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Article

Biomechanical analysis of kinematics in the single whip movement of Tai Chi using video imaging

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Abstract: "Single whip" is a typical movement in Tai Chi, and the study of its kinematics has important practical value for better understanding the laws and characteristics of Tai Chi movements. This study divided 30 Tai Chi practitioners into two groups based on their skill level: an excellent group and a beginner group. The Vicon motion capture system and a three-dimensional force platform were used to obtain kinematic data. Differences in movements between the two groups at various stages were compared. The results showed that the excellent group took longer in stages one and three, but shorter in stage two. In stage one, the left knee joint angle of the excellent group was 95.45° ± 16.02°, while the right knee and left hip joint angles were larger (148.62° ± 12.84° and 133.55° ± 18.61°). In stage two, the angles of the right knee, left ankle, and right ankle joints of the excellent group were significantly smaller than those of the beginner group. In stage three, the angle of the right elbow joint of the excellent group was larger (154.26° ± 12.06°), while the angles of the right wrist angle and the left and right ankle joints were significantly smaller than those of the beginner group ($p < 0.05$). In terms of vertical displacement of the center of gravity, the excellent group exhibited less fluctuation and significantly lower dynamic stability in both anterior-posterior and medial-lateral directions compared to the beginner group ($p < 0.05$).

Keywords: video image; Tai Chi; single whip; kinematics; biomechanics; mechanobiology; motion analysis

1. Introduction

Tai Chi is a traditional martial art originating from China [1], renowned for its graceful movements [2]. It is popular in oriental culture [3]. After several hundred years of development, it has evolved into various different styles [4], with the number of Tai Chi practitioners increasing both domestically and internationally. The movements in Tai Chi are characterized by their gentleness [5]. In Tai Chi, the upper limbs and torso are the main focus of movement, while the lower limbs provide stable support. Through practicing Tai Chi, one can effectively enhance their body's coordination ability [6], improve muscle strength [7]. and strengthen cardio-pulmonary function [8]. Tai Chi is a mind-body exercise [9] that has positive effects on both physical and mental well-being, as well as pain management [10]. Kathleen et al. [11] conducted a study on the preventive effects of Tai Chi practice for arthritis and falls in older adults. A satisfaction survey revealed that 96.8% of elderly participants expressed satisfaction with the program. Jing et al. [12] investigated the clinical efficacy of Tai Chi in patients with acute ischemic stroke. They found that practicing Tai Chi showed significant potential in improving motor function after a four-week treatment period. With an increasing number of individuals practicing Tai Chi, analyzing the kinematics of Tai Chi movements can help researchers gain a better understanding of its essential principles and provide improved guidance for practitioners. Xu et al. [13] utilized wearable devices to acquire motion data from Tai Chi athletes and subsequently employed techniques such as the Gaussian mixture model and support vector machine for classifying different Tai Chi movements. Experimental results revealed that this method achieved a high level of accuracy. Zhu et al. [14] conducted a study on four classic Tai Chi movements performed by a 38-year-old Tai Chi master. They discovered that the characteristics of Tai Chi movements include a large range of motion (ROM) in the lower limbs and a slow increase in joint load, making it suitable for patients with knee osteoarthritis to practice. Currently, research on the kinematics of Tai Chi mainly focuses on the lower limbs and gait [15], with an overall limited quantity of studies; Yang et al. [16] analyzed the biomechanical mechanisms of Tai Chi gait in preventing falls among older adults and found significant differences in ankle joint sagittal and transverse plane peak moments, knee joint three-plane peak moments, and hip joint frontal plane peak moments compared to conventional gait. Wang et al. [17] analyzed the biomechanical characteristics of four Tai Chi movements by collecting data through the Vicon motion capture system and a 3D force measuring platform. They investigated factors influencing knee joint peak moments and vertical ground reaction forces and found that Tai Chi exercise can effectively control knee joint ROM and center of mass displacement, thereby reducing the risk of knee injuries. Tang et al. [18] analyzed the effects of Tai Chi on patients with functional ankle instability (FAI) and found through a 12-week experiment that there were improvements in muscle strength and proprioception in the ankle joint, demonstrating the positive impact of Tai Chi on neuro-muscular function in FAI patients. Duan et al. [19] examined the biomechanical effects of Tai Chi on hip joints and discovered that compared to walking, Tai Chi may have better improvements in hip joint ROM and coordination of the neuro-muscular system, making it suitable for patients with hip osteoarthritis and elderly individuals experiencing severe muscle loss. Moreover, there is more research on routine movements than individual techniques currently. Therefore, this article used the single whip movement in Tai Chi as an example to compare the differences in kinematics during the movement process among practitioners of different levels using video analysis methods. This paper aims to gain a better understanding of the key points of the single whip movement, reveal its rules and characteristics, and provide theoretical support for further development and promotion of Tai Chi.

