Kinematic and electromyographic analysis of the push movement in tai chi

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ORIGINAL ARTICLE

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Background: Tai chi is a form of exercise derived from the martial art folk traditions of China. The force used in tai chi includes different principles of mechanical advantage. No studies on the kinematic features of tai chi exercise have been published.
Objective: To analyse the kinematics and electromyographic characteristics of tai chi.
Methods: An experienced tai chi master was asked to perform a sequence of basic movements: ward off, roll back, press, and push. The movements were videotaped and digitised using a motion analysis system. Electromyographic activities of the lumbar erector spinae, rectus femoris, medial hamstrings, and medial head of gastrocnemius were recorded by surface electrodes. The push movement data were analysed.
Results: The medial hamstrings and medial head of gastrocnemius muscle groups maintained low activity, with higher electromyographic values in the lumbar erector spinae and substantially higher ones in the rectus femoris during the push movement. Both concentric and eccentric contractions occurred in muscles of the lower limbs, with eccentric contraction occurring mainly in the anti-gravity muscles such as the rectus femoris and the medial head of gastrocnemius. The forward and backward shifts in centre of gravity (CG) were mainly accomplished by increasing and decreasing respectively the joint angles of the bilateral lower limbs rather than by adopting a forward or backward postural lean. The path of the CG in the anteroposterior and mediolateral component was unique, and the sway or deviation from the path was small. The master maintained an upright posture and maintained a low CG (hips, knees, and ankles bent) while travelling slowly and steadily from one position to another.
Conclusion: The eccentric muscle contraction of the lower limbs in the push movement of tai chi may help to strengthen the muscles.

Tai chi is a form of exercise derived from the martial art folk traditions of China. Nowadays, it is mainly carried out to aid health and fitness. It is suitable and recommended for the aged and for patients with chronic illnesses.[1] Zhuo *et al*[2] have classified long form tai chi as exercise with moderate intensity. Its intensity does not exceed 50% of maximum oxygen uptake, and the physiological changes in heart rate, noradrenaline, cortisol, and mood measured during tai chi were comparable to those found for moderate exercise.[3]

Tai chi involves a sequence of movements, or forms, that require movement of the whole body in a coordinated fashion, including the trunk, limbs, and breathing pattern. Unlike those in most other martial arts, the movements of tai chi are slow and flowing. Practitioners strive to remain alert and relaxed, without allowing their bodies to become tense or limp. Huang[4] has categorised tai chi into 13 essential and basic movements. These are ward off, roll back, press, push, pull, split, elbow strike, and shoulder force together with step forward, step backward, look left, look right, and centre.

The force used in tai chi seems to include almost all the principles of mechanical advantage available: level, axis, torque, resultant force, gravity, and momentum. Until now, however, concrete research using scientific evidence to support these theoretical concepts has been limited. To our knowledge, no studies of the kinematic features of tai chi exercise have been published. The purpose of this study was to initiate a concrete analysis of the kinematic characteristics and muscular activities involved in tai chi movements.

MATERIALS AND METHODS

Subject

A master of tai chi (49 years of age, 161.2 cm body height, 67.4 kg body weight) participated in the study after giving written informed consent. He had been practising yang tai chi chuan for one and a half hours every day for 22 years. He was asked to demonstrate a sequence of essential basic movements: ward off; roll back; press; push. Each mode was carried out in two trials.

Motion analysis

Two Peak video cameras at 120 Hz and 1/500 shuttle speed were placed on the lateral and posterolateral side, 5 m away from the subject to record the tai chi performance. A 1 m × 1 m × 2 m cubic frame was videotaped for calibration purposes. The recorded tapes were then digitised and analysed by a motion analysis system (APAS, Trabuco Canyon, California, USA). From the anatomical landmarks, the positions of the shoulders, elbows, wrists, fingers, hips, knees, ankles, heels, and toes were indicated. The three dimensional analysis model of the APAS system was used to calculate the centre of gravity (CG) of the body and the displacement and velocity in the Z (anteroposterior), X (mediolateral), and Y (superoinferior) directions. The joint angles of the hip, knee, ankle, and trunk (inclination) formed during the push movement were also analysed.

