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The Surface Electromyographic Characteristics of Different Practice Methods of Chen-Style Tai Chi *Lanzhayi* Movement

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Abstract

This study aimed to deeply understand the movement rules of Tai Chi and provide a basis and reference for its scientific training. In this study, we used a MEGWIN6000 16-channel telemetry surface electromyography tester to collect the surface EMG signals and kinematic data of nine subjects using different practice methods of Chen-style Tai Chi Lanzhayi. The findings of this study were as follows: the primary force-emitting muscles in stages 1 and 2 of the Lanzhayi movement are the left and right anterior tibialis. In stage 3 of the Lanzhayi movement, there was a significant difference in root mean square amplitude (RMS) among the slow practice, rapid power practice and practical combat practice. However, no significant difference was observed in total integrated electromyography (iEMG). Based on the expert-case analysis, the order of muscle power generation in stage 3 of the three exercises does not follow the intuitive experience of "foot-leg-waist-hand". The order of muscle power generation in the three exercises of slow practice, rapid power practice, and practical combat practice is also different. In the standing exercise of Lanzhayi, the iEMG of the left leg (empty leg) is greater than that of the right leg (solid leg). Also, the iEMG of the right arm (yin hand) is greater than that of the left arm (yang hand). Different practice methods of the Chen-style Tai Chi Lanzhayi movement showed different surface electromyographic characteristics. RMS reflected that the exercise intensity increased sequentially from slow practice to rapid power practice and practical combat practice, whereas iEMG showed no significant difference in the total amount of muscle work of the measured muscles among the three practice methods. This suggests that, to improve the combat ability of Tai Chi, practitioners should undertake more training that is closer to practical combat. The findings also suggest that the traditional theory that "the power starts from the feet, travels through the legs, is controlled by the waist, and manifests in the hands" can be regarded as a guiding principle of whole-body coordinated force generation, but should not be simply interpreted as a fixed sequence of muscle activation. The left–right differences observed in the standing exercise of Lanzhayi may be understood from the perspective of the Tai Chi philosophy of yin and yang, namely, "there is yang in yin and yin in yang."

Keywords:
chen-style tai chi, *lanzhayi*, sEMG, RMS, iEMG, health promotion

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Introduction

Tai Chi is a treasure of Chinese culture that combines the techniques of attack and defence, art, and fitness (Li, 2018). It is practised in more than 150 countries and regions and by more than 150 million people worldwide (Zhang, 2019). On December 17, 2020, UNESCO officially included Tai Chi in the Representative List of the Intangible Cultural Heritage of Humanity (The Xinhua News Agency, 2020). Tai Chi originated in Chenjiagou, Wen County, Henan Province, China. The Tai Chi derived from this region is known as Chen-style Tai Chi. Over time, as Chen-style Tai Chi evolved, it gave rise to four additional styles: Yang, Wu, Wu, and Sun Style Tai Chi. Qi Jiguang first described the movement of *Lanzhayi* in the book Ji Xiao Xin Shu – Quan Jing in the Ming Dynasty and later evolved into one of the representative movements of Chen-style Tai Chi and other Tai Chi styles. Tai Chi has eight Jin methods, and *Lanzhayi* focuses on the four positive ones: Peng, Lv, Ji, and An.

Surface electromyography (sEMG) is increasingly used in sports and has been widely recognised by experts and scholars in medicine and sports science (Liu et al., 2022; Liang et al., 2023). The sEMG test is a noninvasive method, and sEMG is assessed via time- and frequency-domain analyses. In the time-domain analysis, two indicators, integral EMG (iEMG) and root mean square (RMS), are mainly used to study the main exertional muscle groups, muscle contribution rate, and synergy between muscles for motor actions. In the frequency-domain analysis, these indicators are mainly used to study median frequency and mean power frequency to investigate muscle fatigue (Wang & Huang, 2019).

The use of EMG in Tai Chi has a long research history. Zhang et al. (1989) conducted a quantitative analysis of the sEMG of the first method of Chen-style Tai Chi using an electronic computer. They discussed the characteristics of EMG and the general rules when performing the Tai Chi exercise, which provided a physiological basis for Tai Chi practice. Wang and Yang (1996) tested the EMG of athletes practising different styles of Tai Chi. Chan et al. (2003) analysed the movements of a Tai Chi master and found that the eccentric muscle contraction of the lower limbs during the push movement may help to strengthen the muscles. Furthermore, Niu (2010) studied the sEMG characteristics of the technical movements of Tai Chi pushing hands in each stage and compared them among athletes at different levels. Zhu (2014) used the Vicon three-dimensional motion analysis system, Kistler force measurement table, Noraxon telemetry DTS, and other techniques to collect data on the different levels of Chen-style Tai Chi Yanshougongquan movement power training to analyse and discuss the characteristics and training methods of Chen-style Tai Chi power delivery. In addition, Yu et al. (2022) investigated the sEMG characteristics of the pre-activation and co-contraction of knee and ankle muscle groups in the lower limbs during straddling knee stance and normal walking in long-term Tai Chi practitioners to explore neuromuscular control strategies for preventing fall in Tai Chi. Recently, Huang et al. (2024) combined three-dimensional motion capture, a force platform, and surface electromyography to examine the relationships among biomechanical characteristics, muscle activation, and stability during the 143D balance movement in competitive Tai Chi. Their study further indicates that sEMG can provide important evidence for understanding muscle exertion and movement control in specific Tai Chi techniques.

