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Association of Dynamic Balance, Hitting Stability, Vertical Jump, and Tennis Performance among Elite Tennis Players with Chronic Ankle Instability- A Correlation Study

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ABSTRACT: Background: Chronic ankle instability (CAI) is a common consequence of recurrent lateral ankle sprains and is associated with impaired proprioception, neuromuscular dysfunction, altered biomechanics, and reduced athletic performance. Although previous studies have independently examined balance, jump performance, and functional deficits, evidence investigating their collective relationship with tennis-specific performance in elite tennis players remains limited.

Objective: To determine the association of chronic ankle instability with dynamic balance, vertical jump performance, hitting stability, and tennis performance among elite tennis players.

Methods: A multicentre observational study was conducted among 200 elite tennis players (142 men and 58 women) aged 18–26 years from five tennis academies in Vellore District, India. Participants with chronic ankle instability were identified using the Cumberland Ankle Instability Tool and the Foot and Ankle Disability Index (FADI). Vertical Jump Test, Dynamic Stability Test, Hitting Stability Test, and Wiebe Tennis Performance Test (forehand and backhand) were performed. Data were analysed using descriptive statistics and Spearman's rank correlation after confirming non-normal data distribution using the Kolmogorov–Smirnov and Shapiro–Wilk tests.

Results: The mean age of participants was 21 ± 2 years, and the mean FADI score was 68 ± 7. FADI demonstrated a strong positive correlation with vertical jump performance ($\varrho = 0.856$, $p < 0.001$) and hitting stability ($\varrho = 0.870$, $p < 0.001$), whereas a strong negative correlation was observed with dynamic stability ($\varrho = -0.896$, $p < 0.001$). Forehand and backhand performance exhibited a very strong positive correlation ($\varrho = 0.988$, $p < 0.001$).

Conclusion: Chronic ankle instability is strongly associated with impaired dynamic balance, reduced vertical jump performance, and diminished tennis-specific performance among elite tennis players.

1. INTRODUCTION

Tennis is characterized by continuous rallies involving sprinting, sliding, and twisting movements, and is classified as an intermittent high-intensity sport. To meet the competitive demands of the sport, tennis players require an optimal combination of technical, tactical, physical, and psychological attributes, supported by high levels of strength, power, agility, reaction speed, and coordination. [1,2] Players require high levels of aerobic and anaerobic conditioning.[3]

Tennis is played on different court surfaces, including grass, clay, carpet, and acrylic courts. Each court surface has unique mechanical properties that influence ball velocity, ball bounce, playing style, and match duration. In grass court and hard court is termed as fastest surface with short bouncing of ball, Conversely the clay court is designed as slowest surface with high bouncing of ball.[4,5] Tennis matches may last for several hours, which can result in muscle fatigue, However Gescheit et al. (2015) states that long matches don't affect the stroke speed; on contrary it decreases the lower limb movement such as sprints and jumps.[6]

In tennis, players perform frequent multidirectional movements which substantially increases the stress load on the ankle joint. The ankle plays a crucial role during static and dynamic sporting movements. The ankle sprain is most prevalent among tennis players, which occurs due to sudden changes of direction, landing from a serve, reaching for wide shots. In grass and hard court, the ground reaction forces are generally higher which significantly increases the load over the ankle joint. These mechanisms result in excessive loading of the lateral ligament complex, particularly the anterior talofibular ligament, making ankle sprains one of the most prevalent injuries in tennis players.

Research indicates that up to 74% of individuals who sustain lateral ankle sprains develop chronic ankle instability. Recurrent ankle sprains occur because of poor balance control, inappropriate shoes, landing errors, which further leads to chronic ankle instability. Recurrent sprains may lead to chronic ankle instability, characterized by persistent pain, recurrent episodes of giving way, impaired proprioception, reduced dynamic balance, and diminished athletic performance. This condition can adversely affect movement efficiency, stroke execution, and overall competitive performance in tennis.

The athletes with chronic ankle instability while running, jumping, often exhibit increased inversion angles, elevated plantar pressure which also substantially cause proximal joint compensations and altered loading strategies which causes recurrent injuries and reduction in performance.[12,13] On parallel it is also being related with reduced corticomotor excitability in ankle stabilizers like peroneus longus and tibialis anterior.[14] The ankle instability damages the mechanoreceptors responsible for proprioception, which further results in the delayed activation of the peroneal muscles, increases postural sway and impaired control of the centre of pressure.[14]

The ankle plays a substantial role during the propulsion phase by generating and transmitting force efficiently. chronic ankle instability, impaired proprioception, reduced plantar-flexor strength, delayed muscle activation, and altered landing mechanics decrease ankle joint power generation and the rate of force development. These deficits reduce countermovement jump height and overall explosive performance.

