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The Effects of Tai Chi Chuan Exercise Training on the Lower Extremities of Middle-Aged and Elderly

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Abstract: Background: It is known that lower-limb muscle strength is easily maintained in elderly people who practice Tai Chi, although it is necessary to maintain lower-limb muscle strength even as age increases in order to prevent falls. However, the effect of long-term Tai Chi practice and age on lower-limb ability is unclear in middle-aged and elderly people. This research was designed to compare lower-extremity parameters during a countermovement jump between middle-aged and elderly individuals who frequently practice Tai Chi Chuan and individuals in the general population who constituted the healthy group. Methods: There were four groups, and each group included 12 participants. Ten Vicon motion system infrared cameras and two Kistler force plates were used. The data were standardized and analysed using independent-measure two-way ANOVA. Results: The statistical results showed that there was no interaction between the age factor and exercise type factor. The statistics of age factor also showed that age may decrease the jump height (36.36%), peak knee power (24.74%) and peak ankle power (21%) during the take-off phase. In the exercise type factor, long-term Tai Chi training significantly increased the jump height (60%), peak knee moment (19.80%), peak ankle moment (8.06%), peak hip power (29.80%), peak knee power (31.23%) and peak ankle power (16.88%) during the take-off phase. Conclusion: This study shows that long-term Tai Chi training can slow ageing-related functional decline. According to the results of this study, middle-aged and elderly people are encouraged to regularly perform Tai Chi exercises to increase the strength of various muscle groups in the lower limbs and slow the lower-limb muscle changes caused by ageing.

Keywords: age; exercise type; fall risk; joint moment; joint power; jump height

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1. Introduction

Ageing is a physiological process, so health issues related to the ageing process or that occur in the elderly population are receiving increasing attention. In the past, studies pointed out that ageing leads to muscle atrophy, decreases in muscle mass, decreases in muscle endurance and related problems such as proprioception, balance and visual impairment [1,2]. Decreases in these abilities may cause elderly individuals to have difficulty performing activities of daily living (ADLs). A decline in lower-limb ability increases the risk of falls. Falls are one of the causes of unintentional injuries that lead to disability or death in older adults [3]. Ageing also causes degeneration of the extensor muscles of the hip joint and a decrease in the torques of the hip joint, knee joint and ankle joint, thus resulting in a smaller push-off force from the lower extremities and reduced power when walking [4]. Therefore, the walking speed of elderly people is slower than that of younger people, their step length is shorter and the range of motion of the lower-limb joint is smaller [4,5]. Muehlbauer et al. [6] also pointed out that lower-limb power is one of the important indicators of whether an elderly person can successfully walk up and down stairs, maintain balance, or stand up from a chair. Regular exercise in elderly individuals can effectively delay muscle degeneration, and improved lower-limb muscle strength can lead to an improved quality of life in elderly individuals [7] and slow functional decline in ADLs.

Tai Chi can improve the body's ability to absorb antioxidants, coordination, proprioception, blood pressure, flexibility and balance [8–10]. Tai Chi may reduce the risk of falls in older adults [11]. Tai Chi is not only very popular among the elderly, but also the exercise intensity can be adjusted according to their abilities. Studies have shown that Tai Chi can significantly improve the lower-limb muscle strength and gait performance of elderly individuals [12]. A previous study also pointed out that the fall risk of the group who regularly engages in Tai Chi exercise is one-third of the group who only engage in low-intensity exercise such as walking and hiking in the elderly over 70 years old [13]. Compared with the normal gait group, the elderly Tai Chi group adopted a gait strategy with longer steps and a faster step frequency [14]. In addition, the knee and ankle joints showed large flexion angles, indicating that the stiffness of the lower-limb joints was slightly smaller than that of the general elderly population [15]. Relevant experiments showed that elderly people practicing Tai Chi have better flexion and extension ranges of motion in the knee joint when jumping [16]. Another study also pointed out that joint stability can be increased by increasing joint torque and the larger knee torque exhibited by the Tai Chi group may lead to higher joint stability [17].