The current study on Tai Chi movements using EMG testing focuses on three areas: EMG analysis of Tai Chi movements during practice, comparison of the EMG characteristics of the same movement in athletes at different levels, and investigation on the health-promoting and influencing effects of Tai Chi. There are various practice methods for the same Tai Chi movement. However, no studies have tested muscle EMG characteristics under different practice methods for the same Tai Chi movement. Therefore, in the present study, we used the MEGWIN6000 16-channel telemetry EMG tester and Sony DCR-HC90 normal-speed camera to collect the EMG signals and kinematic data of nine subjects using different practice methods of Chen-style Tai Chi. Furthermore, we analysed the EMG characteristics of the different practice methods to understand the movement rules of Tai Chi, improve the theoretical system of martial arts teaching and training, and provide a basis and reference for the scientific training for Tai Chi.

Methods

Study subjects

This study included nine participants (seven men and two women) with an average age of 29.44 ± 6.66 years, average height of 170.44 ± 6.65 cm, and average weight of 68.77 ± 7.91 kg. Among the subjects, one was a professor and a Tai Chi expert, three were champions of major domestic Tai Chi tournaments, and five were ordinary Tai Chi practitioners; all were proficient in various Chen-style Tai Chi *Lanzhayi* practices.

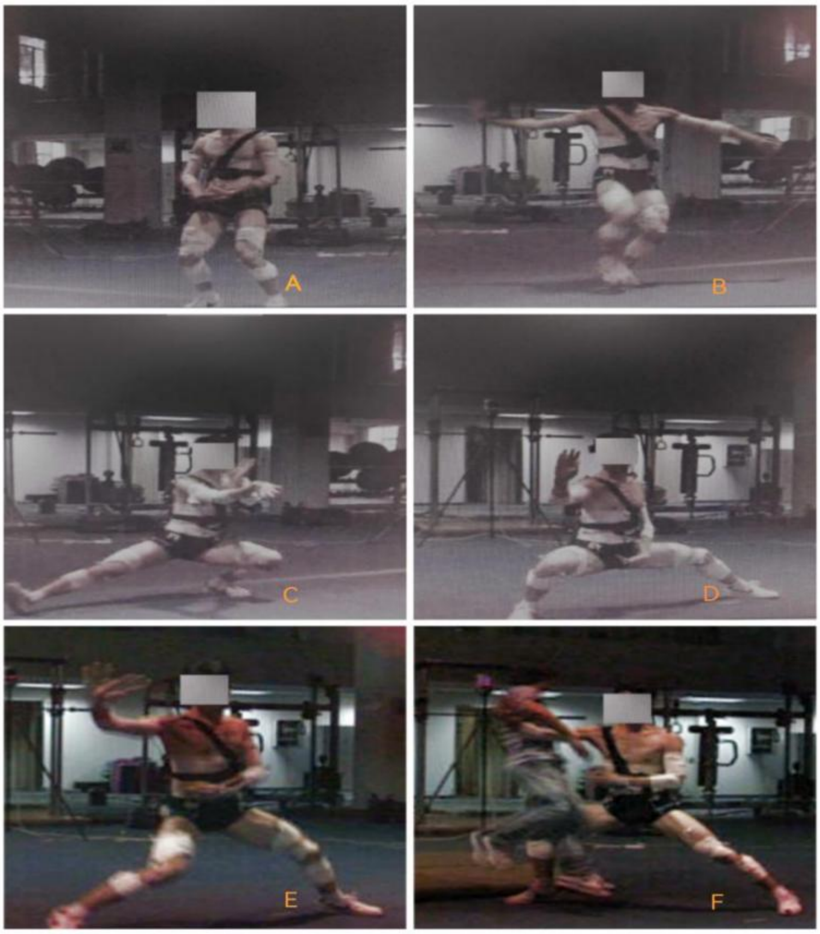

Figure 1. Experimental site layout and division of action stages

Experimental equipment and site

This study was reviewed by an expert panel and approved by the Ethics Committee of Sport Science at Beijing Sport University. All participants provided informed consent before the experiment and were informed that they could withdraw from the study at any time without penalty. To reduce injury risk, the practical combat practice was conducted under the supervision of professional staff, and participants were familiar with fall-safety techniques. The experiment was conducted in the hall of the Sport Science Research Centre at Beijing Sport University (Figure 1). We used a MEGWIN6000 16-channel telemetry EMG tester from Finland and a Sony DCR-HC90 normal-speed camera from Japan. The room temperature was about 20°C, suitable for indoor exercise. The same professional staff prepared, operated, and recorded all the test items. All video and photographic data were stored securely and accessed only by the research team, and all identifying information in the figures was masked before submission.

Action definition and stage division

We divided the *Lanzhayi* movement into three stages according to the Chen-style Tai Chi competition routine's requirements and offensive and defensive meanings of such a movement. The stages were as follows: stage 1 (A-B), "Receiving the opponent's attacking power" (from the end of the Jingangdaozhui movement → the right foot begins to leave the ground); stage 2 (B-C), "Bring in opponents and throw them off balance" (from the moment when the right foot begins to leave the ground → when the right foot contacted the ground); and stage 3 (C-D), "Throw your opponent out" (the right foot contacted the ground → the completion of *Lanzhayi* movement) (China Martial Arts Research Institute, 1999).

Working definitions of various practice movements of *Lanzhayi* are listed below:

(1) Slow practice: movements following the Chen-style Tai Chi competition routine requirements.

(2) Rapid power practice: according to the requirements of the Chen-style Tai Chi competition routine, stages 1 and 2 of the movements should be practised slowly. In contrast, stage 3 should focus on rapid force generation starting from point C of the movement.

(3) Practical combat practice: following the requirements of the Chen-style Tai Chi competition routine, stages 1 and 2 of the movement should be practised slowly. Starting from point C of the movement, prepare to throw a partner to the ground. During stage 3 of the movement, execute the throw, with the same person thrown throughout the practice.

(4) Standing exercise of *Lanzhayi*: *Lanzhayi* fixed action, action point D, hold for 1 minute.