2. Research subjects and methods

2.1. Research subjects

Tai Chi practitioners from Jiangsu Polytechnic University and neighboring colleges were recruited. Thirty students who met the following criteria were selected: (1) no physical or mental illnesses; (2) no limb injuries or surgical history within the past six months; (3) proficient in the single whip movement; (4) have over one year of experience practicing Tai Chi; (5) engage in Tai Chi practice six or seven times per week, with each session lasting at least one hour; (6) understand the purpose and process of the research and sign an informed consent form.

The research subjects were divided into two groups: the excellent group, consisting of individuals with more than five years of practice and outstanding results in large-scale Tai Chi competitions, and the beginner group, comprising individuals with less than five years of practice. The basic information for both groups is shown in **Table 1**.

Table 1. Basic information of research subjects.

	Excellent group (*n* = 15)	**Beginner group (*n* = 15)**
Gender	Male	Male
Age/year	22.36 ± 1.28	21.73 ± 1.16
Height/m	175.84 ± 3.79	174.26 ± 4.07
Weight/kg	71.27 ± 7.85	72.41 ± 7.53
Training time/year	6.42 ± 2.87	2.34 ± 1.31

2.2. Research process

The study focuses on the single whip movement in Tai Chi, which involves the following steps. Relax both hands, open and close them simultaneously, hook with the right hand, lift the left knee, and step out to the left side. Move the center of gravity to the left side while pulling the left hand towards the left side and keeping the right hand hooked. Then move the left hand to the right side with the right hand still hooked, shift center of gravity to the right side, and move the left hand in a counterclockwise arc before joining it with the inner side of the right hooked-hand. Turn palms outwardly and stand by both legs to keep a stable posture.

Three critical moments occur during the single whip movement, as follows: (1) the moment when the left foot lifts its knee (left in **Figure 1**); (2) the moment when the center of gravity shifts to the left and the heel of the left foot touches the ground (middle in **Figure 1**); (3) the moment when both legs reach a stable posture (right in **Figure 1**).

Figure 1. The schematic diagram of the single whip movement.

According to these three time points, three important stages were extracted from the process of the single whip movement, defined as follows: (1) stage one starts from lifting the left knee to shift center of gravity left and place the heel on the ground; (2) stage two starts from placing the left heel on the ground to the entire sole touching the ground; (3) stage three starts from the entire left sole touching the ground to both legs reaching a stable posture.

Originally, the Vicon motion capture system was applied in areas such as remote sensing and measurement control. Subsequently, it was widely used in fields such as medical rehabilitation [20], sports [21], and engineering control [22]. In kinematic mechanics, it has been proven to have good reliability and validity [23]. The system utilizes infrared high-speed cameras to capture luminescent markers, enabling the collection and analysis of motion data. It can achieve both high resolution and high sampling frequency simultaneously, with strong flexibility and easy installation. Moreover, it has low latency and good compatibility. The accompanying software allows for real-time data acquisition and analysis, as well as real-time synchronization with other software. The Kistler 3D force platform is also a biomechanical measurement system widely used in motion technology diagnosis, gait analysis, and other fields [24]. It has a wide measurement range and excellent measurement accuracy, making it extensively utilized in force research in areas such as sports biomechanics and rehabilitation medicine [25]. Therefore, these two devices were used to collect and analyze the data in this study.