Because of the rapid availability of test results, countermovement jumps are often used to assess lower-limb power [18–20]. Previous studies have shown that lower-limb power is highly correlated with the risk of falls in older adults [21]. Therefore, this jump has also been used in elderly individuals to assess the degree of lower-limb function [6,22]. A previous study used the countermovement jump to examine the effects of Tai Chi in older adults. The results showed that elderly people who practiced Tai Chi for long periods of time were superior to the healthy group in terms of flight height, peak power and peak $\text{velocity}_{\text{takeoff}}$ [23]. The results show that Tai Chi may slow the process of functional decline in ADLs in the elderly. The healthy group had a lower jump height than the Tai Chi group in the countermovement jump test, indicating that the healthy group may have weaker lower extremity abilities.

The above studies discussed that better lower-limb ability could reduce the risk of falling. However, most of these research discusses overall lower-limb capabilities and rarely discusses the capabilities of the hip, knee and ankle joints. This study could further understanding of the changes of lower-limb joint ability with age and exercise type factors. The purpose of this study was to further investigate the effect of Tai Chi on hip, knee and ankle joints by age and exercise type factors. Therefore, this cross-sectional study used the countermovement jump to assess these factors and analyse the lower-limb joint moment, power and kinematic parameters by using the inverse dynamics calculation method.

2. Materials and Methods

2.1. Participants

According to the definition of The World Health Organization, more than 7% of the population over the age of 65 is an "aging society". Therefore, this study divided the age categories into 55–64 years old and over 65 years old.

A total of 48 participants in this research were divided into four groups according to their age and exercise type. Individuals who practiced Tai Chi were included in the Tai Chi group (TCG), and the others who had regular physical activity were included in the healthy group (HG). The TCG and HG were further divided into middle-aged (55 to 64 years old) and elderly (65 years old and older) groups.

In middle-aged groups, there were 5 males and 7 females in TCG (age: 60.67 $\pm$ 2.71 years, height: 162.25 $\pm$ 8.16 cm, weight: 64.79 $\pm$ 11.09 kg) and 5 males and 7 females in HG (age: 62.33 $\pm$ 1.61 years old, height: 157.67 $\pm$ 8.55 cm, weight: 60.75 $\pm$ 8.08 kg). In elderly groups, there were 5 males and 7 females in TCG (age: 71.08 $\pm$ 5.55 years, height: 162.75 $\pm$ 6.40 cm, weight: 56.67 ± 6.27 kg) and 4 males and 8 females in HG (age: 69.00 ± 3.81 years, height: 160.25 ± 5.72 cm, weight: 59.17 ± 6.95 kg).

The TCG participants had been regularly practicing Yang-style Tai Chi (108 forms) at least three times a week for over 5 years. The HG was the control group, and the individuals of which were healthy and regularly participated in recreational activities such as walking, jogging or mountain climbing. None of the participants had a history of surgery or sports injuries of the lower limbs, lower back, back, or upper limbs in the past year. Before the experiment, the required sample size was calculated by G*power software, and the power was set at 0.8.

2.2. Measures

Full-body kinematics were recorded with 51 reflective markers placed on the body's bony landmarks and 10 infrared cameras (Vicon MX13+, 250 Hz; Oxford Metrics, Oxford, UK). The kinetic data were collected with two force plates (Kistler 9281, 1000 Hz; Kistler Instruments, Winterthur, Switzerland). Visual 3D v6.00.29 (C-Motion Inc., Germantown, MD, USA) was used to process the kinematic and kinetic data.

2.3. Procedures

Before the experiment, the team explained the procedure to each participant and each participant signed the participant consent form. Each participant stepped onto the force plate. Participants placed their hands on their hips and jumped at their own pace. Each participant performed three successful trials. We also arranged for a team member next to the participant to judge whether the action was successful or not. Experimental data were averaged with three successful data values, and unsuccessful data were not included in data processing. For a countermovement jump, the jumper started from a standing position, moved down by bending the knees and hips and then quickly extended the knees and hips to jump vertically off the ground [24].

2.4. Data Processing

Previous research divided countermovement jump into countermovement phase and take-off phase [23]. This study analysed lower-limb kinematics and joint dynamics during take-off phase. The take-off phase is from the lowest point of the centre of mass (COM) to the toes leaving the force plate.