Test method

Description of muscle selection: Tai Chi movement force is concerned with the coordination and cooperation of the whole body and the overall force. Based on the movement characteristics and combat applications of the *Lanzhayi* movement, and considering consultations with Chinese martial arts experts and exercise physiology experts. 16 muscles from the lower limbs, trunk and upper limbs were selected for sEMG measurement. (Table 1) Electrode placement was determined according to the anatomical position of each selected muscle and the general principles of surface electromyography electrode placement (Hermens et al., 2000).

Table 1. List of selected muscles

Position	Left side muscles and number	Right side muscles and number
Lower limbs	1. Left tibialis anterior muscle	9. Right tibialis anterior muscle
	2. Left gastrocnemius muscle	10. Right gastrocnemius muscle
	3. Left rectus femoris muscle	11. Right rectus femoris muscle
Trunk	4. Left external abdominal oblique muscle	12. Right external abdominal oblique muscle
	5. Left latissimus dorsi muscle	13. Right latissimus dorsi muscle
	6. Left deltoid muscle	14. Right deltoid muscle
Upper limbs	7. Left triceps brachii muscle	15. Right triceps brachii muscle
	8. Left brachioradialis muscle	16. Right brachioradialis muscle

Before attaching the electrodes, hair should be removed using a razor, followed by the skin being gently abraded using fine sandpaper. Subsequently, the skin should be cleansed with 75% alcohol to remove excess oils. After the alcohol has completely evaporated, apply an appropriate amount of electrode paste before attaching the electrodes. Ensure that the electrodes are adhered to the most prominent part of the measured muscle belly, with a distance of 2 cm between the centres of each electrode, and the line connecting the centres of the two electrodes aligned with the direction of the muscle fibres.

Using a MEGWIN 6000-16 conductor surface EMG and analysis software with a sampling frequency of 1000 Hz, the subjects were simultaneously tested for the different exercises of the *Lanzhayi* movement with three practices of each movement and a 5-min rest between each exercise. The MEGWIN 6000-16 sEMG software was used to analyse and process the data with its default settings, segment the data in combination with a synchronised video, and export the values of each segment together with the corresponding video. Due to the limitations of the research conditions, the sEMG amplitudes were not normalised to maximal voluntary contraction (MVC) in this study. SPSS Statistics version 22.0 was used for statistical analysis. RMS and iEMG values of the 16 measured muscles were presented as mean ± SD. For RMS, participant-level mean RMS was calculated by averaging the RMS values of the 16 measured muscles for each participant under each practice condition. For iEMG, participant-level total iEMG was calculated by summing the iEMG values of the 16 measured muscles for each participant under each practice condition. Considering the small sample size, the Friedman test was used to compare the three practice methods. When the overall comparison was significant, post-hoc pairwise comparisons were performed using Wilcoxon signed-rank tests with Bonferroni correction. The significance level was set at $p < 0.05$. The percentage peak method was used to analyse the muscle activation sequence during the *Lanzhayi* movement performed by the No.1 Tai Chi expert. Amplitude values greater than 20% in the EMG signal were used as a marker for beginning muscle discharge in the action area. Conversely, values less than 20% were considered to indicate no muscle activation. We normalised the activation time to the percentage for the sake of comparison. Because this sequence analysis was based on a single expert participant, the results were interpreted as an expert-case illustration rather than a general group-level finding.

Study hypotheses

The hypotheses of this study were as follows:

(1) There are differences in muscle sEMG characteristics among subjects using different exercise methods in the same movement stage. Specifically, RMS and iEMG values are expected to differ among slow practice, rapid power practice, and practical combat practice.

(2) The order of muscle power generation in different practice methods in stage 3 of the *Lanzhayi* movement is as follows: "The source of power is at the feet, transmitted through the legs, transformed at the waist, and finally reaches the hands." The order of muscle excitation should be lower limb muscles–trunk muscles–upper-limb muscles.

(3) The muscle iEMG of the right side of the solid leg is greater than that of the left side of the empty leg.

Results

Stages 1 and 2 of the *Lanzhayi* movement

Root Mean Square (RMS) amplitude refers to the root mean square value of all amplitudes of muscle discharges during a particular time, an index used in surface electromyography (sEMG) data to reflect changes in the magnitude of EMG signals. It is generally believed that RMS amplitude is related to the recruitment of motor units and synchronization of excitation rhythms increases with muscle force. It is commonly used to describe the degree of muscle activation and reflect exercise intensity (Luo, et al., 2017).

From the perspective of attack and defence, stage 1 of the movement is "Receiving the opponent's attacking power", whereas stage 2 is "Bring in opponents and throw them off balance". These two stages of the movement are the preparatory stages for the force generation of the *Lanzhayi* movement, and the RMS of each muscle is shown in Table 2.

It can be seen from Table 2 that in stage 1 of the *Lanzhayi* movement, the top two muscles in terms of RMS were the left anterior tibialis and right anterior tibialis, and the smallest RMS was observed in the right external abdominal oblique muscle. In stage 2 of the *Lanzhay*i movement, the top two muscles in terms of RMS amplitude were also the left anterior tibialis and right anterior tibialis, and the smallest RMS value was observed in the right gastrocnemius.

The iEMG is the total amount of motor unit discharges involved in muscle activity during a certain time. Its value can effectively reflect the amount of work done by the muscle (Sun, et al., 2010). Muscle activity contribution is the percentage of the iEMG value of a muscle at a specific time when completing a particular movement and the sum of the iEMG of all muscles involved in completing that movement. It reflects the magnitude of the role played by each muscle involved in the completed movement and the primary force-emitting muscle in action (Song, et al., 2016). The RMS increases with muscle force, and the iEMG is a good reflection of muscle work capacity (Xu, et al., 2022).

In order to explore the status of each muscle playing a role in the movement, individual muscle iEMG are calculated for the first and second stages, as well as the muscle contribution rates for each muscle, different body parts and left and right sides（Tables 3 and 4）.