The video image of the single whip movement in Tai Chi was obtained for kinematic data analysis using an eight-camera Vicon motion capture system. The dynamic data of the subjects were collected using two Kistler 3D force measurement platforms. Data synchronization during collection was achieved through Vicon Nexus2.5 software. The specific experimental process is shown in **Figure 2**.

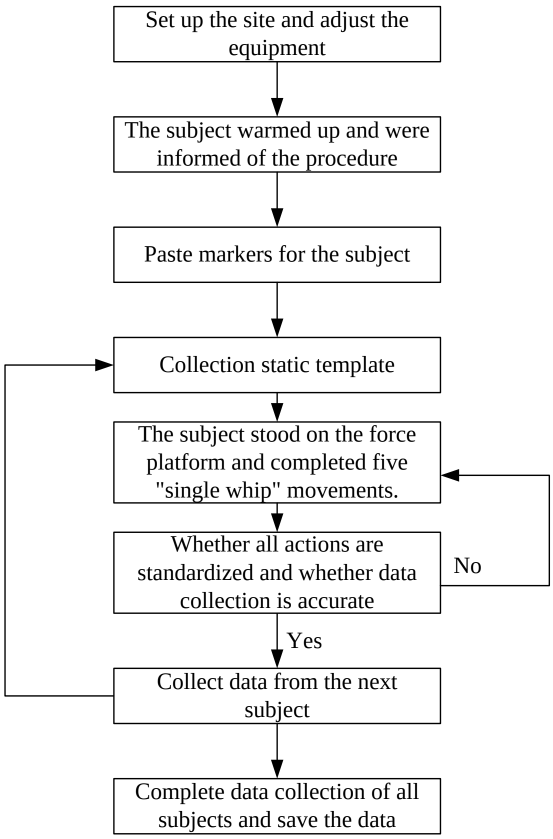

Figure 2. The experimental flow.

According to **Figure 2**, the specific experimental procedure is presented below.

(1) The experimenters set up the site, debugged the system, and conducted simulated experiments.

(2) The participants were informed of the experimental procedures and precautions.

(3) The experimenters attached reflective balls to the positions shown in **Figure 3** and **Table 2**.

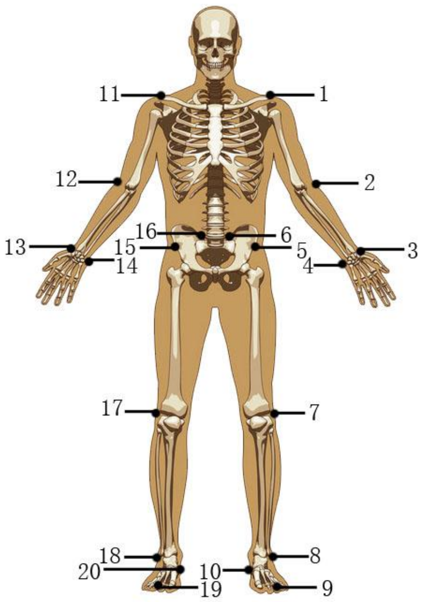

Figure 3. Positions of the markers.

Table 2. Positions of the markers.

Number	**Code**	**Name**	**Number**	**Code**	**Name**
1	LSHO	Left shoulder peak	11	RSHO	Right shoulder peak
2	LELB	Left elbow	12	RELB	Right elbow
3	LWRA	Medial side of the left wrist joint	13	RWRA	Medial side of the right wrist joint
4	LWRB	Lateral side of the left wrist joint	14	RWRB	Lateral side of the right wrist joint
5	LASI	Left anterior superior iliac spine	15	RASI	Right anterior superior iliac spine
6	LPSI	Left posterior superior iliac spine	16	RPSI	Right posterior superior iliac spine
7	LKNEE	Left knee joint	17	RKNEE	Right knee joint
8	LANK	Left ankle	18	RANK	Right ankle
9	LTOE	Left toe	19	RTOE	Right toe
10	LHEE	Left heel	20	RHEE	Right heel

(4) The subjects stood on the force platform and, after collecting static templates, they began the formal experiment. Each subject completed five valid single whip movements. Invalid movements were defined when the feet left the force platform or the marker points fell off. There was an interval of 30 s between the movements.