Visual 3D was used for kinematic and joint dynamics data processing and analysis. The kinematics data were smoothed by using a 6 Hz four-order low-pass Butterworth filter, and the dynamics data were processed by using a 10 Hz fourth-order low-pass Butterworth filter. The COM displacement, peak vertical velocity and peak lower-limb angular velocity were also reported in this study. Instantaneous $\text{velocity}_{\text{takeoff}}$ was the COM vertical velocity at the toe left the force plate. The jump height was the maximum COM height minus the COM height while standing. Peak moment was the maximum value of joint moment data during the take-off phase, and the joint moment was calculated by using inverse dynamics. Peak power was the maximum value of joint power data during the take-off phase, and the power calculation formula was as follows:

$$P = \tau \times \omega$$

The joint dynamics data were standardized by body weight.

The data were reported as the means and standard deviations. Shapiro–Wilk and Levene were used to determine the normality and homoscedasticity assumptions of data. SPSS v20 (IBM, New York, NY, USA) was used to analyse the data, and an independent two-way ANOVA was performed to compare the age factor and exercise type factor (age factor (2) X exercise type factor (2)). If there was an interaction between the two factors, Bonferroni was used for a post hoc comparison of the simple main effect. If there was no interaction between them, the two factors were tested for the main effect. α = 0.05 was set as the significance level, and the eta-squared were also reported in the results.

3. Results

In this study, there were no significant interaction effects between age and Tai Chi exercise. Therefore, only the main effects of age and exercise on each parameter are discussed. And only inverse dynamics were used to calculate joint moment and power, and the results could only infer knee joint moment and power.

3.1. Jump Height during the Airborne Phase

The results showed that jump height significantly differed between the age groups ($F_{(1,44)}$ = 8.81, η^2 = 0.167, $p < 0.05$) and between the exercise groups ($F_{(1,44)}$ = 15.310, η^2 = 0.258, $p < 0.05$). The jump height of the middle-aged group (0.15 m) was higher than that of the elderly group (0.11 m), and the jump height of the TCG group (0.16 m) was also significantly higher than that of the HG group (0.10 m).

3.2. Kinematics during the Take-Off Phase

In terms of the distance of the COM, the significant main effect of exercise ($F_{(1,44)}$ = 13.129, η^2 = 0.230, $p < 0.05$) showed that the TCG (0.38 m) had a longer take-off distance than the HG (0.30 m). In terms of peak vertical velocity, the main effects of age ($F_{(1,44)}$ = 4.572, η^2 = 0.094, $p < 0.05$) and exercise were significant ($F_{(1,44)}$ = 15.171, η^2 = 0.256, $p < 0.05$). According to the statistical results, the peak vertical velocity of the TCG (2.07 m/s) was significantly higher than that of the HG (1.82 m/s) and that of the middle-aged group (2.01 m) was significantly higher than that of the elderly group (1.88 m). In terms of instantaneous velocity, the main effects of age ($F_{(1,44)}$ = 7.762, η^2 = 0.150, $p < 0.05$) and exercise were significant ($F_{(1,44)}$ = 19.557, η^2 = 0.308, $p < 0.05$). The results showed that the instantaneous velocity of the TCG (1.84 m/s) was significantly higher than that of the HG (1.50 m/s) and that of the middle-aged group (1.77 m/s) was significantly higher than that of the elderly group (1.56 m/s).

In terms of peak hip angular velocity, the main effect of exercise was significant ($F_{(1,44)}$ = 15.140, η^2 = 0.256, $p < 0.05$), showing that the peak hip angular velocity in the TCG (405.61 deg/s) was higher than that in the HG (337.45 deg/s). In terms of peak knee angular velocity, the main effects of age ($F_{(1,44)}$ = 4.223, η^2 = 0.088, $p < 0.05$) and exercise were significant ($F_{(1,44)}$ = 12.014, η^2 = 0.214, $p < 0.05$), showing that the peak knee angular velocity in the TCG (601.78 deg/s) was higher than that in the HG (522.14 deg/s) and that the peak knee angular velocity in the middle-aged group (585.57 deg/s) was higher than that in the elderly group (538.35 deg/s). In terms of the peak ankle angular velocity, the main effects of age ($F_{(1,44)}$ = 9.393, η^2 = 0.176, $p < 0.05$) and exercise were significant ($F_{(1,44)}$ = 5.499, η^2 = 0.111, $p < 0.05$), which indicated that the peak knee angular velocity of the HG (581.16 deg/s) was lower than that of the TCG (620.72 deg/s) and that the peak ankle angular velocity of the elderly group (575.09 deg/s) was lower than that of the middle-aged group (626.79 deg/s). All kinematics data are reported in Table 1.