As can be seen from Table 3, the two muscles with the largest iEMG in both stages 1 and 2 were the left anterior tibialis and right anterior tibialis. In stage 1 of the *Lanzhayi* movement, the body weight underwent a left–right–left transformation between the two legs. This indicated that the left and right anterior tibialis were mainly involved during the weight transformation in the flexed-knee slack condition.

During stage 2 of the *Lanzhayi* movement, as evidenced by Table 4, the ratio of the combined iEMG values for the three muscle groups in both the left and right legs throughout the step-opening process is approximately 6:4. This finding implies that in Chen-style Tai Chi, when shifting the centre of gravity during stepping, the right leg, despite being considered the "empty" leg, still exerts force. This observation suggests that the movement of the right leg is effectively regulated by muscle control.

Table 2. RMS (μV) for subjects in stages 1 and 2

Muscles	Stage 1	Stage 2
LTAM	149.56±60.81	272.11±104.97
LGM	58.22±3.19	94.44±21.81
LRFM	101.00±60.69	172.33±65.40
LEAOM	66.22±9.15	76.89±11.05
LLDM	75.56±18.28	83.11±9.66
LDM	86.78±27.86	123.00±59.45
LTBM	65.78±9.93	80.44±19.65
LBM	86.89±45.50	115.11±74.75
RTAM	120.67±56.38	223.33±116.92
RGM	31.56±21.44	52.78±40.62
RRFM	48.56±31.96	84.11±25.22
REAOM	22.56±11.83	82.56±45.32
RLDM	65.00±12.41	82.78±14.24
RDM	82.44±16.52	116.78±31.43
RTBM	72.89±18.15	97.33±24.53
RBM	101.33±28.62	133.44±67.26

Table 3. iEMG (μV·s) and contribution rates (%) of subjects in stages 1 and 2

Muscles	Stage 1	Contribution rate	Stage 2	Contribution rate
LTAM	470.11 ± 167.96	11.62	351.33 ± 176.63	14.78
LGM	206.11 ± 112.78	5.09	119.44 ± 50.44	5.02
LRFM	308.44 ± 117.55	7.62	210.11 ± 95.67	8.84
LEAOM	231.11 ± 117.23	5.71	94.22 ± 26.10	3.96
LLDM	252.22 ± 103.69	6.23	101.22 ± 27.70	4.26
LDM	289.78 ± 125.64	7.16	154.00 ± 91.03	6.48
LTBM	226.67 ± 107.85	5.60	100.22 ± 40.07	4.22
LBM	294.22 ± 203.99	7.27	154.89 ± 137.94	6.52
RTAM	377.44 ± 145.65	9.33	282.00 ± 168.18	11.86
RGM	97.89 ± 67.92	2.42	62.89 ± 62.10	2.65
RRFM	150.67 ± 69.41	3.72	104.11 ± 38.74	4.38
REAOM	76.22 ± 44.29	1.88	114.00 ± 90.73	4.80
RLDM	220.67 ± 99.99	5.45	99.56 ± 27.88	4.19
RDM	275.44 ± 104.41	6.81	148.33 ± 70.40	6.24
RTBM	244.56 ± 103.63	6.04	121.56 ± 45.95	5.11
RBM	325.22 ± 90.21	8.04	159.11 ± 80.06	6.69

Table 4. Comparison of the contribution rates (%) of subjects in stages 1 and 2

Stages	Position	Left side	Right side
Stage 1	Lower limbs	61.13	38.87
Stage 2		60.26	39.74
Stage 1	Trunk	61.95	38.05
Stage 2		47.78	52.22
Stage 1	Upper limbs	48.96	51.04
Stage 2		48.81	51.19
Stage 1	All muscles	56.31	43.69
Stage 2		54.08	45.92

Stage 3 of the *Lanzhayi* movement

From the point of view of attack and defence, stage 1 and stage 2 are the preparation stages of the *Lanzhayi* movement, and the third stage is the force stage of the *Lanzhayi* movement, which is the main stage to realize the technical effect. After calculating the RMS of each muscle of the subjects in the third stage of the three

different practice methods, namely the slow practice, the rapid power practice and the practical combat practice, the participant-level mean RMS was calculated by averaging the RMS values of the 16 measured muscles for each participant under each practice condition. The Friedman test was then conducted to test the differences in RMS among the three practice methods.

From Table 5, the results of the Friedman test of the participant-level mean RMS in stage 3 indicate that in the RMS, slow practice <rapid power practice < practical combat practice. There was a significant overall difference among the three practice methods, $\chi^2(2) = 18.000$, $p < 0.001$. Post-hoc pairwise comparisons using Wilcoxon signed-rank tests with Bonferroni correction showed significant differences between slow practice and rapid power practice (Pab = 0.012), between slow practice and practical combat practice (Pac = 0.012), and between rapid power practice and practical combat practice (*P*bc = 0.012). iEMG can reflect the total amount of muscle discharge during the movement. In order to investigate the differences among the iEMG of the three practice methods, we further calculated the participant-level total iEMG by summing the iEMG values of the 16 measured muscles for each participant under each practice condition. The Friedman test was used to compare the participant-level total iEMG among the three practice methods. At the same time, this study calculated the contribution rate of each muscle based on the iEMG values and performed a comparative analysis of the contribution rates to examine the differences among the three practice methods.

As can be seen from Table 6, the Friedman test revealed no significant difference in participant-level total iEMG among the three practice methods, $\chi^2(2) = 2.889$, $p = 0.236$. This result indicates that the overall amount of muscle discharge did not differ significantly among the three practice methods. As can be seen from Figure 2, the five main muscles involved in the slow practice method are the right anterior tibialis, left anterior tibialis, right brachioradialis, right rectus femoris, and left rectus femoris. In the rapid power practice, the top five muscles involved are the right deltoid, left anterior tibialis, right anterior tibialis, right brachioradialis, and left latissimus dorsi. In combat practice, the five main muscles are the right deltoid, right triceps, right brachioradialis, left anterior tibialis and left deltoid. The proportion of muscle iEMG of the left sides of the trunk and upper limbs decreased in slow practice–rapid power practice–practical combat practice, and the proportion of muscle iEMG of the right side increased in the same order (Table 7).

