

Effects of Kinesio Taping on Landing Strategies During Unanticipated Multidirectional Jumping in Individuals with Ankle Instability

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Abstract

Objective: To investigate the effects of Kinesio tape (KT) on lower limb biomechanics during unanticipated multidirectional jump-landing tasks in individuals with chronic ankle instability (CAI) and healthy controls. **Methods:** Fifteen male CAI patients and fifteen healthy males were recruited. Participants performed forward, lateral, and diagonal jumps under both no-KT and KT conditions. Data were collected synchronously using motion capture and force plate systems. **Results:** Under the condition of consistent jump height, KT significantly optimized the landing strategy of CAI patients. In lateral and diagonal jumps, peak vertical ground reaction force and loading rate showed a decreasing trend, and the time proportion to reach peak force was more favorable, indicating prolonged shock absorption time. Joint moment results revealed direction-dependent biomechanical adaptations. After taping, CAI patients showed a significant reduction in ankle inversion/eversion moments, accompanied by compensatory increases in hip and knee moments in the coronal plane. In contrast, health controls generally exhibited reduced joint moments. This adaptive pattern suggests that KT does not merely provide simple mechanical support but enhances proprioceptive input, helping CAI patients overcome movement inhibition. The effect was most pronounced during lateral jumps, which placed the greatest challenge on lateral ankle stability. **Conclusion:** The primary effect of KT on CAI patients is direction-specific motor pattern modulation, with its effectiveness precisely matching the demands of movement direction on ankle stability. Moreover, KT can guide CAI patients from a fear-driven rigid strategy to a sensation-guided coordinated strategy while maintaining motor output. This demonstrates that KT can serve as an effective intervention tool, providing critical evidence for risk-based precision rehabilitation.

Keywords

Chronic ankle instability, Kinesio tape, Jump landing, Unanticipated multidirectional jumping

Introduction

Chronic ankle instability (CAI), as one of the most common chronic sports injuries in sports medicine, has a pathological mechanism evolving from early mechanical instability to a multidimensional impairment integrating neuromuscular control deficits, proprioceptive disorders, and Kinesiophobia. In sports, unanticipated landing actions are considered a primary maneuver inducing recurrent ankle sprains, with jumping tasks involving lateral forces and multiplanar control being particularly hazardous. Existing research has confirmed that compared to forward jumps, diagonal and lateral jumps pose more severe biomechanical challenges for CAI patients. Revealing that while the joint system of CAI patients retains basic motor capacity, tasks involving

multiplanar control and unexpected loading lead to decreased dynamic stability and aberrant movement adaptations [1].

Currently, external interventions such as rigid taping, elastic taping, and braces are commonly used to improve dysfunction. Among these, Kinesio tape (KT), as a widely applied intervention in clinical and sports practice, can not only enhance proprioceptive input and optimize neuromuscular feedback control through cutaneous sensory pathways but also modulate muscle tone and neuromuscular control strategies through mechanical guidance [2]. Additionally, it can reduce inhibitory responses related to kinesiophobia by providing psychological reassurance regarding joint stability.

However, existing studies are mostly limited to single-plane, low-risk tasks and often assume participants can maintain a stable motor output level, neglecting the modulating effect of task threat level on intervention outcomes. In high-risk, multiplanar jumps, neurobehavioral inhibition induced by fear of re-injury may significantly influence the biomechanical effects of KT, potentially leading to a paradoxical presentation where strategy optimization coexists with movement inhibition. Hou et al., by investigating the effects of different anticipation conditions on CAI patients, found that unanticipated jumps place the ankle joint of CAI patients in an open, vulnerable position, and CAI patients may stabilize the ankle through proximal compensation [3]. Lin et al., studying lower limb biomechanics and laterality during repetitive vertical jumps in CAI patients, concluded that biomechanical characteristics under different states need consideration when formulating rehabilitation plans for CAI patients [4]. Regarding indicator selection, current research often focuses on joint position and load, neglecting sensitive indicators reflecting neural control and injury risk. In terms of task design, there is a lack of systematic comparison of the gradient risk effects among forward, lateral, and diagonal jumps, failing to confirm the task-specificity of KT effects. Theoretically, a unified analytical framework incorporating both motor performance and landing safety is absent, leaving it unclear whether CAI patients, after using KT, land more safely while maintaining performance or reduce performance due to fear.

Therefore, this study aims to systematically investigate the task-dependent modulating effects of KT on the biomechanical strategies of CAI patients through a multidirectional unanticipated jumping experiment, and to comprehensively evaluate the balancing effect of KT between maintaining motor performance and optimizing landing safety. The research hypotheses are: (1) The effect of KT exhibits significant task specificity, manifesting primarily as biomechanical optimization in low-risk forward jumps, but potentially presenting a complex pattern of both biomechanical improvement and motor performance inhibition in high-risk lateral jumps. (2) The mechanism of KT is not simply to restrict joint movement, but to facilitate patients' adaptive transition towards a biomechanically safer landing strategy while preserving task performance.