Electromyographic (EMG) analysis

TELEMEG Multichannel Electromyography (Bioengineering Technology and Systems, Milan, Italy) was used. Bipolar silver/silver chloride surface electrodes were placed longitudinally on the left and right sides of the large muscle groups

Abbreviations: CG, centre of gravity; EMG, electromyography; IEMG, integrated EMG; MVC, maximal voluntary contraction

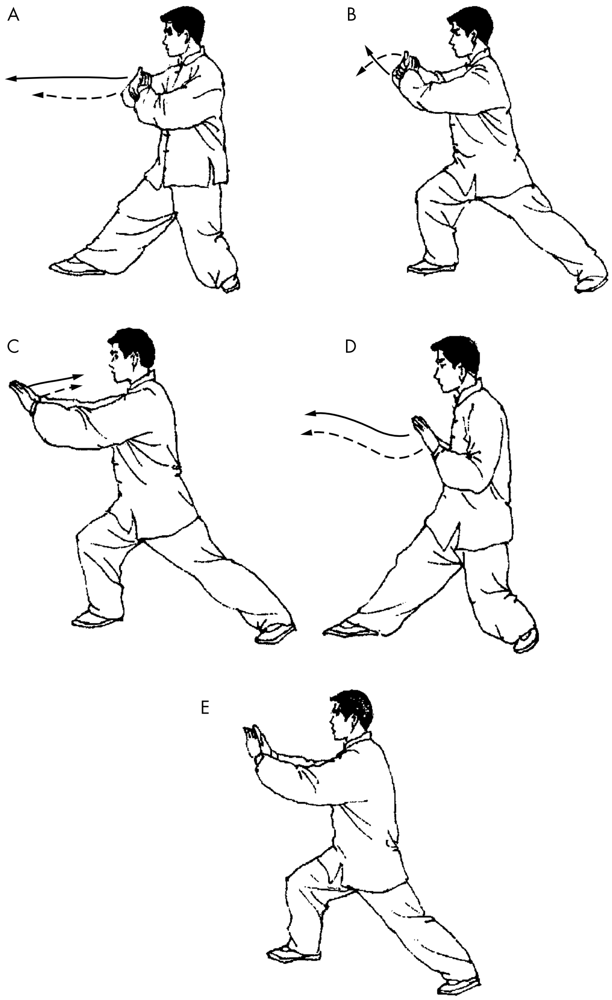

Figure 1 Press and push movements in tai chi

including the lumbar erector spinae, the rectus femoris, the medial hamstrings (semitendinosus and semimembranosus), and the medial head of gastrocnemius. Before the study, the subject was asked to perform a maximal voluntary contraction (MVC), by isometric contraction against manual resistance, of each muscle group. The EMG system was synchronised with the motion analysis system.

Data analysis

Only the second cycle of the push movement was used for motion and EMG data analysis. Figure 1 illustrates the sequence of the press and push movements. Figure 1A,B shows the press movement. The torso is turned to the right, while facing straight ahead. The body weight is shifted forwards for a right “bow stance”. The left arm is then bent and the left palm drawn back. The left fingers are placed near the right wrist, and both hands are pressed forward simultaneously and slowly at shoulder level. With the right palm facing inside and the left palm forward, both arms are kept in a half circle shape. The subject looks at his right wrist. The press movement is followed by the push movement (fig 1C–E). In this movement the left palm is extended past the top side of the right wrist and the palms are separated at shoulder level, facing down; then the upper body is “sat back”, shifting the weight on to the left leg. Both arms are bent, the palms drawn back to the front of the chest, facing forwards and downwards. The look plane is ahead (fig 1C,D). The right leg is bent giving a right “bow stance”. The two palms are curved down past the front of the abdomen, then forwards and upward and pressing out, with wrists at shoulder level. The chest and hips are kept relaxed, with shoulders and elbows held down, wrists sunk, and palms extended. The subject looks directly ahead (fig 1E).[5]

The change of direction of the CG in the anteroposterior dimension was used to decide the starting position. The turning point of the CG moving from the forward to the backward direction was chosen as the starting position of the push movement (fig 1C). The end position was defined by the most forward position of the CG during the pushing forward movement (fig 1E).