Table 5. RMS values and participant-level mean RMS (μV) among the three different practice methods in stage 3

Muscles	Slow	Rapid power	Practical combat	Participant-level
LTAM	170.44 ± 89.15	186.44 ± 70.54	248.11 ± 98.57	—
LGM	102.11 ± 40.06	109.67 ± 40.39	164.78 ± 93.34	—
LRFM	115.00 ± 46.01	147.78 ± 63.62	146.89 ± 51.29	—
LEAOM	75.89 ± 19.72	117.22 ± 44.95	161.00 ± 66.70	—
LLDM	86.44 ± 13.12	141.44 ± 39.28	130.89 ± 31.75	—
LDM	74.67 ± 17.73	118.33 ± 37.05	198.56 ± 117.24	—
LTBM	62.11 ± 7.67	86.78 ± 24.87	120.44 ± 55.91	—
LBM	66.22 ± 16.98	90.11 ± 35.46	164.78 ± 156.32	—
RTAM	173.89 ± 84.16	177.11 ± 57.73	191.00 ± 81.47	—
RGM	50.56 ± 33.52	60.78 ± 33.02	110.33 ± 61.33	—
RRFM	114.89 ± 88.27	120.44 ± 65.60	189.44 ± 105.13	—
REAOM	47.67 ± 21.93	106.33 ± 58.92	148.89 ± 110.81	—
RLDM	66.00 ± 9.76	112.67 ± 32.56	176.67 ± 50.26	—
RDM	93.44 ± 14.01	187.44 ± 40.77	582.78 ± 124.07	—
RTBM	79.67 ± 15.70	135.33 ± 34.15	471.00 ± 385.45	—
RBM	118.22 ± 45.19	167.00 ± 36.83	397.33 ± 295.82	—
Participant-level mean RMS	93.58 ± 21.91	129.06 ± 27.17	225.18 ± 66.17	$\chi^2(2) = 18.000$, $p < 0.001$; *P*ab = 0.012, *P*ac = 0.012,

Note. Participant-level mean RMS was calculated by averaging the RMS values of the 16 measured muscles for each participant under each practice condition. The Friedman test was used for the overall comparison, followed by Wilcoxon signed-rank tests with Bonferroni correction for post-hoc pairwise comparisons. Pab, Pac, and Pbc represent comparisons between slow practice and rapid power practice, slow practice and practical combat practice, and rapid power practice and practical combat practice, respectively.

Table 6. iEMG values and participant-level total iEMG (μV·s) among the three different practice methods in stage 3

Muscles	Slow practice（a）	Rapid power practice（b）	Practical combat practice（c）	Participant-level Friedman test
LTAM	449.00 ± 151.52	462.33 ± 128.07	342.11 ± 128.64	—
LGM	301.11 ± 137.74	278.11 ± 92.14	224.89 ± 106.76	—
LRFM	317.67 ± 89.48	363.00 ± 111.54	204.33 ± 86.68	—
LEAOM	224.22 ± 78.28	301.67 ± 118.71	222.78 ± 79.55	—
LLDM	261.67 ± 110.74	366.11 ± 107.92	184.22 ± 55.89	—
LDM	220.22 ± 72.45	299.22 ± 67.22	272.33 ± 151.85	—
LTBM	183.44 ± 55.51	220.33 ± 47.75	170.33 ± 91.53	—
LBM	195.00 ± 74.94	228.56 ± 78.33	224.89 ± 193.99	—
RTAM	475.89 ± 169.82	444.11 ± 126.17	269.89 ± 134.49	—
RGM	134.11 ± 70.13	156.22 ± 84.02	154.89 ± 76.94	—
RRFM	325.11 ± 209.86	301.22 ± 131.29	263.11 ± 138.23	—
REAOM	152.11 ± 121.06	281.22 ± 177.63	197.33 ± 123.19	—
RLDM	195.00 ± 58.97	286.33 ± 67.72	251.67 ± 73.20	—
RDM	281.67 ± 103.96	486.33 ± 131.55	833.00 ± 163.13	—
RTBM	235.56 ± 83.70	352.89 ± 106.37	651.00 ± 479.35	—
RBM	340.22 ± 118.35	432.67 ± 124.85	554.33 ± 379.35	—
Participant-level total iEMG	4292.00 ± 925.47	5260.33 ± 901.16	5021.11 ± 1138.66	$\chi^2(2) = 2.889$, $p = 0.236$

Note. Participant-level total iEMG was calculated by summing the iEMG values of the 16 measured muscles for each participant under each practice condition. The Friedman test was used for the overall comparison among the three practice methods.