Methods

Subjects

G*Power 3.1.9 software was used to estimate the required sample size for this study, based on previous research and the statistical methods employed. The power, type I error rate α , and effect size were set at 0.95, 0.05, and 0.25, respectively, calculating a minimum required sample size of 24 participants [5]. Considering a 20% rate of invalid samples, the final minimum sample size was determined to be 29 participants. According to the diagnostic criteria for ankle instability established by the International Ankle Consortium, 15 male participants with ankle instability were recruited from Dalian University of Technology. They were assigned to the CAI group based on their Cumberland Ankle Instability Tool (CAIT) scores. A healthy control group of 15 male participants with no history of ankle injury, matched for age, height, and body mass to the CAI group, was also recruited. All participants were informed of the testing procedures and provided written informed consent before the experiment. There were no significant differences in the basic characteristics between the groups ($P > 0.05$), as shown in Table 1.

Table 1. Basic information on subjects.

Parameter	CAI group	Control group
Age (years)	22.8±1.9	23.5±1.3
Height (cm)	181.0±6.0	179.5±6.7
BMI (kg/m ²)	23.8±3.5	22.9±1.8
CAIT Score	19.3±3.1	29.4±2.3
Affected side	Left	/

Inclusion criteria for the CAI group were: (1) At least one significant lateral ankle sprain within the past year, accompanied by a sensation of instability. (2) CAIT score ≤ 24 [6]. (3) No other severe lower limb injuries, except for ankle sprains. (4) No use of interventions such as taping or bracing during sports activities. Exclusion criteria for the CAI group were: (1) Surgery, fracture, or acute musculoskeletal injury to a lower limb joint within the past 3 months. (2) Other ankle or foot pathologies. (3) Known allergy to KT.

Inclusion criteria for the health control group were: (1) CAIT score ≥ 28 . (2) Matched to CAI group participants based on morphological parameters like age, height, body mass, as well as years of sports participation and type of sports. Exclusion criteria for the health control

group were: (1) CAIT score <28. (2) History of surgery affecting the musculoskeletal structure of the lower limbs.

Experimental instruments

A Vicon three-dimensional motion capture system (Vicon V5, Oxford Metrics, UK) equipped with 8 infrared cameras was used, with a sampling frequency of 100 Hz. Marker placement followed the Plug-in Gait Lower Body model, including key anatomical landmarks on the pelvis and lower limbs, to reconstruct the three-dimensional skeletal movement system. Simultaneously, two Advanced Mechanical Technology, Inc. (AMTI) three-dimensional force platforms were used to collect ground reaction forces at a sampling frequency of 1,000 Hz. The force platforms were embedded in the laboratory floor and synchronized with the motion capture system for subsequent kinetic analysis and inverse dynamics modeling.

Experimental procedure

After completing a 10-minute standardized warm-up, participants changed into form-fitting athletic tops, shorts, and identical test shoes to eliminate variations in clothing and footwear. Sixteen 14-mm retro-reflective markers were then placed on key bony landmarks of the lower limbs according to the Vicon motion capture protocol, ensuring accurate tracking of joint trajectories during movement.

The formal test included two phases: pre-taping and post-taping. In the pre-taping phase, participants performed 9 unanticipated jump-landing tasks (3 forward, 3 laterals, 3 diagonal) from each of two starting positions (A and B) located 70 cm from the force plates, resulting in 18 jumps total (see Figure 1). During each jump, participants kept their hands on their hips, looked forward, took off using their affected (or matched) limb, landed with both feet centered on the force plate, and held a stable landing posture for 2-3 seconds. Jump directions were randomly signaled by a color-changing screen in front (red for forward, blue for lateral, yellow for diagonal), and participants were instructed to jump as high and react as quickly as possible.

Kinematic data were collected by the Vicon motion capture system, and kinetic data were recorded by AMTI force plates. Nine technically successful trials (without marker dropout, improper foot placement, or unstable posture) were selected as the pre-taping baseline for subsequent analysis.

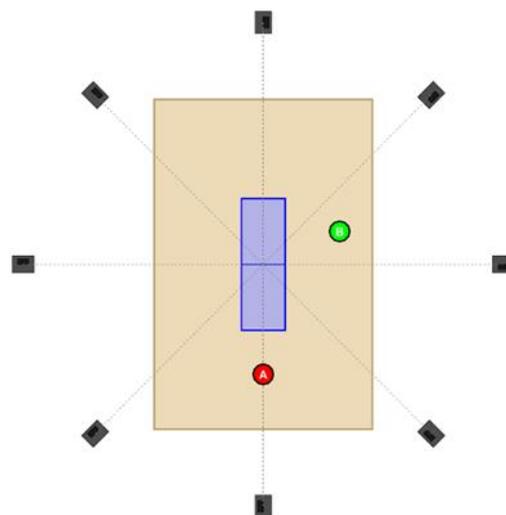


Figure 1. Laboratory layout diagram.