All integrated EMG (IEMG) values were normalised using the corresponding MVC of the individual muscle in question. Descriptive statistics were used to analyse the displacement and velocity of the CG and the angles of the trunk and lower limbs. The IEMG values measured for the different muscles were examined. From the data collected, the extent of Z (anteroposterior) and X (mediolateral) distances travelled by the CG in metres over time was assessed. To look at the path of the CG in these two directions, Pearson correlation was performed in the Z and X directions.

Table 1 Maximum amplitude of centre of gravity in Z (anteroposterior) and Y (superoinferior) dimensions

Dimension	Direction	Maximum amplitude (m)
Z	Backward	0.336
	Forward	0.338
Y	Superior	0.886
	Inferior	0.775

RESULTS

The whole process of the push movement lasted 7.25 seconds. The push movement was divided into two components. The first part included the retracting movement of the body, and the second part included the forward pushing movement of the body. The turning point of the execution of the push movement from backward direction to the forward direction occurred after 3.5 seconds.

Centre of gravity

In the Z direction, CG moved first backward for 0.336 m, followed by a movement forward with an amplitude of 0.338 m. It therefore almost returned to the original frontal position. The CG in the vertical direction was maintained in a low position, ranging from 0.775 to 0.886 m from the ground (table 1).

If the CG movement paths in the Z and X directions are viewed, the successive retraction and pushing movement appear to retrace a similar path (fig 2). When the CG moved from its frontal position to its most backward position, the X

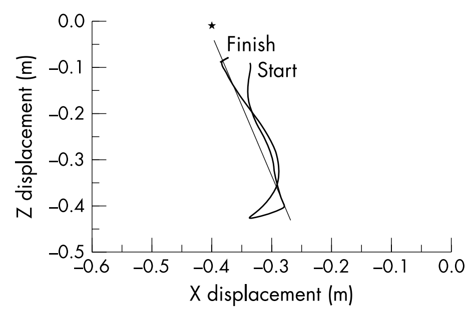

Figure 2 The path of the centre gravity of the anteroposterior (Z) and mediolateral (X) direction of the push movement. The starting and finishing positions are shown and the line of best fit. *$p<0.0001$.

Table 2 Correlation of centre of gravity in Z (anteroposterior) and X (mediolateral) directions

	X direction	Z direction
Pearson correlation (*r*)	–0.814	–0.814
p Value		<0.0001*
Number	870	870

*Two tailed.

component moved from right to left, which was towards the foot that was placed furthest back. When the CG reached its hindmost position, the subject changed direction from retracting to pushing and the X component of the CG moved from left to right and returned via a similar path. The correlation coefficient between the CG in the Z direction and that in the X direction was –0.814 (table 2).

The speeds of movement of the CG in the Z and X directions were low, ranging from 0 to 0.203 m/s and 0 to 0.086 m/s respectively. The mean speeds for the Z and X directions were 0.096 and 0.041 m/s respectively. In the Y direction, the maximum velocity of movement of the CG was only 0.086 m/s, with a mean of 0.033 m/s. This reflects the fact that, generally, the master moved in all directions at slow speeds.

Range of motion of the trunk and lower limbs

Figure 3 illustrates the variation in the angle between the trunk and the lower limbs with time. The whole push movement took 7.25 seconds to execute. The subject retracted his CG backward during the first 3.5 seconds, and this was followed by a forward pushing movement, which lasted 3.75 seconds as shown in fig 3. During the retracting component of the movement, all the large joints of the left lower limb were flexing. The hip was flexed from 160° to 132°, the knee from 158° to 97°, and the ankle (dorsiflexes) from 88° to 65°. The opposite response was observed at all three joints on the right side of the body. The right hip was extended from 125° to 141°, the right knee from 118° to 175°, and the right ankle from 107° to 150°. After the retraction excursion, the subject began to move forward again. All the large joints of the left lower limbs were then extending as shown by the upward sloping pattern of the second part of fig 3 during the forward pushing movement. In contrast, all the large joints of the right lower limbs were flexing as shown by the downward sloping pattern shown in fig 3. The upper body was in an upright position, and the trunk angle ranged from 75.7° to 85.4° during the whole process.

