

Tai Chi exercises with multi-parameter balance feedback enhance recovery in athletes after orthopedic injuries: A case study

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Abstract:

Purpose: This study aimed to examine the impact of a Tai Chi exercise regimen on the dynamic balance and kinematic parameters of a taekwondo athlete with functional instability of the tibiofemoral joint. **Methods:** The Tai Chi training program, comprising eight techniques and five steps, was introduced during the late rehabilitation phase for a taekwondo athlete recovering from a tibiofemoral joint injury. This program aimed to restore the athlete's body balance by incorporating Tai Chi exercises tailored to the biomechanical movement patterns specific to Taekwondo. The athlete's balance was assessed using the BTrackS electronic balance assessment platform, which enables the evaluation of body balance in various positions, including standing on different legs. It also allows for the assessment of the stability of different body parts, including various segments of the body axis. This approach is particularly appropriate for taekwondo athletes, who frequently shift from one leg to another during fights and must maintain balance in various positions, such as on one leg, on both legs, and in a bent position. **Results:** The late stage of rehabilitation spanned nine weeks, during which the principles of Tai Chi, encompassing eight movements and five steps, were implemented. This led to considerable improvements across all balance parameters assessed using the BTS electronic platform, including weight distribution, sensory integration, body stability limits, neck challenges, center of gravity shifts, and single-leg standing test scores. The research findings demonstrate that a carefully selected combination of Tai Chi exercises can enhance athletes' balance control, making it a valuable addition to routine training programs. **Conclusion:** The Tai Chi exercise program, combined with multiparametric balance feedback, serves as an effective alternative therapy for promoting balance recovery after orthopedic injuries or blunt traumatic brain injuries.

Keywords: Tai Chi, techniques, Taekwondo, joint instability, multiparametric assessment, balance platform, rehabilitation

Introduction

The widespread adoption of Tai Chi system exercises has extended their application to rehabilitation, with numerous researchers referencing this method in their studies (Kao et al., 2019). Various studies employing different methodologies have been performed to assess the beneficial effects of Tai Chi on human physical and mental functions. Ankle sprains are among the most common sports injuries, often leading to chronic ankle instability in a large proportion of athletes with a history of recurrent sprains (De Vries et al., 2011). This instability is associated with reduced muscle strength and impaired postural control. Traditional management strategies for chronic ankle instability include balance training, joint mobilization, resistance training, passive calf stretching, and the use of orthotics (Kosik et al., 2019). Among these, balance training has proven to be the most effective, demonstrating a high rate of functional improvement in injured athletes (O'Driscoll & Delahunt, 2011). Evidence from various systematic reviews (Mollà-Casanova et al., 2021; Chen et al., 2020) highlights the efficacy of balance training in addressing sensorimotor deficits in athletes with chronic ankle instability.

Taekwondo is one of the most popular martial arts and a contact sport where athletes strike their opponents with great force and speed using their feet and hands, adhering to the rules of the discipline. Matches for adult athletes consist of two 2-min rounds, separated by a 1-min rest interval. The dynamic techniques of Taekwondo, such as double and twist kicks, present a constant risk of injury to athletes, both during training (particularly in sparring) and in competition (Pan et al., 2018; Yao et al., 2021). Research evidence shows that 54% of injuries occur during competitions, while 36% are associated with training incidents (Saglam et al., 2019; Petrosyan, 2014). The majority of injuries affect the lower extremities (46.5%), followed by the upper extremities (18%), with the remaining injuries involving the back (10%) and head (3.6%) (Altinkök et al., 2021; Andreu-Caravaca et al., 2021).

Given these findings, numerous researchers have investigated the characteristics of injuries occurring during taekwondo training and competitions (Nilgün, 2018; Kang & Kim, 2019; Jing et al., 2021). The injury rate in Taekwondo is considered lower than in some sports, such as mixed martial arts, but higher than in others, including karate, aikido, kung fu, football, hockey, and basketball (Yeh et al., 2020). Consequently, it is crucial to identify the specific characteristics of injuries—such as type, affected body part, and mechanism—as well as the associated risk factors, including age, body weight, and sports experience. This knowledge is essential for developing effective models for trauma prevention in Taekwondo.