Subsequently, the KT intervention was applied. Waterproof, elastic, breathable tape with a 1.8x stretch capacity was used. A single trained sports medicine practitioner applied the tape to the affected side of the experimental group and the dominant side of the control group. First, the participant's skin was cleaned to remove oil and impurities. The KT was then cut into 30 cm strips. During application, the participant lay supine with the lower limb extended and the ankle maintained in a neutral position, as illustrated in Figure 2.



Figure 2. Schematic diagram of kinesiology tape application.

Step 1: The base of the first strip was fixed without tension on the medial ankle, and the end was fixed without tension on the lateral ankle. The middle section was applied with 75% tension, extending under the foot, turning at the lateral malleolus, passing behind the heel, and continuing to the lateral ankle.

Step 2: The base of the second strip was fixed without

tension just below the lateral ankle, and the end was fixed without tension on the dorsum of the foot. The middle section was applied with 75% tension, extending around the heel, passing behind the medial malleolus, and continuing to the dorsum of the foot.

Step 3: The base of the third strip was fixed without tension just below the medial ankle, and the end was fixed without tension on the dorsum of the foot. The middle section was applied with 75% tension, extending around the heel, passing the lateral malleolus, circling the midfoot, and finally extending to the dorsum of the foot. After taping, participants completed another 18 unanticipated jump-landing trials following the same procedure. Kinematic and kinetic data were collected post-taping, and 9 successful trials were selected for subsequent analysis. All participants underwent the no-tape and tape conditions in a random order to control effects. After the experiment, equipment and data were organized for analysis.

Experimental indicators

Based on the participant trajectory data collected by the Vicon system and ground reaction force data from the AMTI force plates, the following indicators were selected: Jump height was used as the core outcome measure of motor performance. Kinetic data, including joint moments at the hip, knee, and ankle at initial contact, were evaluated. These indicators were considered relevant to the neuromuscular system's pre-activation and postural control capabilities at movement initiation. Touchdown moment (TM) was defined as the initial instant when the vertical ground reaction force exceeded 10 N, as the landing phase is considered the period when ankle sprains are most likely to occur [7,8]. Additional indicators included the peak ground reaction force, normalized to body mass, reflecting the maximum load experienced by the body during the movement. The loading rate of the peak ground reaction force, indicating the suddenness of load application and serving as a dynamic measure of impact severity and neuromuscular control sensitivity. And the ratio of the time to reach peak ground reaction force to the total landing duration (time to peak force/landing time), reflecting the timing of force application and the effectiveness of the buffering strategy.

Statistical analysis

Statistical analysis was performed using SPSS 27.0 software. All results are presented as mean \pm standard deviation. First, all kinematic and kinetic indicators were

tested for normality (Shapiro-Wilk test) and homogeneity of variance (Levene's test). For data following a normal distribution, paired-sample t-tests were used for within-group comparisons, otherwise, the Wilcoxon signed-rank test was applied. For between-group comparisons, independent-sample t-tests were used for normally distributed data with homogeneous variance, otherwise, the Mann-Whitney U test was applied. A three-way repeated measures analysis of variance (ANOVA) was conducted with group (experimental, control) as the between-subjects factor, and taping (pre-taping, post-taping) and jump direction (forward, lateral, diagonal) as within-subjects factors. The dependent variables were the measured indicators.

The analysis focused on the three-way interaction effect of group, taping, and jump direction, as well as the two-way interaction effects of group \times taping and taping \times jump direction. When significant interaction effects were found, simple main effects analysis was performed for further investigation, with multiple comparisons corrected using Bonferroni adjustment. For data not meeting the assumptions of normality or homogeneity of variance, the Friedman test was used as a non-parametric alternative to repeated measures ANOVA. Between-group comparisons in such cases were performed using the Wilcoxon rank-sum test, with appropriate multiple comparison corrections. P-value <0.050 was considered statistically significant.