Although previous studies have demonstrated that chronic ankle instability impairs dynamic balance, postural control, neuromuscular function, and lower-limb power, most investigations have examined these outcomes independently or in athletes from sports other than tennis. Evidence simultaneously evaluating the relationship between chronic ankle instability, dynamic balance, vertical jump performance, hitting stability, and overall tennis performance in elite tennis players remains scarce. Understanding these associations is important for identifying performance-limiting factors and developing targeted injury prevention and rehabilitation strategies.

Therefore, the present study aimed to determine the correlation between chronic ankle instability and dynamic balance, vertical jump performance, hitting stability, and tennis performance among elite tennis players.

2. METHODOLOGY

2.1 Ethical Consideration

This study was approved by the SRM Institutional Ethics Committee (Reg. No: ECR/431/Inst/TN/2013/RR-24) IEC No: 9200. A detailed orientation regarding the study objectives, procedures, and possible outcomes was provided prior to obtaining written informed consent from the participants. This study was conducted in accordance with the Declaration of Helsinki.

2.2 Study Design, Period, and Study Area

This was a multicentre observational study conducted between December 2025 and March 2026 in five tennis academies in the Vellore district. A total of 200 elite tennis players of both genders were recruited. To minimize bias, participants competing at the district, state, and national tournament levels were included.

The Vellore district is located in the northeastern region of Tamil Nadu, India, between latitudes 12°15' and 13°15' North and longitudes 78°20' and 79°50' East. The district covers a total area of 5,920.18 square kilometres. According to the 2011 Census, the population of the district is 3,936,331. The urban area of Vellore has approximately 20 tennis training academies, where nearly 800 students are trained under different categories, including recreational and professional players for competitive matches.

2.3 Sampling Method

Convenience sampling was used in this study. The sample size was calculated using the assumptions for a single population proportion, with a 95% confidence interval, an infinite population, a 5% margin of error, and an expected prevalence of 50% to obtain the maximum variability. Accordingly, the estimated sample size was n = 200. Twenty tennis academies were identified, of which five training centres were proportionally selected, and participants were proportionally recruited from the selected coaching centres.

2.4 Procedure

Participants from five tennis academies in the Vellore district were recruited according to the study criteria. Participants who scored 24 or below on the Cumberland Ankle Instability Tool and those who reported 50% Moderate pain or difficulty and 25% Severe pain or extreme difficulty on the Foot and Ankle Disability Index (FADI) were recruited. The participants were then scheduled for assessment on consecutive days.

The assessments were conducted with the assistance of physiotherapists, and the screening was divided into different stations. At Station I, the participants were provided with a detailed explanation of the study procedure, following which written informed consent was obtained. At Station II, the participants performed the Vertical Jump Test. At Station III, the participants performed the Dynamic Stability Test. The Wiebe Tennis Performance Test and Hitting Stability Test were performed on a clay court.

2.5 Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics version XX (IBM Corp., Armonk, NY, USA). Categorical variables were summarized as frequencies and percentages, whereas continuous variables were presented as mean ± standard deviation (SD), median, interquartile range (IQR), minimum, and maximum values, as appropriate. The distribution of continuous variables was evaluated using both the Kolmogorov–Smirnov and Shapiro–Wilk tests. As all variables significantly deviated from normality ($p < 0.05$), non-parametric statistical methods were adopted for inferential analyses. Associations between ankle function (FADI score), vertical jump performance, dynamic stability, hitting stability, forehand performance, and backhand performance were examined using Spearman's rank correlation coefficient (ϱ).