Injury rates in Taekwondo also vary considerably between countries. For instance, Greek taekwondo athletes report the lowest injury rates compared to their counterparts in the United States, Europe, Canada, Australia, the United Kingdom, and Turkey (Liu et al., 2018). These differences may be attributed to factors such as the athletes' level of sports experience, mastery, quality of training, adherence to safety regulations, and overall athletic performance.

Studies have shown that individuals trained in Tai Chi perform better on vestibular tests assessing sensory organization, relying primarily on their vestibular system during stances. Balance function is heavily dependent on inputs from the visual, somatosensory, and vestibular systems (Tsang & Hui-Chan, 2004). Tai Chi training focuses on the active reproduction of joint positions and movement directions, which likely enhances practitioners' ability to accurately reproduce ankle joint angles—an essential component of the proprioceptive system and balance control. Enhanced proprioception through Tai Chi exercises directly contributes to substantial improvements in balance.

A variety of standard rating scales are currently used to assess the balance of patients with neurological conditions and musculoskeletal injuries in rehabilitation settings. However, these scales offer limited insights into the potential underlying mechanisms of balance disturbances (Alghadir et al., 2018), highlighting the need for a more quantitative approach to evaluate standing balance. Balance platforms utilizing advanced technologies provide objective measurements of subtle changes in postural control, allowing for accurate targeting of the underlying causes during therapy (Sonobe & Inoue, 2023).

The aim of this study was to investigate the effect of a Tai Chi exercise regimen combined with multi-parameter balance feedback on the balance recovery of a taekwondo athlete.

Materials and methods

This case study describes the rehabilitation of a 15-year-old athlete, S.M., who sustained an injury in September 2023—a tear of the lateral ligament of the tibiofemoral joint. After the injury, S.M. received treatment at a clinic, including surgery and post-operative physiotherapy. The rehabilitation process was divided into three stages. The first stage, performed immediately after surgery, focused on stabilizing the patient's condition. During this period, isometric stretching of the lower limb muscles, passive and active range-of-motion exercises for the joints, and proprioceptive stimulation techniques were implemented. The primary objective of physical rehabilitation during the second (intermediate) or post-hospital phase was to restore movement in the tibiofemoral joint and enhance joint stability. During this stage, the athlete attended an outpatient rehabilitation center before progressing to the late rehabilitation phase at the athletic medical facility of the taekwondo national team. The 8-week intervention program at the athletic medical facility focused primarily on plyometric exercises, performed twice a week for 1 h per session. The plyometric exercises involved jumping in various directions, with or without stepping, and single or double-leg jumps. These exercises were performed in three sets of eight repetitions, aiming to enhance proprioceptive sensitivity. The athlete performed foot repositioning exercises (passive flexion of the tibiofemoral joint) in the supine position without visual control.

A key objective during the late phase of rehabilitation was to restore the taekwondo athlete's ability to maintain body stability, which is closely linked to the stability of the injured ankle joint and is crucial for striking (often with one leg) and defending during taekwondo matches. The athlete performed a series of exercises taken from the Tai Chi system, both independently and in collaboration with a training partner as part of active sparring.

The training program was performed over nine weeks, with sessions on Mondays, Wednesdays, and Fridays. Each session consisted of three parts: a warm-up, the main training, and a final relaxation phase. The first week served as a preparatory phase, focusing on mastering the general principles and content of the rehabilitation training, which included the eight methods and five steps. This ensured that, after the initial testing, the athletes could independently perform all the movements and complete the full exercise routine. Weeks 2–8 focused on the actual training program, during which athletes practiced the eight Tai Chi methods and the principles of the five steps.

Of the eight techniques and five movements in Tai Chi, the eight refer to distinct strength techniques, while the five correspond to specific footwork patterns:

1. Peng (defense): The palm of the hand moves forward along a bottom-up trajectory to execute a defensive action.
2. LV (repulsion): The athlete uses body strength to bend the opponent's arm, redirecting the force to prevent falling from the impact.
3. Ji (push): The entire body applies external force to control the opponent's pushing hand.

4. An (pressure): Rapid, strong pressure is applied to the opponent's body, typically with the palm or fingers.
5. Cai (grip): The power of both hands is used to redirect the opponent's push.
6. Lie (separation): The opponent's hand is twisted, and the athlete steps toward the opponent's back.
7. Zhu (elbow strike): An elbow strike is performed using the body's inertia.
8. Khao (body blow): The athlete jumps forward and strikes the opponent with their entire body.
9. Jin (forward): A step forward
10. Tu (retreat): A step backward
11. Gu (bending left): The head turns to the left.
12. Pan (bend right): The head turns to the right.
13. Deen (central balance): A stable standing position.