Electromyography

Figure 4 illustrates the variations in normalised values of IEMG measurements for different muscle groups with time. The normalised IEMG values measured for most muscle groups were less than 20% of MVC values throughout the push movement, showing that the muscles were working at low level IEMG activities. Of the four groups of muscles examined, the lowest IEMG activities occurred in the medial hamstrings and the medial head of gastrocnemius, with a higher value measured in the lumbar erector spinae muscle and the highest by far in the left rectus femoris muscles. The IEMG value for the rectus femoris of the left lower limb reached as much as 68.3% of the MVC (fig 4).

During the first 3.5 seconds of the movement, the left knee was flexing; this flexion of the knee was facilitated by the concentric contraction of the left medial hamstrings. The activity of the left medial hamstrings was found to increase slightly during the flexing of the left knee (fig 4). The activity of the left rectus femoris, however, was found to be unexpectedly high. This was due to the eccentric contraction of the left rectus femoris. This is shown clearly in fig 5. The IEMG value during the contraction reached as much as 68.3% of the MVC. The muscle activity was found to increase with a concurrent decrease in the joint angle of the left knee during the first 3.5 seconds of the retracting movement. The results show that the quadriceps contracted eccentrically. This eccentric mode of contraction also occurred in the left medial head of gastrocnemius; the activity of the left medial head of gastrocnemius increased with increasing dorsiflexion angle of the ankle during the first 3.5 seconds (fig 6).

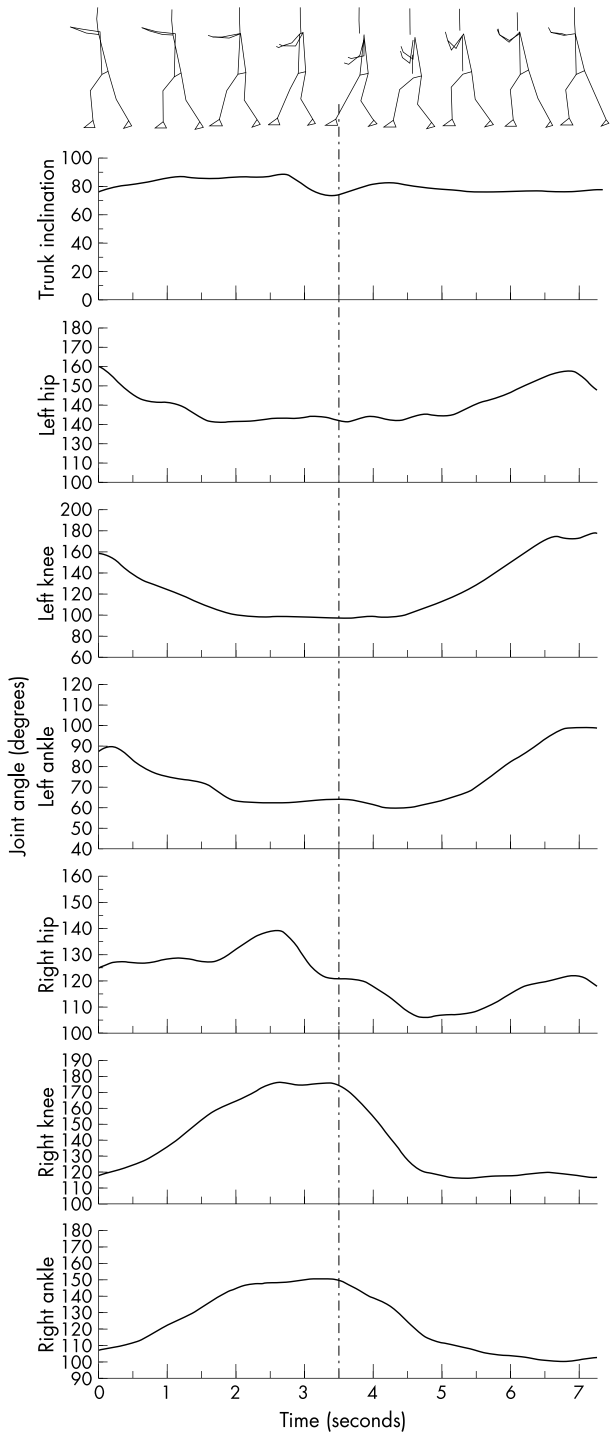

Figure 3 Variations in joint angles during the push movement.