Table 1. Kinematics data during the take-off phase.

	Middle-Aged		**Elderly**	
	TCG	**HG**	**TCG**	**HG**
COM displacement (m) ◆	0.39 ± 0.08	0.29 ± 0.1	0.36 ± 0.04	0.30 ± 0.08
Peak vertical velocity (m/s) ▼◆	2.16 ± 0.20	1.86 ± 0.28	1.98 ± 0.17	1.78 ± 0.22
Instantaneous velocity$_{takeoff}$ (m/s) ▼◆	1.96 ± 0.23	1.59 ± 0.34	1.72 ± 0.22	1.40 ± 0.26
Peak hip angular velocity (deg/s) ◆	−426.28 ± 29.02	−343.24 ± 72.16	−384.94 ± 56.41	−331.67 ± 62.75
Peak knee angular velocity (deg/s) ▼◆	644.28 ± 68.53	526.86 ± 88.39	559.28 ± 63.26	517.43 ± 93.96
Peak ankle angular velocity (deg/s) ▼◆	−658.04 ± 68.55	−595.55 ± 51.25	−583.41 ± 35.48	−566.78 ± 71.25
Jump height (m) ▼◆	0.18 ± 0.06	0.12 ± 0.05	0.13 ± 0.03	0.09 ± 0.03

Note: hip flexion was (+), hip extension was (−), knee flexion was (−), knee extension was (+), ankle dorsiflexion was (+), and ankle plantar flexion was (−). ▼ indicates a significant difference between age factor ($p < 0.05$); ◆ indicates a significant difference between exercise type factor ($p < 0.05$).

3.3. Dynamics during the Take-Off Phase

In terms of peak hip moment, the main effects of age and exercise were not significant, indicating that peak hip moment tended to be consistent among the four groups. In terms of peak hip power, the main effect of exercise was significant ($F_{(1,44)}$ = 9.695, η^2 = 0.181, $p < 0.05$), showing that the peak hip power of the TCG (3.31 W/kg) was significantly higher than that of the HG (2.55 W/kg). In terms of peak knee moment, the main effect of exercise was significant ($F_{(1,44)}$ = 7.032, η^2 = 0.138, $p < 0.05$). The results show that the peak knee moment of the TCG (1.21 N-m/kg) was significantly higher than that of the HG (1.01 N-m/kg). In terms of peak knee power, the main effects of age ($F_{(1,44)}$ = 4.779, η^2 = 0.098, $p < 0.05$) and exercise were significant ($F_{(1,44)}$ = 7.183, η^2 = 0.140, $p < 0.05$), showing that the peak knee power of the middle-aged group (4.89 W/kg) was significantly higher than that of the elderly group (3.92 W/kg) and that the peak knee power of the TCG (5.00 W/kg) was also significantly higher than that of the HG (3.81 W/kg).

In terms of peak ankle moment, the main effect of age was not significant, and that of exercise was significant ($F_{(1,44)}$ = 4.254, η^2 = 0.088, $p < 0.05$), showing that the peak ankle moment of the TCG (1.34 N-m/k/kg) was significantly higher than that of the HG (1.24 N-m/kg). In terms of peak ankle power, the main effects of age ($F_{(1,44)}$ = 20.370, η^2 = 0.316, $p < 0.05$) and exercise were significant ($F_{(1,44)}$ = 13.603, η^2 = 0.236, $p < 0.05$), showing that the peak ankle power of the middle-aged group (9.22 W/kg) was significantly higher than that of the elderly group (7.62 w/kg) and that the peak ankle power of the TCG (9.07 W/kg) was also significantly higher than that of the HG (7.76 W/kg). All dynamics data are reported in Table 2.

Table 2. Joint dynamic during take-off phase.