Results

Jump height

Jump height indicators in this study were normalized to body height. Jump height is in mm, and body height is in cm. A three-way repeated measures ANOVA was conducted to compare differences in jump height calculated using the heel displacement method between groups, directions, and pre/post KT application (Table 2). The results showed a main effect for direction ($p < 0.001$) and taping ($p = 0.874$); as well as two-way interaction effects for direction \times group ($p = 0.270$), taping \times group ($p = 0.017$), and direction \times taping ($p = 0.581$); and a three-way interaction effect for direction \times taping \times group ($p = 0.017$). Post-hoc comparisons revealed that for jump height calculated by heel displacement, in the experimental group both pre-taping and post-taping: forward jump $>$ diagonal jump $>$ lateral jump ($p = 0.001$, $p = 0.009$, $p = 0.720$). In the control group both

pre-taping and post-taping: forward jump > diagonal jump > lateral jump (p=0.009, p=0.078, p=0.516). To compare the differences in jump height calculated using the pelvis displacement method between the two groups in different directions before and after KT application, a three-way repeated measures ANOVA was conducted. The results showed a main effect for direction (p=0.166) and taping (p=0.711); two-way interaction effects for direction × group (p = 0.002), taping × group (p=0.212), and direction × taping (p=0.836); and a three-way interaction effect for direction × taping × group (p=0.537). Post-hoc comparisons revealed that for jump height calculated by pelvis displacement, in the experimental group both pre-taping and post-taping: forward jump > diagonal jump > lateral jump (p=0.208, p=0.692, p=0.362). In the control group both pre-taping and post-taping: diagonal jump > lateral

jump > forward jump (p=0.537, p=0.468, p=0.216). To compare the differences in the discrepancy (heel-derived height minus pelvis-derived height) between the two groups in different directions before and after KT application, a three-way repeated measures ANOVA was conducted on this difference. The results showed a main effect for direction (p<0.001) and taping (p=0.648); two-way interaction effects for direction × group (p=0.742), taping × group (p=0.030), and direction × taping (p<0.001); and a three-way interaction effect for direction × taping × group (p = 0.060). Post-hoc comparisons revealed that for this height discrepancy, the discrepancy in forward jumps was greater than in lateral jumps both pre-taping and post-taping (p=0.014, p=0.003). Furthermore, taping reduced the discrepancy in the experimental group and increased the jump height (heel-height) in the control group (p=0.151, p=0.308).

Table 2. Jump height.

Direction	Height	Pre-taping		Post-taping	
		Experimental group	Control group	Experimental group	Control group
Forward jump	Heel height	1.47±0.09	1.52±0.17*	1.44±0.12 [#]	1.58±0.18
	Pelvis height	0.46±0.17 [#]	0.65±0.22	0.43±0.15 [#]	0.68±0.27
	Difference	1.01±0.22 [#]	0.87±0.16	1.01±0.19	0.90±0.15
Lateral jump	Heel height	1.27±0.16 [#]	1.41±0.17	1.26±0.19	1.42±0.22
	Pelvis height	0.39±0.14 [#]	0.70±0.20	0.39±0.11 [#]	0.71±0.21
	Difference	0.87±0.24 [#]	0.72±0.12	0.86±0.24 [#]	0.71±0.15
Diagonal jump	Heel height	1.45±0.16*	1.52±0.16	1.39±0.19 [#]	1.57±0.24
	Pelvis height	0.41±0.15 [#]	0.73±0.23	0.40±0.10 [#]	0.71±0.25
	Difference	1.04±0.26* [#]	0.79±0.13	0.99±0.23 [#]	0.81±0.15

Note: *Significant difference within the same group pre-taping to post-taping, [#]significant difference between groups for the same jump direction.

Peak ground reaction force

Ground reaction forces in this experiment were statistically normalized to participants’ body mass. Ground reaction force (GRF) in this experiment were normalized to body mass and expressed in units of body weight (BW) (Table 3). The unit of GRF was Newton (N), and body mass was measured in kilograms (kg). To further compare the differences in peak GRF between the

two groups in different jump directions before and after taping, three-way repeated measures ANOVA were conducted. The results showed a main effect for direction (p<0.001) and taping (p=0.137); two-way interaction effects for direction × group (p = 0.028), taping × group (p=0.299), and direction × taping (p=0.987); and a three-way interaction effect for direction × taping × group (p=0.140).

Table 3. Peak ground reaction force (BW).

Direction	Pre-taping		Post-taping	
	Experimental group	Control group	Experimental group	Control group
Forward jump	29.39±7.74*	35.41±11.14*	27.60±4.26	34.41±13.27
Lateral jump	29.22±4.09* [#]	37.24±11.40*	27.52±4.30 [#]	38.09±12.48

Direction	Pre-taping		Post-taping	
	Experimental group	Control group	Experimental group	Control group
Diagonal jump	32.60±5.97	37.93±12.27*	29.84±5.92	36.94±11.52

Note: *Significant difference within the same group pre-taping to post-taping, #significant difference between groups for the same jump direction.