A basic Tai Chi exercise program can be structured using various combinations of the abovementioned movements. The athlete's balance was assessed using the BTrackS electronic balance assessment platform (BTS USA), which has been approved by the US Food and Drug Administration. The platform's validity and reliability have been confirmed through numerous clinical studies (Lavretsky et al., 2022; Goble et al., 2019A; Goble et al., 2019B).

We specifically chose this system because it enables the assessment of body balance in various positions, including standing on different legs, and evaluates the stability of different body parts, including segments of the body axis. This makes it highly suitable for assessing taekwondo athletes because they frequently transition from one leg to another during a fight and must maintain balance in various positions: on one leg, on both legs, and in a bent position.

The BTS system first shows the distribution of body weight across both legs, then separately for the right and left feet, as well as in the anteroposterior direction. The pressure distribution across different parts of the platform is represented by corresponding percentages. By analyzing these numerical values, the software includes a mathematical prediction model that estimates the body's center of gravity.

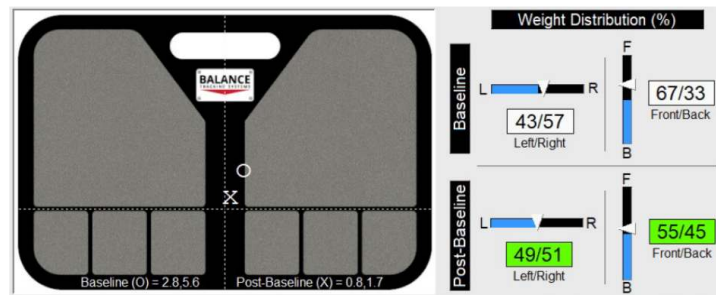


Figure 1. Evaluation of weight distribution

The test performed in sensory integration and balance mode evaluates how the influx of sensory input influences the body's postural control. The first test is performed with the eyes open and standing on both feet on the platform. The second test is performed with the eyes closed. The third test is performed with the eyes open while standing on a sponge layer on the platform, and the fourth test is performed with the eyes closed on the sponge surface. These four tests evaluate the impact of proprioception, vision, and balance on the body's ability to maintain stability.

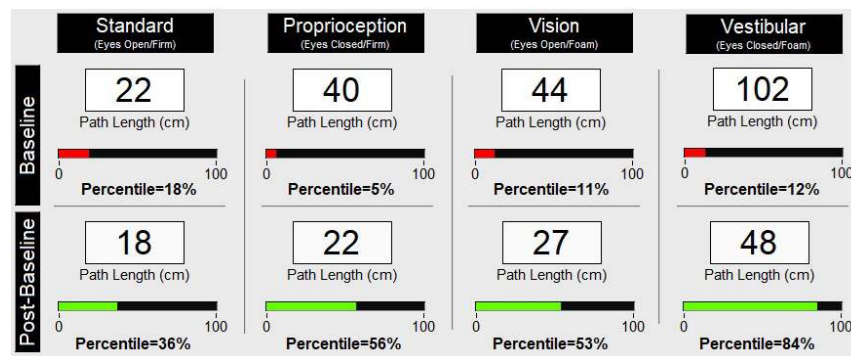


Figure 2. Sensory integration assessment using four tests

The body stability limit test evaluates the functional support surface. In this test, the examinee stands at the center of the BTS platform and gradually bends the body forward, backward, and to the right and left. Data are recorded for the total contact surface, as well as for the front, back, right, and left quadrants.

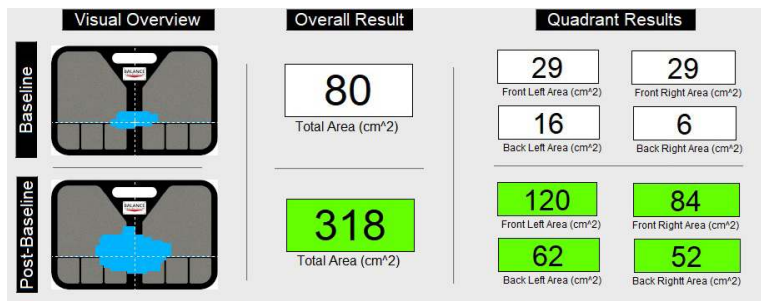


Figure 3. Assessment of body stability limits

The neck challenge test evaluates body stability while the head is held in various positions. Typically, ten different positions are used, and the results are compared to the values recorded in the neutral head position.