During the last 3.75 seconds of the movement, the CG moved forward again; this action was mainly produced by the

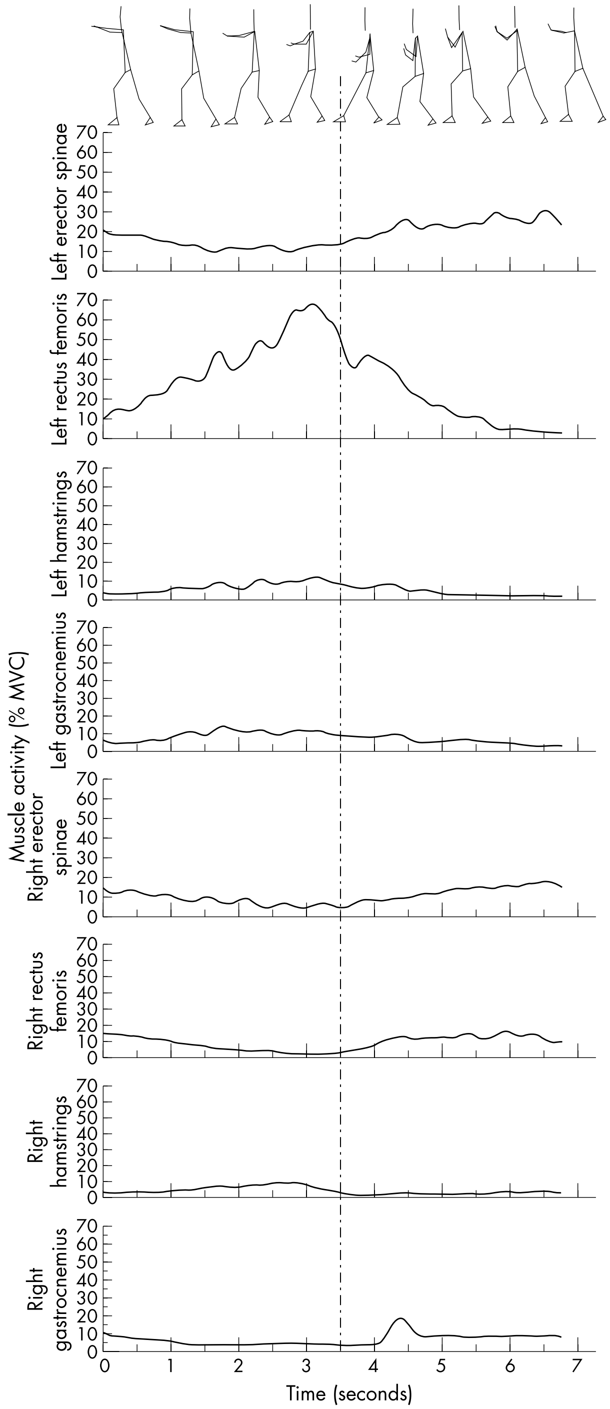

Figure 4 Variations in muscle activities of trunk and lower limbs during push movement. MVC, Maximal voluntary contraction.