Loading rate

To compare peak force timing between the two groups, a three-way repeated measures ANOVA was conducted on the ratio of time to peak GRF to total landing buffer time (Table 4). The results showed a main effect for direction ($p < 0.001$) and taping ($p = 0.873$); two-way interaction

effects for direction \times group ($p = 0.266$), taping \times group ($p = 0.002$), and direction \times taping ($p = 0.135$); and a three-way interaction effect for direction \times taping \times group ($p = 0.648$). Post-hoc comparisons revealed that for the ratio of time to peak GRF to total buffer time: lateral jump > diagonal jump > forward jump.

Table 4. Ratio of time to peak GRF to buffer time (%).

	Forward jump		Lateral jump		Diagonal jump	
	Control group	Experimental group	Control group	Experimental group	Control group	Experimental group
Pre-taping	0.52±0.13#	0.31±0.16	0.67±0.12**	0.54±0.16	0.54±0.15#	0.39±0.19
Post-taping	0.50±0.14	0.38±0.20	0.60±0.16	0.56±0.16	0.52±0.17	0.41±0.22

Note: *Significant difference within the same group pre-taping to post-taping, #significant difference between groups for the same jump direction.

To compare loading rate differences between the two groups, a three-way repeated measures ANOVA was conducted on peak GRF loading rate (Table 5). The results showed a significant main effect for direction ($p < 0.001$) and taping ($p = 0.123$); two-way interaction effects for direction \times group ($p = 0.036$), taping \times group ($p = 0.192$), and direction \times taping ($p = 0.045$); and a three-way interaction effect for direction \times taping

\times group ($p = 0.529$). Post-hoc comparisons indicated that lateral jump loading rate was significantly lower than forward and diagonal jumps. Further post-hoc tests revealed: In the control group pre-taping: forward jump > lateral jump. In the experimental group pre-taping: forward jump > diagonal jump > lateral jump. In the experimental group post-taping: diagonal jump > forward jump > lateral jump.

Table 5. Loading rate (BW/s).

	Forward jump		Lateral jump		Diagonal jump	
	Control group	Experimental group	Control group	Experimental group	Control group	Experimental group
Pre-taping	259.7±111.8	368.5±223.3	180.4±69.7	164.4±48.3	259.3±151.3	289.9±116.4
Post-taping	231.7±125.7	263.0±118.3	201.7±100.1	144.7±57.4	253.4±117.0	268.0±82.1

Note: *Significant difference within the same group pre-taping to post-taping, #significant difference between groups for the same jump direction.

Joint moments at touchdown

To compare the differences in hip flexion/extension moment at touchdown across conditions between the two groups, a three-way repeated measures ANOVA was conducted (Table 6). The results showed a main effect for direction ($p < 0.001$) and taping ($p = 0.284$); significant two-way interaction effects for direction \times group

($p = 0.017$), taping \times group ($p = 0.775$), and direction \times taping ($p = 0.194$); and a three-way interaction effect for direction \times taping \times group ($p = 0.851$). Post-hoc comparisons revealed that the CAI group exhibited the smallest flexion/extension moment during all lateral jumps. In the control group: forward jump > diagonal jump > lateral jump.

Table 6. Hip joint flexion/Extension moment (N·mm/kg).

	Forward jump		Lateral jump		Diagonal jump	
	Control group	Experimental group	Control group	Experimental group	Control group	Experimental group
Pre-taping	367.7±168.5	351.0±169.8	137.5±66.9 [#]	240.7±109.8	225.4±96.1 [#]	362.6±116.7
Post-taping	397.8±151.1	398.36±162.7	131.09±47.0 [#]	236.4±104.1	229.4±98.3 [#]	358.1±146.1

Note: *Significant difference within the same group pre-taping to post-taping, [#]significant difference between groups for the same jump direction.

To compare the differences in hip adduction/abduction moment at touchdown between the two groups, a three-way repeated measures ANOVA was conducted (Table 7). The results showed a main effect for direction ($p < 0.001$) and taping ($p = 0.951$); two-way interaction effects for direction \times group ($p = 0.031$), taping \times group ($p = 0.005$), and direction \times taping ($p = 0.045$); and a three-way

interaction effect for direction \times taping \times group ($p = 0.851$). Post-hoc comparisons revealed that taping significantly decreased the adduction/abduction moment in the control group ($p = 0.034$) and tended to increase it in the cai group ($p = 0.066$). The hip adduction/abduction moment during forward jumps was the smallest in both groups pre-taping and post-taping.

Table 7. Hip joint adduction/Abduction moment (N·mm/kg).

	Forward jump		Lateral jump		Diagonal jump	
	Control group	Experimental group	Control group	Experimental group	Control group	Experimental group
Pre-taping	19.1±8.2 ^{**}	11.6±6.0	35.6±17.0	40.2±12.5	33.0±15.2	32.5±8.5
Post-taping	9.4±3.0	10.3±5.2	34.3±15.3 [#]	47.8±16.5	31.0±15.7	39.4±13.9

Note: *Significant difference within the same group pre-taping to post-taping, [#]significant difference between groups for the same jump direction.