	Middle-Aged		Elderly	
	TCG	**HG**	**TCG**	**HG**
Peak hip moment (N-m/kg)	−1.06 ± 0.24	−0.81 ± 0.35	−1.04 ± 0.25	−1.02 ± 0.38
Peak knee moment (N-m/kg) ◆	1.25 ± 0.22	1.08 ± 0.32	1.16 ± 0.26	0.94 ± 0.22
Peak ankle moment (N-m/kg) ◆	−1.37 ± 0.14	−1.27 ± 0.20	−1.31 ± 0.13	−1.21 ± 0.17
Peak hip power (W/kg) ◆	3.57 ± 0.72	2.44 ± 1.18	3.05 ± 0.66	2.70 ± 0.69
Peak knee power (W/kg) ▼◆	5.52 ± 1.91	4.25 ± 1.81	4.47 ± 1.11	3.37 ± 1.12
Peak ankle power (W/kg) ▼◆	9.80 ± 1.25	8.64 ± 1.18	8.35 ± 1.30	6.88 ± 1.19

Note: hip flexion was (+), hip extension was (−), knee flexion was (−), knee extension was (+), ankle dorsiflexion was (+), and ankle plantar flexion was (−). ▼ indicates a significant difference between age factor ($p < 0.05$); ◆ indicates a significant difference between exercise type factor ($p < 0.05$).

4. Discussion

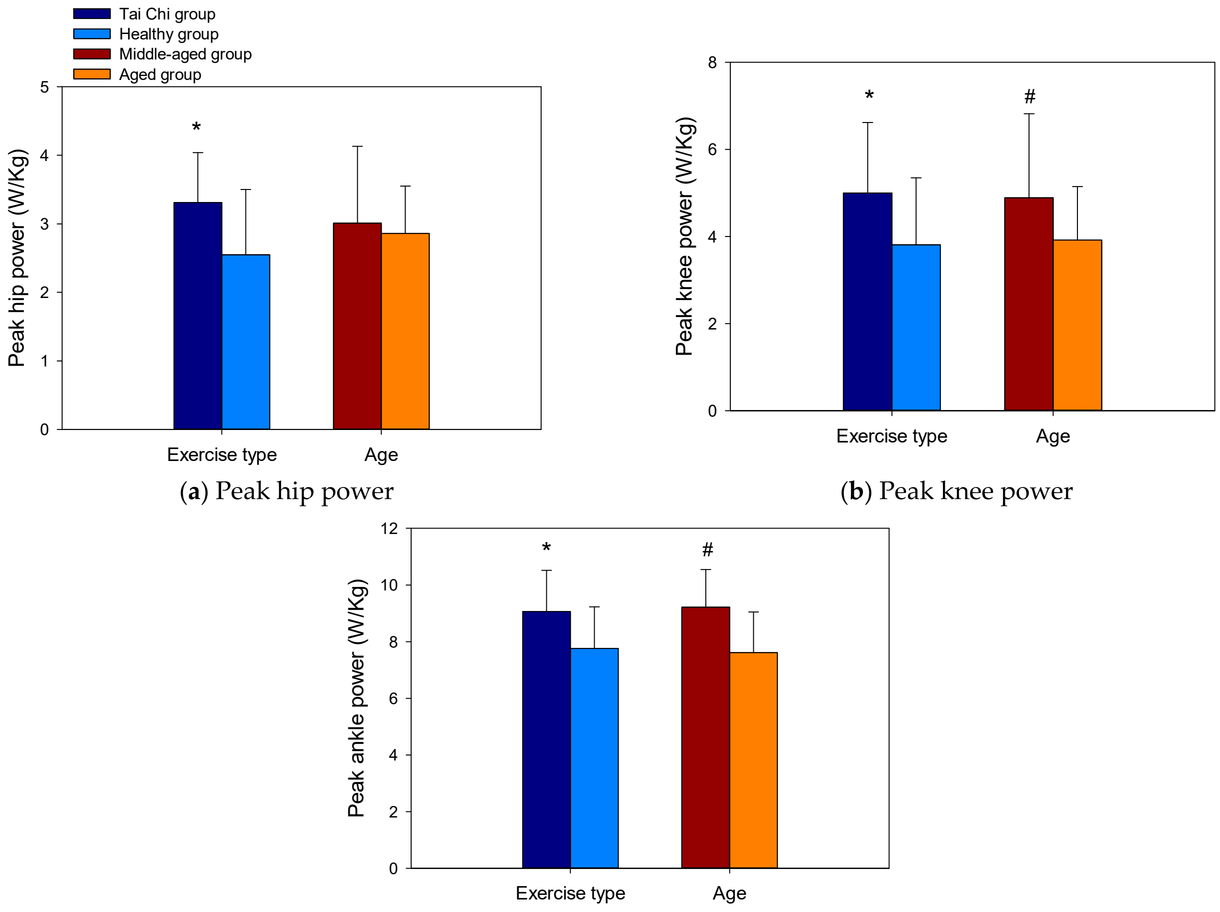
There was no interaction observed in the present results. It showed that there may be no interaction between age factor and exercise type factor. Age factor and exercise type factor were discussed using the main effect. Therefore, the two factors could only be discussed separately.