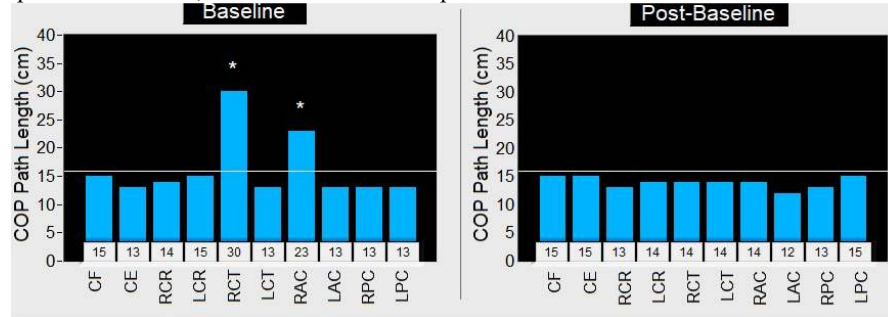


Figure 4. Cervical challenge test

The body's stability under different neck challenges is evaluated based on the center of gravity, as clearly shown in Figure 5.

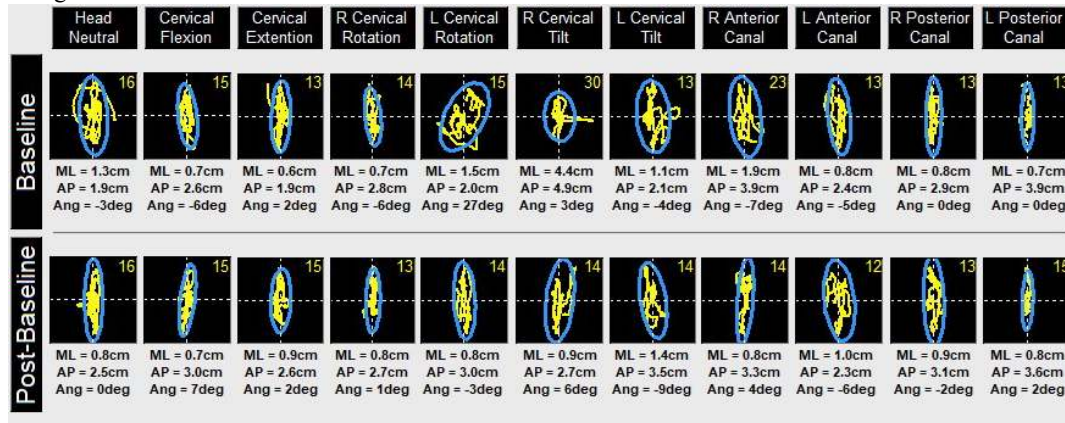


Figure 5. Changes in the body's center of gravity owing to the "cervical challenge test"

BTrackS also measures body stability while standing on one leg, comparing the amount of body sway on the right and left legs. The test is repeated twice for each leg, and a "symmetry index" is then calculated. Results are considered in the normal range if the difference in sway between the two legs does not exceed 15%.

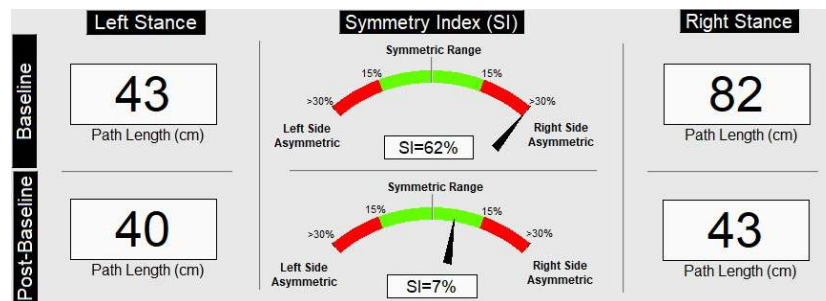
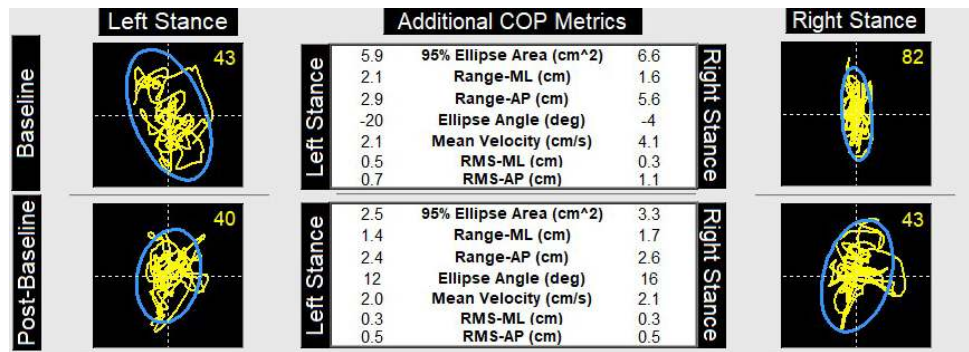