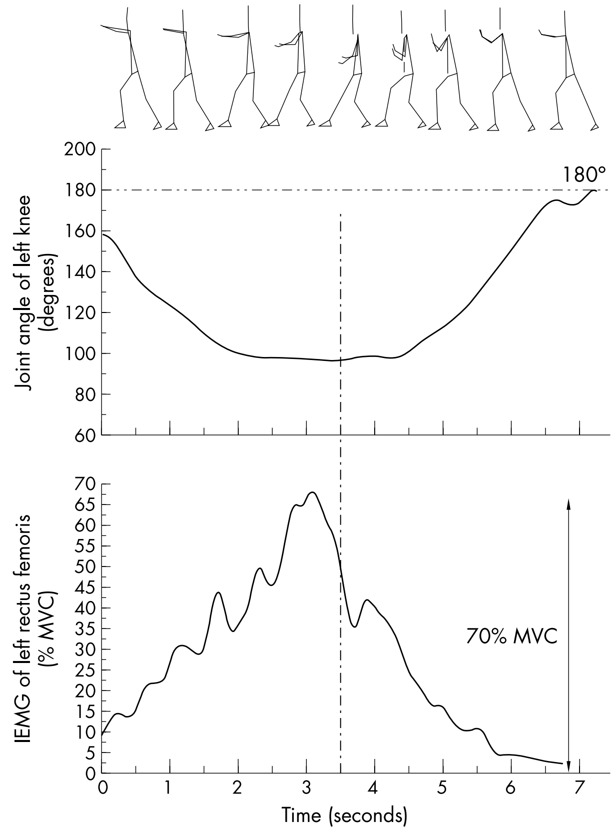

Figure 5 Variation in joint angle of left knee and the integrated electromyography (IEMG) of the left rectus femoris with time. MVC, Maximal voluntary contraction.

left rectus femoris (fig 5). The muscle contracted concentrically to produce a push movement and resulted in the shifting of the whole body weight to the right fore foot. The signal produced by the concentric contraction was relatively small compared with that of the previous eccentric contraction.

DISCUSSION

CG and range of motion

The forward and backward shifts in CG were mainly accomplished by increasing or decreasing the joint angles of the bilateral lower limbs rather than by adopting a forward or backward postural lean. The backward displacement of the trunk (CG) during the first 3.5 seconds of the movement was mainly accomplished by changing the angles of both lower limbs resulting in a relatively small effect on the vertical position of the CG. Computations based on the measurements obtained indicated that during the first 3.5 seconds of the backward displacement of the CG, the coordinated (dorsi) flexion of the left ankle (about 23°), left knee (about 61°), and left hip (about 28°) and the coordinated extension of the right ankle (about 43°), right knee (about 57°), and right hip (about 16°) caused the CG to move at a similar vertical level along the path. Similarly, displacement of the CG when the subject moved forward during the last 3.75 seconds resulted primarily in a coordinated extension of the left ankle (about 36°), left knee (about 81°), and left hip (about 11°) and caused the CG to move at a similar vertical level along the path during the forward pushing action.

The upper body was in an upright position, not bent too far forward or backward. Maintaining an upright position of the trunk and CG at low level may facilitate the maintenance of balance during the voluntarily movement. The joints of the hips, knees, and ankles were kept free to allow shifts in movement forward and backward with little change in the trunk angle.

The movement path of the CG in the Z and X directions occurred predictably along the same path when moving backward and forward. The paths were diagonally from the right fore foot to the left rear foot when the CG was moving backward, returning on a similar path from the left rear foot diagonally to the right front foot. The amplitude of deviation from this path was small. From this, it can be postulated that the body movement was well controlled and coordinated. The subject maintained an up right posture and steady CG position while moving from one position to another. As the subject was able to move along a stable trajectory during