4.1. Effects of Age Factor on Kinematics and Dynamics of Lower Limbs

The results showed that the jump height of the elderly group was 26.67% lower than that of the middle-aged group. Performance in the countermovement jump decreased due to the age factor. Previous studies also showed that a decline in lower-limb muscle capacity due to the age factor reduces performance in the countermovement jump [25].

Regarding age factor, this study showed that compared with the middle-aged group, the elderly group had a lower peak vertical velocity of 6.47% and the instantaneous $velocity_{takeoff}$ declined by 11.86%. This result showed that the peak vertical velocity and the instantaneous $velocity_{takeoff}$ may have been lower due to age increase. The peak vertical velocity and instantaneous $velocity_{takeoff}$ were related to the sum of the angular velocities of the hip, knee and ankle during the countermovement jump. The peak knee and ankle angular velocities of the elderly group in this experiment were 8.06% and 8.25% lower than those of the middle-aged group, respectively. DeVita and Hortobagyi [4] pointed out that younger individuals exhibit more knee and ankle joint activity during walking. In comparison, the middle-aged group in this study had relatively high peak angular velocities of the knee and ankle joints, indicating that elderly people may have a lower angular velocity due to age increase.

Ststead et al. [26] pointed out that lower-limb power also decreases with age, and this result was similar to the age factor results in this study. The peak knee and ankle power values of the elderly group were 19.84% and 17.35% lower than those of the middle-aged group, respectively (Figure 1). During the take-off phase, the knee joint stretches and the ankle joint plantar flexes. Therefore, take-off requires extension power of the knee joint and plantarflexion power of the ankle joint. Many studies suggested that the plantarflexion power of the ankle joint decreases with age [5,27,28]. Izquierdo et al. [29] also pointed out that the power of the lower limbs decreases sharply with age. Therefore, in the elderly group, the peak knee and ankle joint power may have declined due to age increase. This may also be the main reason why the elderly group had a lower jump height than the middle-aged group.



(**a**) Peak hip power (**b**) Peak knee power (**c**) Peak ankle power

Figure 1. Peak hip, knee and ankle power. Note: * indicates a significant difference between age factor. # indicates a significant difference between exercise type factor.

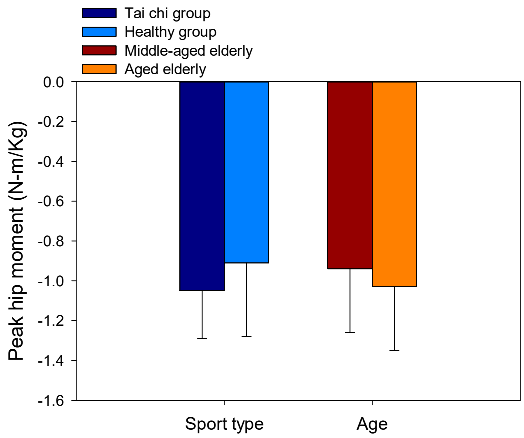
4.2. Effects of Long-Term Tai Chi Practice on Kinematics and Dynamics of Lower Limbs

In this study, we statistically analysed exercise type factor and found that the TCG had a 60% higher jumping ability than the HG. Past studies also showed that participants who have practiced Tai Chi for a long time have a better jump height in the countermovement jump [23]. The results showed that TCG has better jumping ability than HG.

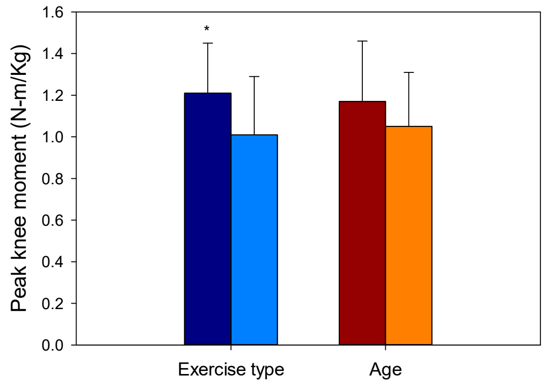
The results of this study also showed that the peak vertical velocity and the instantaneous $velocity_{takeoff}$ of the TCG increased by 13.74% and 22.67%, respectively, compared with those of the HG. Moreover, the TCG had 6.81%, 20.20% and 15.25% larger values for peak hip, knee and ankle angular velocity than the HG. This was the main reason that the TCG had a faster peak vertical velocity and instantaneous $velocity_{takeoff}$.