Figure 6. Evaluation of the single-leg stance test



The body's center of gravity is located inside the blue ellipse at the intersection of the two axes.

Figure 7. Evaluation of body stability in single-leg stance based on the body center of gravity

Results

The exercise training program used in this study was entirely based on Tai Chi exercises, which helped normalize the taekwondo athlete's balance and improve the kinematic data of his lower limbs and spatiotemporal parameters during the late phase of rehabilitation following a tibiofemoral injury. After completing the nine-week training program, nearly all recorded indicators showed improvement (Figures 8–13). All data presented in the tables of assessed parameters were obtained from the BTS software program.

DATE	L/R	F/B	COPx	COPy	NOTE
1/8/2024 3:20:10 PM	46/54	63/37	3.0	4.5	Wk 1 Follow-up
3/2/2024 4:24:24 PM	45/55	63/37	2.2	4.5	Wk 4 Follow-up
4/1/2024 2:27:11 PM	48/52	61/39	1.1	3.5	Wk 8 Follow-up
4/28/2024 3:37:54 PM	49/51	58/42	0.4	2.5	Wk 12 Follow-up
5/2/2024 3:41:18 PM	50/50	56/44	0.0	1.8	Wk 16 Follow-up

Figure 8. Center of gravity distribution

DATE	STD	%	PRO	%	VIS	%	VES	%	COMP	%	NOTE
1/8/2024 15:20	23	14	39	7	44	11	78	28	184	12	Wk 1 Follow-up
3/2/2024 16:24	20	26	36	10	40	15	70	41	166	22	Wk 4 Follow-up
4/1/2024 14:27	18	36	33	15	34	29	60	62	145	37	Wk 8 Follow-up
4/28/2024 15:37	19	31	28	31	30	43	55	71	132	52	Wk 12 Follow-up
5/2/2024 15:41	19	31	23	52	25	61	52	76	119	66	Wk 16 Follow-up

Figure 9. Sensory integration

DATE	FL	BL	BR	FR	TOTAL	NOTE
1/8/2024 3:20:10 PM	24	45	20	22	111	Wk 1 Follow-up
3/2/2024 4:24:24 PM	55	25	27	48	155	Wk 4 Follow-up
5/2/2024 3:41:18 PM	81	35	30	84	230	Wk 16 Follow-up

Figure 10. Limits of body stability

DATE	NEU	CF	CE	RCR	LCR	RCT	LCT	RAC	LAC	RPC	LPC	NOTE
3/2/2024 4:24:24 PM	16	15	15	13	14	14	14	14	12	13	15	Post 4 week intervention

Figure 11. Neck challenges

DATE	LP	RP	LA	RA	Diff	SI	SYM	SIDE	NOTE
1/8/2024 3:20:10 PM	44	78	43	75	-32	54	NO	RIGHT	Wk 1 Follow-up
3/2/2024 4:24:24 PM	44	61	40	53	-13	28	NO	RIGHT	Wk 4 Follow-up
5/2/2024 3:41:18 PM	44	42	40	43	-3	7	YES		Wk 16 Follow-up

Figure 12. Assessment of body stability in single-leg stance

TRIAL NAME	DUR	PL	COPx	COPy	RG-ML	RG-AP	ELL	MAJ	MIN	DIS-max	DIS-avg
1. Upright Standing	5	9.0	0.3	-0.5	0.9	1.6	1.8	2.5	0.9	1.0	0.5
2. Quarter Squat	5	12.0	0.3	1.3	1.1	2.3	2.6	2.7	1.2	1.4	0.5
3. Half Squat	5	15.0	0.9	1.5	0.7	3.5	2.6	4.1	0.8	1.8	0.7
4. Full Squat	5	19.0	0.2	1.8	1.5	4.0	5.8	4.9	1.5	2.2	0.9

