantly lower for the Tai Chi practitioner as compared to the non-practitioner for both the left and right foot in all three directions. Such results indicate that force exerted by the Master fluctuated through a smaller range as compared to the non- practitioner. Furthermore, his frequency of fluctuation was also much lower.

The smaller range and frequency of fluctuations suggests a lower degree of shaking and throbbing, thereby indicating that the Master had better balance and stability as compared to the non-practitioner.

Given the obvious and consistent (in all direction, for both feet) difference in standard deviation of ground reaction force between the *"rooted"* and *"non-rooted"* case, we therefore conclude that standard deviation in ground reaction force is a suitable parameter by which the achievement of *"rooting"* can be determined