(5) After all subjects completed the movements, the experimental personnel removed the markers and properly saved video images and data.

2.3. Data processing and statistical analysis

Data processing was conducted using Vicon Nexus 2.5 software. A fourth-order low-pass filter was used to filter the kinematic and dynamic data, and the cut-off frequencies were set at 8 Hz and 50 Hz. The kinematic and dynamic parameters were calculated using software, and the data was output. All data was recorded as mean ± standard deviation. Independent sample t-tests were performed using SPSS software [26] to compare the differences between the two groups of data, with a significance level set at p < 0.05. Finally, the data was organized and analyzed in Excel software, and corresponding charts were created.

3. Results

Firstly, the time taken by the two groups of subjects to complete the single whip movement is shown in **Table 3**.

Table 3. Comparison of the time taken to complete the single whip movement.

	The beginner group (*n* = 15)	**The excellent group (*n* = 15)**
Stage one	1.35 ± 0.01	1.74 ± 0.01*
Stage two	0.74 ± 0.04	0.43 ± 0.03*
Stage three	5.21 ± 0.11	7.84 ± 0.12*

Note: * indicates $p < 0.05$ compared to the beginner group.

According to **Table 3**, the beginner group took 1.35 ± 0.01 s in Stage one, while the excellent group took significantly longer with a time of 1.74 ± 0.01 s ($p < 0.05$). In Stage two, the beginner group completed the task in a shorter time (0.74 ± 0.04 s) compared to the excellent group (0.43 ± 0.03 s) ($p < 0.05$). Lastly, in Stage three, the beginner group took significantly more time with a duration of 5.21 ± 0.11 s compared to the excellent group (7.84 ± 0.12 s) ($p < 0.05$).

Comparisons were made between two groups of subjects in terms of knee and hip joint angles and angular velocities during Stage one (**Table 4**).

Table 4. Comparison of angles and angular velocities of knee and hip joints in Stage one.

		The beginner group (*n* = 15)	**The excellent group (*n* = 15)**
Joint angle (°)	Left knee	125.34 ± 15.77	95.45 ± 16.02*
	Right knee	131.07 ± 12.53	148.62 ± 12.84*
	Left hip	90.27 ± 12.61	133.55 ± 18.61*
	Right hip	87.44 ± 10.11	74.37 ± 12.34
Joint angular velocity (rad/s)	Left knee	6.51 ± 233.77	35.66 ± 280.13*
	Right knee	−7.84 ± 208.56	−12.67 ± 249.81
	Left hip	6.42 ± 255.18	−7.51 ± 452.33*
	Right hip	22.34 ± 241.26	12.07 ± 245.17

Note: * indicates $p < 0.5$ compared to the beginner group.