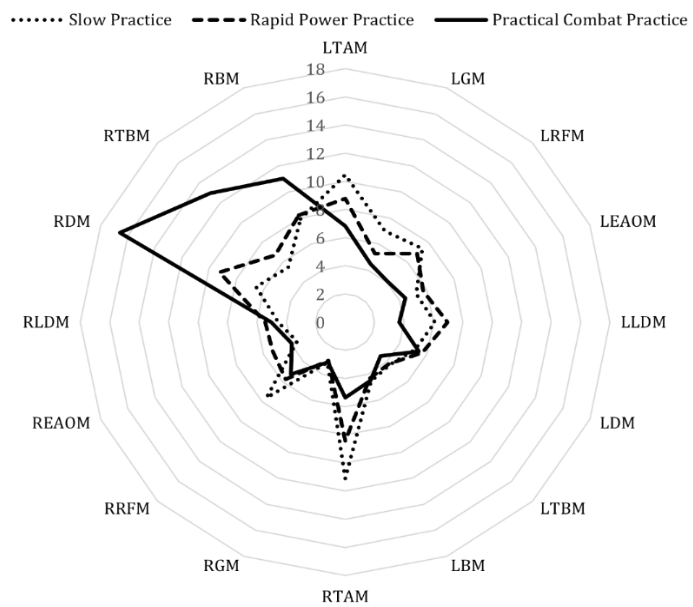

Figure 2. Stage 3 of the *Lanzhayi* movement: three practice methods' muscle contribution rate

Table 7. Comparison of the contribution rates (%) of the left and right sides of the three practices in stage 3 of the *Lanzhay*i movement

Practice methods	Parts	Left side	Right side
Slow practice	Lower limbs	53.31	46.69
Rapid power practice		55.03	44.97
Practical combat practice		52.86	47.14
Slow practice	Trunk	58.33	41.67
Rapid power practice		54.06	45.94
Practical combat practice		47.55	52.45
Slow practice	Upper limbs	41.11	58.89
Rapid power practice		37.04	62.96
Practical combat practice		24.67	75.33
Slow practice	All muscles	50.15	49.85
Rapid power practice		47.89	52.11
Practical combat practice		36.76	63.24

Analysis of the muscle power sequence of the three practice methods in stage 3 of the *Lanzhayi* movement

Due to the large number of selected muscles, the order of muscle activation significantly varied among the nine subjects for the three different practice methods. The error would be too large if the averaging method was used for comparison; thus, the order of muscle discharges in the three different practice methods of the professor with rich theoretical and practical experience among the subjects was selected for the analysis. Determination of the threshold value of the EMG activity is subjective, and previous studies have reported the corresponding criteria, which is commonly 10%–20% of the maximum amplitude. In this study, we used 20% of each muscle's maximum amplitude of the EMG value to confirm the activated state by analysing muscle discharge.

The following findings were obtained from Table 8:

Slow practice: the sequence of muscle activation was right brachioradialis = right anterior tibialis–right triceps–right deltoid = right triceps–left rectus femoris = right external abdominal oblique = left brachioradialis–left deltoid–left triceps = right rectus femoris–left external abdominal oblique–left latissimus dorsi = right gastrocnemius–left gastrocnemius, left anterior tibialis, and right latissimus dorsi were always in the activated state.

Rapid power practice: the sequence of muscle activation is right brachioradialis–right anterior tibialis–left brachioradialis–left anterior tibialis = right deltoid–left external abdominal oblique = left deltoid = right rectus femoris–left latissimus dorsi = right gastrocnemius = right external abdominal oblique = right triceps–left rectus femoris = left triceps = right latissimus dorsi, and left gastrocnemius is always activated.

Practical combat practice: the sequence of muscle activation is right rectus femoris–right latissimus dorsi–left triceps–left brachioradialis–right gastrocnemius–left deltoid–right brachioradialis. Other muscles are always in the activated state.

The rapid power practice and practical combat practice muscles are instantly activated. Many muscles reach the crest simultaneously, synergizing strongly and aligning with Tai Chi's loose, active, elastic, and shaky force characteristics.

Standing exercise of *Lanzhayi*

The standing exercise is a unique training method in Chinese martial arts. This exercise maintains a specific static standing posture and moves outside and inside. Studies have demonstrated that the standing exercise can maintain spinal stability, strengthen the lower-back muscles (Zhou, et al., 2018), enhance leg strength, improve body stability and balance (Duan & Lin, 2019). In this study, the subjects stood for the 60-s with the standing exercise of *Lanzhayi*. During the training, we analysed the iEMG and contribution rate and recorded the feeling of the stance process after the exercise.

Table 9 demonstrates that the top five muscles involved in the 60-s course of the standing exercise of *Lanzhayi* are the left rectus femoris, right rectus femoris, left anterior tibialis, right brachioradialis, and right deltoid. Furthermore, it can be seen from the table that the iEMG are greater on the left than on the right side of the anterior tibialis, gastrocnemius, rectus femoris, external abdominal oblique muscle, and latissimus dorsi. In addition, the iEMG values are greater on the left than on the right side of the five muscles selected from the upper limbs and trunk. The three upper-limb muscles, namely, the deltoid, triceps, and brachioradialis, also have greater iEMG values on the right than on the left side.

Table 10 shows that the ratio of the sum of the three lower limb muscles on the left and right sides is about 6:4, which significantly differs from that obtained by ancient people through perception of the body.

The subjects reported extreme fatigue after 30 s of the standing exercise of *Lanzhayi*. Their muscles started to shake, and 60 s had reached the body's limit, and it was difficult for them to maintain the exercise of *Lanzhayi* with their posture intact (Figure 3).

Table 8. Order of muscle activation (%) in the three practices of the expert subjects for the Lanzhayi movement

Muscles	Slow practice	Rapid power practice	Practical combat practice
LTAM	——	36.14	——
LGM	38.18	——	——
LRFM	5.45	48.19	6.67
LEAOM	10.91	40.16	——
LLDM	14.55	44.18	——
LDM	7.27	40.16	46.67
LTBM	9.09	48.19	6.67
LBM	5.45	32.13	26.67
RTAM	0.00	24.10	——
RGM	14.55	44.18	33.33
RRFM	9.09	40.16	0.00
REAOM	5.45	44.18	——
RLDM	——	48.19	0.00
RDM	3.64	36.14	——
RTBM	3.64	44.18	——
RBM	0.00	8.03	53.33

Note. "——" indicates that the muscle remained active throughout the analysed stage.