McMahon et al. [30] also pointed out that a higher jump height in the countermovement jump is caused by faster stretching velocities of the hip, knee and ankle during the take-off phase. The presence of a large angular velocity of the lower-limb joint indicates that the subject likely had a fast take-off velocity. This result showed that the TCG may have exhibited a better lower-limb ability because they long-term practiced Tai Chi.

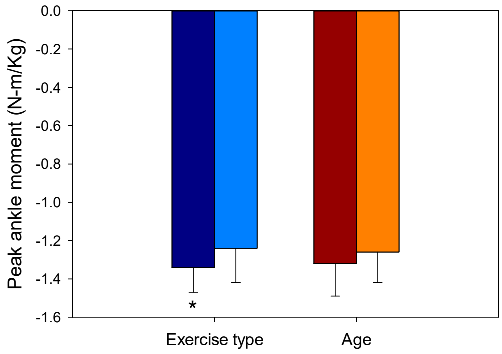
The TCG showed higher peak knee (19.80%) and ankle (8.06%) joint moments (Figure 2) and peak hip (29.80%), knee (31.23%) and ankle (16.88%) joint power (Figure 1) values than the HG. Past studies have also shown that the muscle strength and power of the lower limbs during the take-off phase of the countermovement jump are positively correlated with jump height. People may achieve a higher jump height when they generate lower-limb power [25,31]. Therefore, it can be inferred that the jump height of the TCG was higher than that of the HG due to larger peak vertical velocity and instantaneous $velocity_{takeoff}$. The faster peak vertical velocity and instantaneous $velocity_{takeoff}$ were due to the faster peak hip, knee and ankle joint angular velocities. The faster angular velocities of the lower-limb joints were attributed to the larger peak knee and ankle joint moments and peak hip, knee and ankle joint powers of the TCG. Previous studies have indicated that TCG exercisers show better knee extensor strength than low-intensity exercisers [32–34]. Therefore, the regular practice of Tai Chi can increase knee extension moment and power. The TCG had better lower-limb performance, which may have occurred because in Tai Chi individuals need to maintain a low COM position between Tai Chi punches and movements, such as squats, horse-riding stances, lunges mimicking the wild horse mane, brushing the knees and pushing, grasping the sparrow's tail, a single whip movement, the repulse monkey movement and hand waving like they are touching the clouds. This long-term training effect may have a transforming effect on the moment and power of the lower limbs during the countermovement jump. The intensity of Tai Chi can be adjusted according to an individual's physical status. For example, when an old form is practiced, more squats with a lower COM are performed. The long-term training effect of this type of action may have been reflected in the results of the TCG. Accordingly, the TCG had larger peak knee and ankle joint moments and peak hip, knee and ankle joint power values in the countermovement jump test, which may be the result of long-term Tai Chi practice.



(**a**) Peak hip moment



(**b**) Peak knee moment



(**c**) Peak ankle moment

Figure 2. Peak hip, knee and ankle moments. Note: * indicates a significant difference between age factor.

5. Conclusions

In this study, the elderly group showed more deterioration in knee and ankle power than the middle-aged group. The lower limbs exhibit functional decline, which may decrease elderly individuals' independence in ADLs and increase their risk of falls.

This study showed that participants who had practiced Tai Chi had better lower-limb power. These individuals exhibited better performance in most parameters in the squatting phase and the take-off phase, showing that Tai Chi exercises are beneficial for different age groups. In particular, the lower-limb joint moment and power of elderly individuals are important indicators for preventing falls and maintaining quality of life.

Therefore, according to the results of this study, middle-aged and elderly individuals are encouraged to regularly practice Tai Chi exercises. Tai Chi is expected to slow the functional decline in the lower limbs due to ageing and reduce the risk of falls.

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Informed Consent Statement: All subjects signed a subject informed consent form.

Conflicts of Interest: The authors declare no conflict of interest.

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