From **Table 4**, it can be observed that there were significant differences in knee joint angles between the two groups in Stage one. In the beginner group, the left knee joint angle was 125.34° ± 15.77°, and the right knee was 131.07° ± 12.53°, showing a small difference. However, in the excellent group, the left knee joint angle was 95.45° ± 16.02°, and the right knee joint angle was 148.62° ± 12.84°, indicating a large disparity. Additionally, it is evident that the left knee joint angle of the excellent group was significantly smaller than that of the beginner group while the right knee joint angle was significantly larger ($p < 0.05$). The left hip angle in the beginner group was 90.27° ± 12.61°, and the right hip angle was 87.44° ± 10.11°. In contrast, the left hip angle in the excellent group was significantly greater at 133.55° ± 18.61° compared to that of the beginner group ($p < 0.05$). However, there was no statistically significant difference in the right hip angle between the excellent and beginner groups (74.37° ± 12.34° vs. 87.44° ± 10.11°, $p > 0.05$). In terms of joint angular velocity, the excellent group exhibited significantly higher left knee joint angular velocity (35.66 ± 280.13 rad/s) and left hip joint angular velocity (−7.51 ± 452.33 rad/s) compared to the beginner group ($p < 0.05$). However, no significant differences were observed in the right knee and right hip joint angular velocities. These results indicated that in Stage one, the excellent group demonstrated a more pronounced knee lifting and foot hooking movement with faster joint transitions, while the beginner group exhibited a narrower range of joint activity.

The shoulder and elbow joint angle and angular velocities in Stage one was compared between the two groups, and the results are presented in **Table 5**.

Table 5. Comparison of angles and angular velocities of shoulder and elbow joints in Stage one.

		The beginner group (*n* = 15)	**The excellent group (*n* = 15)**
Joint angle (°)	Left shoulder	95.46 ± 7.58	92.07 ± 5.16
	Right shoulder	85.77 ± 7.64	80.26 ± 7.64
	Left elbow	105.37 ± 7.89	106.71 ± 7.46
	Right elbow	120.34 ± 12.33	144.52 ± 13.74*
Joint angular velocity (rad/s)	Left shoulder	6.74 ± 243.15	0.48 ± 216.48*
	Right shoulder	−1.87 ± 224.16	1.36 ± 222.15
	Left elbow	−6.87 ± 282.36	−9.11 ± 327.18
	Right elbow	11.12 ± 423.17	12.37 ± 431.21

Note: * indicates $p < 0.05$ compared to the beginner group.

According to **Table 5**, significant differences were observed between the two groups in terms of right elbow joint angle and left shoulder joint angular velocity during Stage one. The beginner group had a right elbow joint angle of 120.34° ± 12.33°, while the excellent group had a significantly larger angle (144.52° ± 13.74°) ($p < 0.05$). Additionally, the beginner group exhibited a left shoulder joint angular velocity of 6.74 ± 243.15 rad/s, which was significantly higher than the excellent group (0.48 ± 216.48 rad/s) ($p < 0.05$). These results indicated that during Stage 1, compared to the beginner group, the excellent group demonstrated greater right elbow joint angles and faster changes in left shoulder joint angular velocity.

In Stage two, the main changes in movement focused on the joints of the lower limbs. The variations of joint angles in the lower limbs for both groups of subjects are shown in **Table 6**.

Table 6. Comparison of lower limb joint angles in Stage two (unit: °).

	The beginner group (*n* = 15)	**The excellent group (*n* = 15)**
Left hip	112.36 ± 8.94	113.75 ± 9.02
Right hip	113.28 ± 8.87	104.52 ± 8.97
Left knee	133.24 ± 8.98	134.56 ± 9.18
Right knee	148.64 ± 22.31	129.37 ± 11.27*
Left ankle	101.21 ± 15.12	95.74 ± 8.07*
Right ankle	115.24 ± 15.24	80.21 ± 14.32*

Note: * indicates $p < 0.05$ compared to the beginner group.

From **Table 6**, it can be observed that in Phase 2, there were no significant differences in hip joint angles between the two groups. However, regarding knee joints, the excellent group exhibited a right knee joint angle of 129.37° ± 11.27°, which was significantly smaller than that of the beginner group ($p < 0.05$). Similarly, the left ankle and right ankle joint angles for the excellent group were 95.74° ± 8.07° and 80.21° ± 14.32° respectively, both significantly smaller than those of the beginner group ($p < 0.05$). This result indicates that during Stage two when shifting weight to the left and relying on support from the left foot, the excellent group demonstrated greater control over lower limb joints compared to beginners.

The angles of the joints in Stage three were compared between the two groups of subjects, as shown in **Table 7**.