Table 9. iEMG (μV·s) and contribution rate (%) of each muscle of the subjects performing the standing exercise of *Lanzhayi*

Muscles	Left side	Contribution rate	Right side	Contribution rate
TAM	834.78 ± 227.17	17.14	287.56 ± 275.25	7.86
GM	504.67 ± 48.43	10.36	110.44 ± 51.34	3.02
RFM	838.44 ± 331.86	17.21	838.22 ± 333.63	22.90
EAOM	566.33 ± 41.52	11.63	83.78 ± 28.81	2.29
LDM	577.11 ± 63.49	11.85	496.22 ± 36.56	13.56
DM	573.89 ± 72.31	11.78	631.67 ± 186.76	17.26
TBM	508.44 ± 51.86	10.44	522.78 ± 59.85	14.28
BM	467.78 ± 44.25	9.60	689.89 ± 116.55	18.85

Table 10. Comparison of the muscle contribution rates (%) between the left and right sides of the subjects in the standing exercise of *Lanzhayi*

Part	Left side	Right side
Lower limbs	63.79	36.21
Trunk	66.35	33.65
Upper limbs	45.67	54.33
All muscles	57.10	42.90

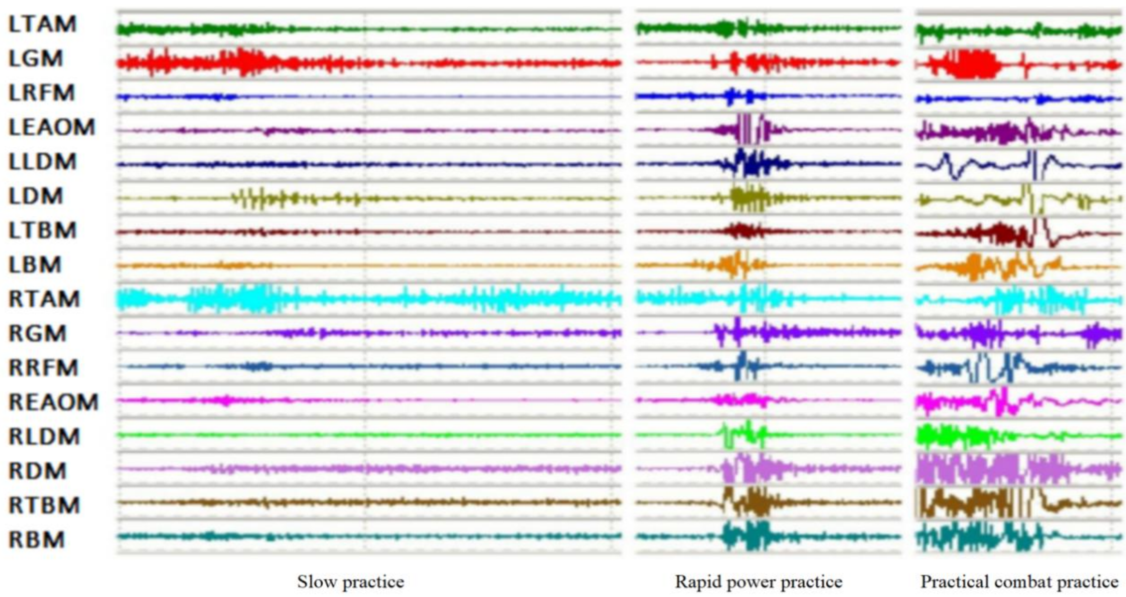

Figure 3. Electromyography of the three practices in stage 3 of the expert subject's *Lanzhayi* movement

Discussion

The following issues can be identified after analysing the RMS, iEMG, and muscle activity contribution rate data of the subjects in different stages and practice methods of the *Lanzhayi* movement.

The Tai Chi movements include standing exercises, routines practice, pushing hands, and casual, practical combat (Ma, 2003). From the viewpoint of actual combat techniques, the various practices of Tai Chi simulate actual combat. As the ancient Tai Chi theory states: "Practising Tai Chi is like someone fighting against you." There are many different ways to practice the *Lanzhayi* movement. Regarding the degree of simulation of actual combat, the practical combat practice is the closest to actual combat, followed by rapid and slow power practice. From the data of RMS, we can see that the slow practice, rapid power practice, and practical combat practice are increasing sequentially and significantly different from each other; and because the RMS can reflect the degree of muscle recruitment and exercise intensity. Therefore, the degree of exercise intensity and muscle recruitment of the slow practice, rapid power practice, and practical combat practice are increasing sequentially. However, when they were compared, no significant difference was observed in each iEMG. iEMG is the sum of muscle discharges to complete the action, which can reflect the muscle work done. This indicates no significant difference in the total volume of the three exercises to complete the movement.

Regarding the order of transmission of Tai Chi power, previous generations have described it as "The source of power is at the feet, transmitted through the legs, transformed at the waist, and finally reaches the hands "(Tang & Gu, 1996), based on overall observation and physical perception. Later, this theory was widely accepted by generations of Tai Chi practitioners and thus became their guiding principle. Zhou and Fan (2018) analysed the relationship between the ankle, knee, and hip joints in the *Lanzhayi* movement in terms of time and joint range of motion, and the theory of Tai Chi is highly compatible. However, according to the movement characteristics and technical meanings of stage 3 of the *Lanzhayi* movement, observing the muscles of the subject's left lower limbs, trunk, and right upper limbs, the order of muscle excitation of the three practices did not follow this rule. The data presented in the sEMG study of Chen-style Tai Chi Yanshougongquan movements by Ma (2017) indicated that the order of muscle activation did not follow the rule either. The first two muscles stimulated by slow practice and rapid power practice are the same, namely, the slightly joint muscles of the upper limbs and the root-joint muscles of the lower limbs, consistent with what Chen Changxing described in "The Ten Essentials of Tai Chi ": "As for the initiation of qi, it starts from the slightly jointed section, the middle section follows and the following section is only urged (Chen, 2004)," with the slightly joint muscles and root-joint muscles being activated first and the middle section following the adjustment. In the rapid power practice, each muscle is concentrated on the force point before and after being stimulated. In combat practice, the body may produce greater overall strength; eight muscles are always in the activated state to cooperate with the general force of the need. Overall, the *Lanzhayi* movement muscle activation order varies in three different practice methods.