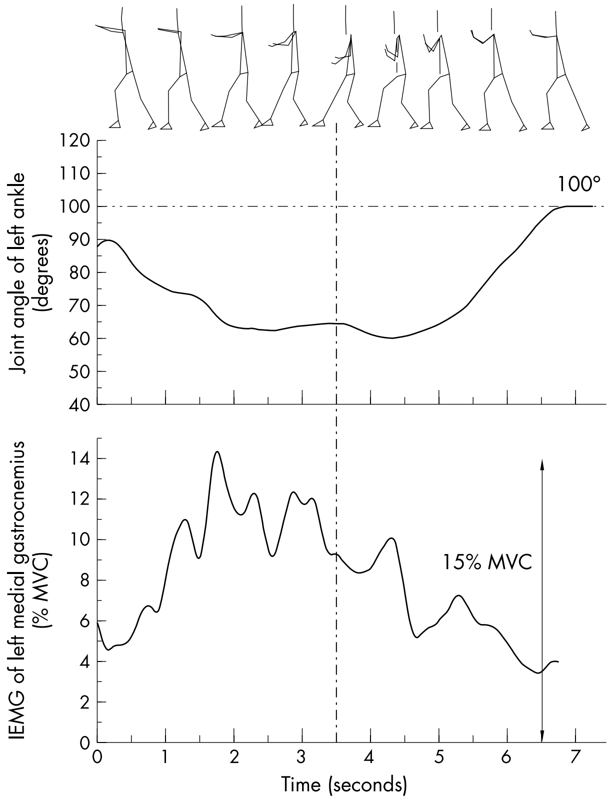

Figure 6 Variation in joint angle of left ankle and the integrated myography (IEMG) of left medial head of gastrocnemius with time. MVC, Maximal voluntary contraction.

weight shifting, while keeping the body in an upright posture, the balance of the practitioner during the push movement was maintained.

EMG responses

The contractile activity of individual muscles could be compared after normalisation with the MVC values for each muscle. The IEMG values measured for the lumbar erector spinae were relatively high compared with those of the other muscle groups. The contraction of the lumbar erector spinae may help to maintain the upright posture during the whole movement.

Changes in the rotational movement of the knee joint during reciprocal forward and backward displacement of the CG did alter the pattern of IEMG activity in which muscles were coupled on the opposite dorsal and ventral aspects of the thigh and calf and the contractile modes were sometimes concentric and sometimes eccentric. Eccentric contraction occurred mainly in the anti-gravity muscles such as the rectus femoris and the medial head of gastrocnemius. Tai chi requires the lower limbs to move bent and in slow motion. This entails a considerable workload, especially for the lower limbs. The frequent bending of the hips, knees, and ankles by eccentric and concentric contraction of the muscles may help to increase the strength of the lower limbs.

Tai chi incorporates emphasis on the balance control mechanism, postural alignment, and muscle work of the lower limbs and trunk. Lower limb strength has been shown to affect balance. A previous study in elderly subjects with impaired balance and a history of falls showed greatly decreased strength in the ankle muscles.[6] Several other studies have shown impaired balance to be associated with falls in this age group.[7 8] Therefore, if tai chi directly increases the strength of the lower limbs and improves balance, it may be a good form of exercise to use for health maintenance and fall prevention. There is encouraging evidence that training the elderly in tai chi may reduce the risk falling. Province *et al*[9] reported a meta-analysis of the effects of exercise in the elderly and identified tai chi training as a successful means of preventing falls. In the Atlanta frailty and injuries cooperative study of intervention techniques trials, 200 subjects participated in a study and were randomly assigned to 15 weeks of tai chi, computerised balance training classes, or an education control group.[10] Only the tai chi group showed a reduced occurrence of falls four months after the study's completion. Also, a reduction in the fear of falling in both the tai chi and balance training groups was observed.

Conclusions

The kinematic features and EMG characteristics of a fundamental movement of tai chi were examined. Forward and backward shifts in the position of the CG were mainly accomplished by increasing and decreasing respectively the joint angles of bilateral lower limbs rather than by adopting a forward or backward postural lean. Both concentric and eccentric muscle contractions occurred in lower limb muscles, and the eccentric mode of contraction occurred mainly in anti-gravity muscles such as the rectus femoris and the medial head of gastrocnemius. This repeated workload may help to strengthen the muscles of the lower limbs especially the anti-gravity muscles. The master, who was the subject of the study, demonstrated good control of CG trajectory during the voluntary push movement. He maintained an upright posture and a low level of CG while travelling slowly and steadily from one position to another. A stable trajectory was followed during weight shifting movements, while the balance of the entire body was maintained. The path of the CG during the retracting and pushing movements was unique, and the sway or deviation from this path was small. It may be postulated that movement control of the body was good. Tai chi may therefore have a favourable impact, preventing injuries sustained as the result of poor balance control or poor eccentric strength of the lower limbs.

This study was initiated to carry out a small scale investigation of the kinematic features of a basic movement of tai chi. Further studies including more subjects and all the movements are necessary. A quantitative analysis of the training effects of tai chi on muscle strength and balance may also be necessary.

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