Table 7. Comparison of joint angles in Stage three (unit: °).

	The beginner group (*n* = 15)	**The excellent group (*n* = 15)**
Left shoulder	94.33 ± 5.64	93.67 ± 6.07
Right shoulder	87.56 ± 6.13	92.73 ± 5.91
Left elbow	102.37 ± 21.84	112.34 ± 23.64
Right elbow	115.34 ± 15.27	154.26 ± 12.06*
Left wrist	130.82 ± 28.27	125.37 ± 29.32
Right wrist	160.77 ± 12.66	123.54 ± 15.37*
Left hip	115.15 ± 6.78	102.36 ± 9.87
Right hip	114.36 ± 7.12	103.27 ± 9.64
Left knee	148.12 ± 10.87	138.94 ± 10.61
Right knee	126.78 ± 9.64	127.49 ± 9.83
Left ankle	106.75 ± 6.88	95.78 ± 15.34*
Right ankle	98.64 ± 7.81	80.16 ± 12.33*

Note: * indicates $p < 0.05$ compared to the beginner group.

According to **Table 7**, firstly, in the comparison of upper limb joint angles, there was no significant difference observed in the shoulder joint angle between the two groups ($p < 0.05$). In the beginner group, the left elbow joint angle was 102.37° ±

21.84°, and the right elbow joint angle was 115.34° ± 15.27°, while for the excellent group, the left elbow joint angle was 112.34° ± 23.64° and the right elbow joint angle was 154.26° ± 12.06°, both higher than those of the beginner group. The difference in the right elbow joint angle was statistically significant ($p < 0.05$). The left and right wrist joint angles in the excellent were both smaller than those in the beginner group. Specifically, the angle of the right wrist joint was significantly smaller in the excellent group (123.54° ± 15.37°) compared to the beginner group ($p < 0.05$). The beginner group exhibited significant differences in the left and right wrist joints. Additionally, while large differences were observed in elbow joint angles for the excellent group, small differences were noted for shoulder and wrist joints.

In terms of the comparison of lower limb joint angles, there were minimal differences in hip joint angles between the two groups, with the excellent group having slightly smaller hip joint angles than the beginner group, but $p > 0.05$. There were also no significant differences in knee joint angles between the two groups; however, the beginner group exhibited a larger difference in knee joint angles between left and right sides compared to the excellent group, indicating an uneven ROM for both joints. When comparing the angles of the ankle joints, it was found that the excellent group had a left ankle joint angle of 95.78 ± 15.64° and a right ankle joint angle of 80.16 ± 12.33°, both lower than those in the beginner group ($p < 0.05$).

The displacement of the center of gravity in the vertical direction was compared between two groups of subjects, as shown in **Figure 4**.

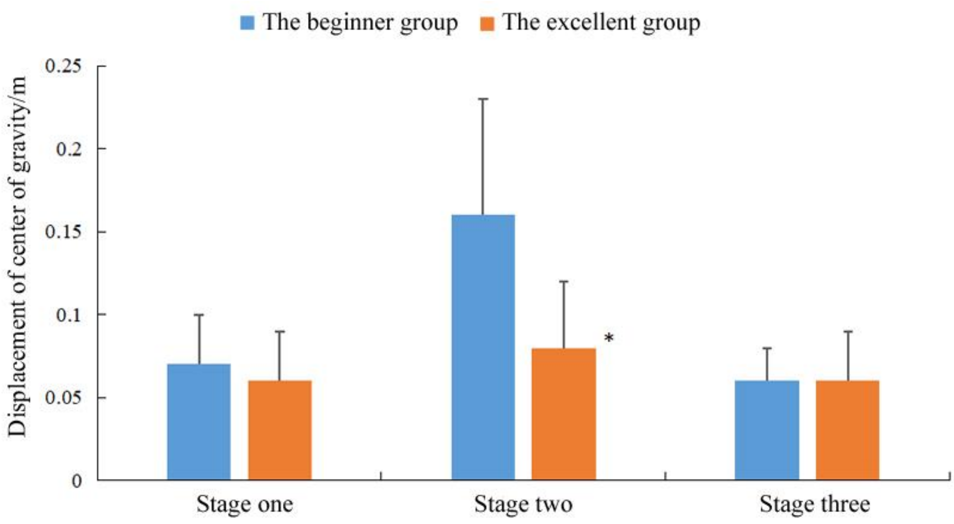

Figure 4. Comparison of displacement of the center of gravity in the vertical direction.