As one of the representative styles of traditional Chinese martial arts, Tai Chi is based on the theory of yin and yang, and the thought pattern of yin and yang changes is always present in its movements. According to the requirements of Chen-style Tai Chi competition routines for practising the *Lanzhayi* movement, the empty leg is believed to apply less force in stepping. Still, the experimental data proves that the contribution ratio of the empty and solid legs in this process is about 6–4. This proves that solid and empty legs can be well trained during the Chen-style Tai Chi practice. Chen Xin, in Chen's Tai Chi diagram, describes the *Lanzhayi* movement: "The flexor is yin, the extender is yang, the right hand is yin, and its runner is yin in the yang. The left hand is yang, and its operation is like the yin of the yang." Based on this theory, in the

Lanzhayi movement, the left leg is extended relative to the right leg, so the left leg is yin, and the right leg is yang; furthermore, the right hand is yin, and the left hand is yang. From the perspective of iEMG, the iEMG of the three muscles of the right arm was greater than those of the three muscles of the left arm, and the iEMG values of the three muscles of the right leg were greater than those of the three muscles of the left leg. This finding is in line with the Tai Chi philosophy of yin and yang, which states that in yin, there is yang, and in yang, there is yin and reflects the spiritual realm of Chinese martial arts, where art is in harmony with the Tao (Cai et al., 2017). The upper-limb action of the right-hand side muscle iEMG is greater than the left- hand muscle iEMG, which is in line with our perception that the right arm is often sorer, but the lower limb muscle iEMG left is greater than the right is not in line with our perception. The traditional Tai Chi theory holds that the *Lanzhayi* movement is in the ratio of the left leg and the right leg bearing the weight of three left to seven right, or four left to six right.

Through the analysis, the lower limb of the *Lanzhayi* movement is a bowed horse stance, the body's centre of gravity between the two legs. As long as the body's centre of gravity is between the two legs, the two legs equally distribute the weight of the trunk and upper limbs. And because the right leg tibia is perpendicular to the ground, the right leg tibia bears more femur stress in the vertical direction, so the right leg tibialis anterior muscle and the right gastrocnemius muscle do not need to send too much force to maintain the balance of the right leg. Wu et al. (2012) confirmed that the iEMG of rear portion is greater than that of the foreleg in the Santi shi practice, which seems contradictory to this study's results. Through practice and careful analysis, the main conflict is whether the two legs bear the weight equally. According to the experience of practising, the supporting leg bears more weight when practising the Santishi, so the supporting leg bears more weight. In the *Lanzhayi* movement, the torso is vertical to the ground, with the lower limbs in a bow and horse stance. The body's centre of gravity is between the two legs, both legs evenly distribute the weight of the torso and upper limbs. Since the right leg's tibia is essentially vertical to the ground, it can easily bear more stress on the femur in the vertical direction. Thus, the right tibialis anterior muscle and the right gastrocnemius muscle do not need to exert too much force to maintain the balance of the right leg. As a result, the sum of the iEMG of the three muscles in the left leg is greater than that of the right leg. To confirm these findings, further comparative study is warranted.

Conclusions

The primary force-emitting muscles in stages 1 and 2 of the *Lanzhayi* movement are the left and right anterior tibialis. In stage 3 of the *Lanzhayi* movement, there was a significant difference in the RMS among the slow practice, rapid power practice and practical combat practice, suggesting that the intensity of the three exercises increased sequentially. However, no significant difference was observed in the total iEMG, suggesting that there was no significant difference in the total volume of the slow practice, rapid power practice and practical combat practice.

Based on the expert-case analysis, the order of muscle power generation in stage 3 of the three exercises did not follow the intuitive experience of "foot-leg-waist-hand" and the order of muscle power generation in the three exercises of slow practice, rapid power practice, and practical combat practice is also different in this expert case.

In the standing exercise of *Lanzhayi*, the iEMG of the left leg (empty leg) is greater than that of the right leg (solid leg). Also, the iEMG of the right arm (yin hand) is greater than that of the left arm (yang hand). This finding may be interpreted from the perspective of the Tai Chi philosophy of yin and yang, "there is reality in emptiness and emptiness in reality; there is yang in yin and yin in yang" which reflects the cultural characteristics of Tai Chi: "The martial arts carry the Tao"(Li et al., 2021).

Recommendations and limitations

Most Tai Chi practitioners emphasize routine, slow practice, and lack of practical combat practice. The difference in the EMG between routine practice and actual combat practice is so great that it is unrealistic to imagine that one can achieve a high level of technical combat ability by practising boxing ten thousand times. To improve the level of Tai Chi, practitioners should undergo as much training as possible that is closer to combat.

"The power starts from the feet, travels through the legs, is controlled by the waist, and manifests in the hands." This is a requirement that the Tai Chi ancestors summed up through physical perception. This traditional requirement can be a guiding principle, but practitioners should not interpret it as a sequence of muscle force generation.

The limitations of this study were the insufficient number of subjects and movements studied. Further studies involving a greater sample size and using more scientific instruments and representative martial arts movements or movement links are warranted to conduct in-depth analysis from multiple perspectives. It is an inevitable trend for future development to use modern technology to study Tai Chi, to use a scientific and universal language to describe traditional martial arts, to summarise the laws, to make martial arts more scientific and standardised, and to promote the inheritance and development of martial arts.

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During preparation of this manuscript, the authors used ChatGPT (OpenAI) to support translation and improve language clarity. The authors reviewed and revised the output, verified the final text, and accepted full responsibility for the manuscript content.

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