To compare knee flexion/extension moment at touchdown between the two groups, a three-way repeated measures ANOVA was conducted (Table 8). The results showed a main effect for direction ($p < 0.001$) and taping ($p = 0.699$); two-way interaction effects for direction \times group ($p = 0.343$), taping \times group ($p = 0.006$),

and direction \times taping ($p = 0.581$); and a three-way interaction effect for direction \times taping \times group ($p = 0.192$). Post-hoc comparisons revealed that taping significantly decreased the moment in the control group ($p = 0.007$). The knee flexion/extension moment during lateral jumps was the smallest in both groups.

Table 8. Knee joint flexion/Extension moment (N·mm/kg).

	Forward jump		Lateral jump		Diagonal jump	
	Control group	Experimental group	Control group	Experimental group	Control group	Experimental group
Pre-taping	551.9±134.0	555.3±292.9	317.7±224.1	406.0±167.7	522.9±340.2	508.4±286.6
Post-taping	498.4±211.4	563.2±260.9	213.8±144.1 [#]	426.0±158.6	371.1±226.5 [#]	696.2±338.0

Note: *Significant difference within the same group pre-taping to post-taping, [#]significant difference between groups for the same jump direction.

To compare the differences in knee varus/valgus moment at touchdown between the two groups, a three-way repeated measures ANOVA was conducted (Table 9). The results showed a main effect for direction ($p < 0.001$) and taping ($p = 0.034$); two-way interaction effects for direction \times group ($p < 0.001$), taping \times group ($p = 0.003$),

and direction \times taping ($p = 0.310$); and a three-way interaction effect for direction \times taping \times group ($p = 0.114$). Post-hoc comparisons revealed that taping significantly increased the varus/valgus moment in the CAI group ($p = 0.005$). In the experimental group: lateral jump $>$ diagonal jump $>$ forward jump.

Table 9. Knee joint varus/Valgus moment (N·mm/kg).

	Forward jump		Lateral jump		Diagonal jump	
	Control group	Experimental group	Control group	Experimental group	Control group	Experimental group
Pre-taping	44.0±33.7	26.6±19.7	60.1±44.6 [#]	100.8±51.9*	37.4±21.2 [#]	62.4±34.2
Post-taping	24.7±19.3	30.8±20.2	49.5±28.8 [#]	141.7±54.0	46.7±39.0	73.4±38.2

Note: *Significant difference within the same group pre-taping to post-taping, [#]significant difference between groups for the same jump direction.

To compare the differences in ankle plantarflexion/dorsiflexion moment at touchdown between the two groups, a three-way repeated measures ANOVA was conducted (Table 10). The results showed a main effect for direction ($p < 0.001$) and taping ($p = 0.003$); as well as two-way interaction effects for direction \times group ($p < 0.001$), taping \times group ($p = 0.351$), and direction \times

taping ($p = 0.207$); and a three-way interaction effect for direction \times taping \times group ($p = 0.212$). Post-hoc pairwise comparisons revealed that taping significantly and notably decreased the ankle flexion/extension moment ($p = 0.002$). Notably, the ankle flexion/extension moment during forward jumps was the smallest in the control group.

Table 10. Ankle joint plantarflexion/Dorsiflexion moment (N·mm/kg).

	Forward jump		Lateral jump		Diagonal jump	
	Control group	Experimental group	Control group	Experimental group	Control group	Experimental group
Pre-taping	46.4±12.4*	36.9±20.1	74.7±19.2 [#]	33.2±15.3	55.2±18.4 [#]	36.7±16.2
Post-taping	31.6±15.7	28.7±11.7	57.7±24.1 [#]	30.4±20.5	55.9±21.2 [#]	32.8±17.0

Note: *Significant difference within the same group pre-taping to post-taping, [#]significant difference between groups for the same jump direction.

To compare ankle inversion/eversion moments at touchdown between groups across jump directions pre- and post-taping, a three-way repeated measures ANOVA was performed (Table 11). The results showed a main effect for direction ($p < 0.001$) and taping ($p = 0.163$); two-way interaction effects for direction \times group

($p = 0.014$), taping \times group ($p = 0.018$), and direction \times taping ($p = 0.380$); and a three-way interaction effect for direction \times taping \times group ($p = 0.958$). Post-hoc comparisons revealed that taping significantly decreased the moment in the CAI group ($p = 0.017$). For both groups: lateral jump $>$ diagonal jump $>$ forward jump.

Table 11. Ankle joint inversion/Eversion moment (N·mm/kg).