Note: * indicates $p < 0.05$ compared to the beginner group.

From **Figure 4**, it can be observed that there was a significant difference in the displacement of the center of gravity between the two groups during Stage two. In Stage one, the displacement of the center of gravity for the beginner group was 0.07 ± 0.03 m, while for the excellent group it was 0.06 ± 0.03 m; in Stage two, the displacement for the beginner group was 0.16 ± 0.07 m, whereas for the excellent group it was 0.08 ± 0.04 m; and in Stage three, the displacement of the beginner group was 0.06 ± 0.02 m, and the displacement of the excellent group was 0.06 ± 0.03 m.

Comparatively speaking, the beginner group experienced a significantly greater displacement of the center of gravity in Stage two compared to the excellent group. The excellent group exhibited minimal changes in center of gravity displacement from stage one to Stages two and three, indicating their superior control over their center of gravity.

The comparison of the dynamic stability between the two groups during left knee lifting is shown in **Table 8**.

Table 8. Comparison of dynamic stability of the human body.

	The beginner group (n = 15)	**The excellent group (n = 15)**
Dynamic stability in the forward and backward directions (m/s)	−0.18 ± 0.03	−0.01 ± 0.02*
Dynamic stability in left and right directions (m/s)	0.03 ± 0.01	0.01 ± 0.01*

Note: * indicates $p < 0.05$ compared to the beginner group.

According to **Table 8**, in terms of dynamic stability in forward and backward directions, the beginner group was −0.18 ± 0.03 m/s, while the excellent group was −0.01 ± 0.02 m/s; in terms of dynamic stability in left and right directions, the beginner group was 0.03 ± 0.01 m/s, while the excellent group was 0.01 ± 0.01 m/s. Comparatively speaking, both in the forward-backward and left-right directions, the dynamic stability of the excellent group was significantly higher than that of the beginner group ($p < 0.05$), indicating a stronger overall body stability.

4. Discussion

Tai Chi, as a form of exercise, has been widely applied not only in the field of sports but also in medical rehabilitation [27]. From a kinematic perspective, Tai Chi has unique characteristics in terms of joint ROM, shifting of body weight, and gait. It can enhance lower limb muscle strength and improve balance ability and coordination function. Therefore, many studies have shown that practicing Tai Chi has significant effects on improving physical and living quality [28], preventing falls among elderly individuals [29], delaying cognitive decline in older adults [30], slowing bone loss [31], and providing certain therapeutic benefits for chronic diseases such as diabetes [32] and hypertension [33], and exhibiting positive effects on symptoms of anxiety and depression [34]. Therefore, studying Tai Chi holds great practical significance. This paper primarily focuses on analyzing the single whip movement through video image analysis.

The excellent group took longer time in Stage one compared to the beginner group, allowing for a more stable transition of movements. In Stage two, the excellent group had a shorter duration from heel contact to forefoot contact, which improved overall movement efficiency. In Stage three, the two legs alternated in knee joint movement, transitioning into a fixed position. At this stage, the excellent group spent more time, so their movements were more stable. Tai Chi is a form of exercise that requires a balanced pace. The slow movements in Stages one and three in the excellent group allow the joints and muscles to relax, enabling better energy storage. The fast movements in Stage two enhance body momentum, resulting in improved movement effectiveness.