Figure 13. Results of pre- and post-training squat test assessment

Discussion

The primary goal of the study was to examine the impact of Tai Chi training on the balance parameters of an athlete undergoing rehabilitation following an ankle joint injury. Multiparametric balance assessment is crucial because body balance refers to the ability to maintain bodily movement (Thiamwong et al., 2023; Kittipong Pengsri et al., 2024; Avagyan et al., 2021), relying on visual input, vestibular sensory information, and proprioceptive input. The single-leg stance is a key outcome measure in physical rehabilitation because it enhances postural balance during both training and competition (Donal Syafrianto et al., 2023). In our study, the taekwondo athlete demonstrated improved outcomes across all assessment types measured by the BTS system in response to Tai Chi training (Figures 8–13). The improved center of pressure during single or double-leg stances on the supporting foot (feet) helps minimize the center of gravity in the support area, positively impacting overall body balance. Taekwondo athletes, as well as those in other martial arts, must improve—or at least stabilize—the anteroposterior displacement of the center of pressure because this can negatively affect body balance. The balance platform training was combined with proprioceptive and plyometric exercises to improve the athlete's balance skills (Tigran Petrosyan et al., 2021; Donal Syafrianto et al., 2023; Tigran Petrosyan et al., 2024). Numerous biomechanical factors influence balance control in taekwondo and other martial arts. According to the concept of static stability, a larger support surface is generally more stable than a narrower support area (Joseph P. Carzoli & Roger M. Enoke, 2023). The inner support area of the foot is narrower than the outer support area, which is limited by the foot arch. If a shift occurs toward the outer side rather than the inner side, it may enhance stability by providing better physical control. In our study, the cervical challenges consisted of various testing movements focused on body balance, aimed at stabilizing the center of mass at the lower part of the body. According to the principle of static stability, the center of mass at the "bottom" contributes to better body stability (Petrosyan, 2013; Petrosyan et al., 2021). This concept reinforces the idea that strengthening the lower extremity muscles can enhance the stability of the center of mass, a goal that can be achieved through specific Tai Chi exercises.

After Tai Chi training, the taekwondo athlete showed improved extensor muscle strength, which contributed to better balance, coordination, and increased kicking force. To generate maximum power in a kick, both the knee and hip joints must be extended, requiring the activation of the knee and hip extensor muscles (Noor Izzati Azhar et al., 2023). Adolescent athletes, who are still growing, must continue to strengthen their extensor muscles (A. Fogliata et al., 2023), even though the strength of the extensor muscles in the knee joint can vary during the growth period. A taekwondo athlete must have the proper skills to execute rapid, powerful movements to attack opponents, with lower extremity strength being the most crucial factor in performance (Aleksander Osipov et al., 2023). Tai Chi training strengthens the lower extremities, helping the athlete develop quicker side steps and improved agility, which are essential for rapid direction changes (Fong et al., 2012; Yoo et al., 2018). By improving their balance, taekwondo athletes can considerably improve their performance in various aspects of the sport.

Conclusions

The Tai Chi (eight techniques and five steps) training program used in this study was implemented during the third phase of physical rehabilitation for a taekwondo athlete with a tibiofemoral joint injury. The program aimed to restore body balance by adapting Tai Chi exercises to the biomechanical characteristics of movements in Taekwondo. The rehabilitation phase lasted nine weeks, during which the principles of Tai Chi's eight movements and five steps were applied. This led to improvements in all balance indicators assessed by the BTS electronic platform, including weight distribution, sensory integration, body stability limits, neck challenges, center of gravity changes, and single-leg standing test values. Research results showed that a carefully selected combination of Tai Chi exercises could improve athletes' balance control, making the method suitable for regular training. The multiparametric balance assessment provides valuable feedback for athletic training. Balance training, when combined with Tai Chi exercises that actively replicate joint positions and movement directions used in Taekwondo, improves proprioception, leading to considerable balance improvements. The integration of Tai Chi exercises with multiparametric balance feedback offers an effective alternative therapeutic approach for ensuring timely balance recovery after orthopedic or blunt traumatic brain injuries.

Conflicts of interest - The authors declare no conflicts of interest.

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