	Forward jump		Lateral jump		Diagonal jump	
	Control group	Experimental group	Control group	Experimental group	Control group	Experimental group
Pre-taping	15.0±6.3*	10.8±5.6	32.4±18.3	40.9±12.0	29.4±17.1	32.8±9.3
Post-taping	10.1±3.5	13.0±7.9	31.7±14.5 [#]	47.3±11.9	30.3±16.2	40.0±13.5

Note: *Significant difference within the same group pre-taping to post-taping, [#]significant difference between groups for the same jump direction.

Discussion

This study, via multi-dimensional biomechanical analysis, revealed KT's nuanced modulatory effects on CAI patients' performance in unanticipated multidirectional jump-landing tasks. First, this study ensured a critical prerequisite for evaluating intervention

effects: the stability of motor output levels. The jump height results showed that, regardless of KT application, there were no significant differences in jump height calculated from either the pelvis center or the heel between the CAI patients and the healthy control group across all directions.

This indicates that the reduction in landing impact force

after taping was not due to a decrease in jump height, confirming that the subsequent biomechanical differences observed during the landing phase resulted from adjustments induced by the KT intervention, rather than changes in motor output levels. Concurrently, the jump height of the CAI group was consistently lower than that of the control group across all conditions, highlighting a deficit in motor capacity among CAI patients.

Building on this foundation, the study found that KT facilitated the adoption of a more coordinated impact attenuation strategy in CAI patients. With jump height unchanged, CAI patients post-taping exhibited lower peak GRF, a reduced GRF loading rate, and a more optimized time to peak force ratio. These results suggest that, under constant potential energy from the drop, the motor system of CAI patients no longer resists ground impact in a rapid, rigid manner. Instead, it actively adjusts the coordination of lower limb joints to create a smoother loading curve. Further analysis of peak GRF across different unanticipated jump directions revealed that post-taping, the CAI group showed a trend toward decreased peak GRF during diagonal and forward jumps, while changes during lateral jumps were minimal.

This may be because in directions perceived as relatively safer, KT allows CAI patients to employ a softer landing strategy, thereby reducing peak GRF. In the highest-risk lateral jumps, KT may partially release movement inhibition, optimizing the quality of force production, specifically manifested in a better loading rate. Sarvestan et al. tested the biomechanical characteristics of collegiate CAI athletes during single leg drop landings and found that the taped group had a significantly lower vertical loading rate compared to the non-taped group [9]. Reductions in GRF and vertical loading rate are significant for alleviating ankle joint load. This suggests that KT, by providing stability confidence and enhanced proprioception, may allow the nervous system of CAI patients to release excessive restrictions on joint movement, thereby prolonging the effective cushioning time and allowing for a more gradual dissipation of impact force. This further demonstrates that KT can help shift the landing pattern of CAI patients from passive structural weight-bearing to an active muscle energy dissipation mode. Although the latter consumes more energy, it significantly protects the related tissues of the

lower limb. The results also showed that without taping, the cushioning time of CAI patients was significantly shorter than that of healthy individuals, directly reflecting their neuromuscular control deficits. KT significantly narrowed this gap between groups, again proving its ability to help restore the capacity to execute proper landing strategies. Therefore, the kinetic data from this study strongly supports the neuromodulatory role of KT, with its most direct biomechanical benefit being a significant reduction in the peak stress and loading rate experienced by the passive stabilizers around the ankle during a single landing.

Building on the above analysis, this study further examined the effect of KT on lower limb joint moments at touchdown during unanticipated multidirectional jumps, revealing nearly opposite modulating effects on the CAI and control groups. For the CAI group, the modulation by KT involved neuromuscular relearning and compensatory increases. The reduction in ankle inversion/eversion moment represents the most direct protective effect of KT. By providing mechanical restriction and enhanced proprioception, KT reduces load on the unstable plane of the ankle, decreasing the risk of re-inversion. The increase in hip adduction/abduction and knee varus/valgus moments reflects a proximal compensation strategy in CAI patients. Post-taping, with the ankle supported, CAI patients may feel more confident or find it necessary to engage hip and knee muscles more actively to control lower limb stability, especially during lateral jump tasks. This outcome points towards improved neuromuscular control. KT may release the fear-driven inhibition of movement in CAI patients, prompting them to adopt a more optimal, albeit more energy-consuming, proximal strategy. However, KT's effect on CAI patients is not simply a mechanical substitute but acts as a neuromuscular modulator. While reducing load on the unstable ankle, it may induce a more active and engaged proximal control strategy at the hip and knee by enhancing sensory feedback. Lin et al. found that KT could lead to a softer landing while altering ankle range of motion [10]. For the control group, KT's modulation manifested as load sharing and economy optimization. Hip, knee, and ankle moments generally decreased or remained unchanged. This is because healthy individuals possess good proprioception and neuromuscular control.