In Stage one, the right foot mainly served as a support while the left knee was raised, the left hand pulled to the left, the right hand hooked, and the center of gravity shifts to the left side. According to **Tables 4** and **5**, it can be observed that in the excellent group, there was a faster variation speed in the left knee and right elbow joints, while the shoulder joint variation was slower. In the beginner group, there was a fast variation in the left elbow and right hip joints, while the knee joint variation was slower. These results indicated that in Stage one, members of the excellent group demonstrated better participation effects and stability when performing movements.

From **Table 6**, it can be observed that in Stage two, significant changes occurred in the right knee joint angle and ankle joint angles for the beginner group. This may be attributed to their poor stability during movements, resulting in a abrupt landing of the left foot. Additionally, their muscle strength was not as good as that of the excellent group, leading to instability in the right knee joint and increased ROM in both left and right ankle joints. Therefore, the injury risk in the beginner group was higher.

In Stage three, the left and right knee joints alternated in performing bow step movements, transitioning into a stable posture with both feet supporting. According to **Table 7**, there was a significant difference in the ROM between the knee joints in the beginner group. The angle of the left knee joint was 148.12 ± 10.87°, while that of the right knee joint was 126.78 ± 9.64°; furthermore, the ankle joint angle was also significantly greater than that of the excellent group. In Stage three, during the single whip movement, the ankle joint played a role in stabilizing and supporting while the elbow joint controls stability in upper limbs. The above results suggested that individuals from the excellent group exhibited better stability when performing this movement.

Tai Chi requires sinking shoulders and dropping elbows. The excellent group demonstrated good control over the shoulder and elbow joints during the execution of movements, resulting in flexibility and stability in the shoulder and back. Similarly, the hip joint exhibited sufficient rotation when exerting force to achieve power accumulation, while the knee joint flexed and extended to generate forward propulsion. As a result, the completion level of the movement was higher.

From the perspective of vertical displacement of the center of gravity, there was an obvious fluctuation in the beginner group, while the excellent group's center of gravity movement was more stable with smaller variations. Tai Chi requires high control over the body's center of gravity, and it is necessary to maintain a stable center of gravity when performing movements. In this aspect, the performance of the excellent group was better. Similarly, when comparing the dynamic stability in the human body (**Table 8**), it can be observed that the excellent group exhibited significantly lower dynamic stability than the beginner group, indicating a higher level of physical stability. The single whip movement in Tai Chi is a relatively slow exercise that requires greater body stability, which must be maintained through coordinated control of various joints and muscles.

According to kinematic analysis results, the excellent group demonstrated stronger joint control ability and greater joint flexibility, thereby having better support and buffering capacity in the lower limbs during the single whip movement. However, the beginner group exhibited poor knee joint control, which may result in knee pain or injury. Therefore, attention should be paid to joint and center of gravity control during the practice or teaching process of the single whip movement to prevent limb injuries. For coaches, in the practice of the 'single whip' movement in Tai Chi, emphasis on improve body stability by strengthening the core strength should be strengthened, and waist movements should be paid attention to. Scientific guidance should be provided for vulnerable knee joints and ankle joints to enhance teaching effectiveness and quality.

5. Conclusion

The present study conducted a kinematic analysis of the single whip movement in Tai Chi practitioners of different skill levels using video image analysis. The results showed that, compared to the beginner group, the excellent group exhibited better control over various joints of the human body and maintained a more stable body posture. However, the beginner group displayed shortcomings such as abrupt changes in movements and significant differences in joint variations in the left and right sides, which need to be corrected to avoid injuries. The results verify the reliability of the video image analysis method in kinematic analysis, which can be further applied in the study of other movements in Tai Chi. In future work, this method can be used to research more movements in Tai Chi, and the sample size can be expanded to verify the differences discovered in this paper. Furthermore, other factors, such as gender and age, which contribute to kinematic differences apart from skill level, can be analyzed, thus enriching the theoretical research on Tai Chi and providing support for its further promotion and dissemination.

Ethical approval: Not applicable.

Conflict of interest: The author declares no conflict of interest.

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