KT provides additional external support, allowing the lower limb to perform movements more efficiently, transferring some of the load normally handled by active muscle contraction to the tape, thereby reducing joint moments. These comprehensive results indicate that the active joint moments at touchdown reflect strategy optimization. KT, through enhanced proprioceptive input, may facilitate the nervous system's pre-activation and coordinated recruitment of stabilizing muscles before landing. Ensuring joints are pre-activated and in a more stable state upon ground contact, thus laying the neuromuscular foundation for efficient and safe impact absorption. This finding extends the understanding of KT's role from superficial changes in mechanical parameters to reprogramming at the sensorimotor control level. However, Kaminski et al. pointed out that when studying the effects of ankle braces, one cannot focus solely on the ankle joint itself but must also consider potential effects on other proximal joints of the lower limb [11]. This is because compensatory mechanisms in proximal joints adapting to the brace's constraints might increase injury risk [12]. Therefore, the use of KT by healthy populations requires caution.

Furthermore, the improvement in movement coordination confirms an overall strategy optimization. The heel-derived height reflects the propulsive output of the distal limb. The pelvis-derived height approximates the vertical displacement of the body's center of mass, representing the overall jump performance. The difference between these two values quantifies the mismatch between the displacement of the body's center of mass and the heel. A larger difference suggests potential compensation or poor coordination during the take-off phase. Analysis of the results revealed that without taping, CAI patients exhibited a significantly larger discrepancy, indicating an inefficient pattern involving excessive upper body and trunk compensation coupled with uncoordinated lower limb force generation. Post-taping, this discrepancy showed a decreasing trend in multiple directions, particularly forward and diagonal. This suggests that the ankle stability and confidence provided by KT allows CAI patients to re-trust and utilize their lower limbs, adopting a more efficient, lower limb-dominant, whole-body coordinated take-off pattern. In this pattern, force is generated sequentially from ankle to knee to hip, effectively transmitted through the core,

and synchronized with coordinated arm movement, leading to more simultaneous heel propulsion and pelvis rise. Consequently, the discrepancy decreases, indicating improved neuromuscular coordination. Atallah et al. research found that KT use could enhance self-confidence in CAI patients, thereby stabilizing postural control through psychological means [13]. The visual cue provided by KT on the body surface allows users to focus attention on the injured or functionally weak area, enhancing awareness and sense of control over their body state. Simultaneously, trust in KT's supportive and analgesic effects can reduce anxiety and fear related to injury, lessen the psychological burden during movement, and thus facilitate more natural movement execution, indirectly improving sports performance and rehabilitation outcomes. This psychological effect can synergize with mechanical and neural mechanisms, strengthening the overall intervention. The lack of a significant increase in jump height after this short-term intervention is likely because overcoming deficits takes time. CAI patients first need to learn to jump correctly, they may not yet be able to immediately achieve higher power output. However, jumping correctly is the foundation for jumping higher and reduces the risk of proximal injury associated with compensatory patterns. Finally, all effects demonstrated clear task-dependent specificity, verifying that KT's modulating effect is not uniform but is closely related to the demands placed on the ankle by the specific task. The optimizing effects of KT on landing loading rate, cushioning time, and movement coordination were most pronounced during lateral and diagonal jumps, while weaker or absent during the relatively simpler forward jumps. This aligns precisely with the gradient of challenge to lateral ankle stability posed by the different directional tasks (lateral > diagonal > forward). Research by Delahunt and Remus found that landing in different directions can influence ankle movement patterns, potentially leading to a higher risk of ankle sprain [14]. However, during the high-risk lateral jumps, although KT did not fully improve the patients' motor performance (jump height remained relatively low), its effect on optimizing landing strategy was most prominent (e.g., a substantial reduction in loading rate). This reveals that even in tasks where patients may still feel psychological fear and motor output is constrained,

KT can effectively guide them towards adopting a safer landing biomechanical strategy.

Conclusion

This study verifies that the primary effect of Kinesio tape (KT) on individuals with chronic ankle instability (CAI) is task-specific functional and strategic modulation, rather than mere mechanical support. The research confirms that the modulating effect of KT precisely corresponds to the demands placed on ankle stability by the movement direction. In forward jumps, which pose a lesser challenge to lateral ankle stability, KT primarily manifests as an optimization of landing biomechanical parameters. In contrast, during high-risk lateral jumps, KT not only significantly improves the quality of neuromechanical control during landing but also partially alleviates the movement inhibition induced by fear in CAI patients. Furthermore, this study reveals that KT can guide CAI patients to transition from a rigid compensatory strategy to a coordinated and stable strategy, while maintaining established motor performance. The findings validate KT's role as a neurosensory amplifier, providing critical evidence for implementing precise, task-risk-based interventions in dynamic rehabilitation training.

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Conflict of Interest

The authors declare no conflict of interest.

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