3. DATA ANALYSIS

Table 1. Table illustrates the Distribution of participants according to gender and functional performance categories

Variable	Category	n	%
Gender	Men	142	71.0
	Women	58	29.0
FADI	Poor function / Marked disability	89	44.5
	Fair function / Moderate disability	74	37.0

	Severe disability	21	10.5
	Good function / Mild disability	16	8.0
Vertical Jump Test	Average	88	44.0
	Very Good	83	41.5
	Below Average	17	8.5
	Excellent	8	4.0
	Good	3	1.5
	Poor	1	0.5
Dynamic Stability Test	Fair	108	54.0
	Good	92	46.0
Hitting Stability Test	Very Good	91	45.5
	Excellent	89	44.5
	Good	19	9.5
	Poor	1	0.5

Table 2. Table Illustrates the Distribution of continuous variables

	Age	FADI Scoring	Vertical Jump test	Dynamic stability test	Hitting stability test	Fore Hand	Back Hand
Mean	21	68	54	2.1	19	58	63
Standard Deviation	2	7	13	.6	3	9	15
Minimum	18	45	28	1.0	13	40	30
Percentile 25	20	64	45	1.5	17	55	60
Median	22	68	47	2.5	17	55	60
Percentile 95	25	82	70	3.0	23	70	80
Maximum	26	85	75	3.0	24	80	80

Table 3. Table illustrates the tests of normality for study variables

Variable	Kolmogorov–Smirnov Statistic	p-value	Shapiro–Wilk Statistic	p-value
FADI Scoring	0.080	0.003	0.978	0.003
Vertical Jump Test	0.228	<0.001	0.854	<0.001

Dynamic Stability Test	0.301	<0.001	0.792	<0.001
Hitting Stability Test	0.299	<0.001	0.777	<0.001
Forehand	0.301	<0.001	0.799	<0.001
Backhand	0.306	<0.001	0.758	<0.001

Table 4. Spearman's rank correlation among study variables

Variable	1	2	3	4	5	6
1. FADI Scoring	1.000					
2. Vertical Jump Test	0.856**	1.000				
3. Dynamic Stability Test	-0.896**	-0.865**	1.000			
4. Hitting Stability Test	0.870**	0.852**	-0.915**	1.000		
5. Forehand	0.675**	0.580**	-0.700**	0.709**	1.000	
6. Backhand	0.700**	0.607**	-0.721**	0.734**	0.988**	1.000

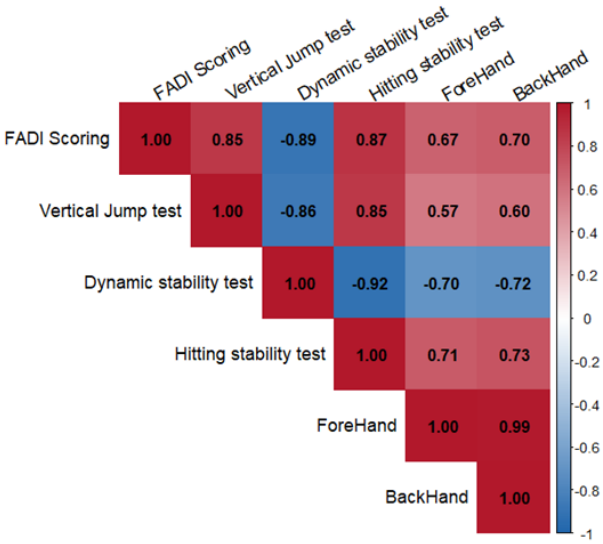

Fig I. Various test values

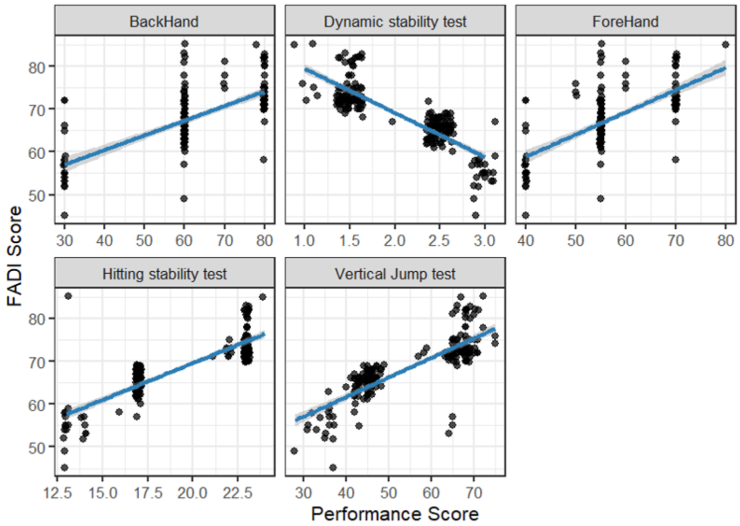

Fig II. Performance Analysis

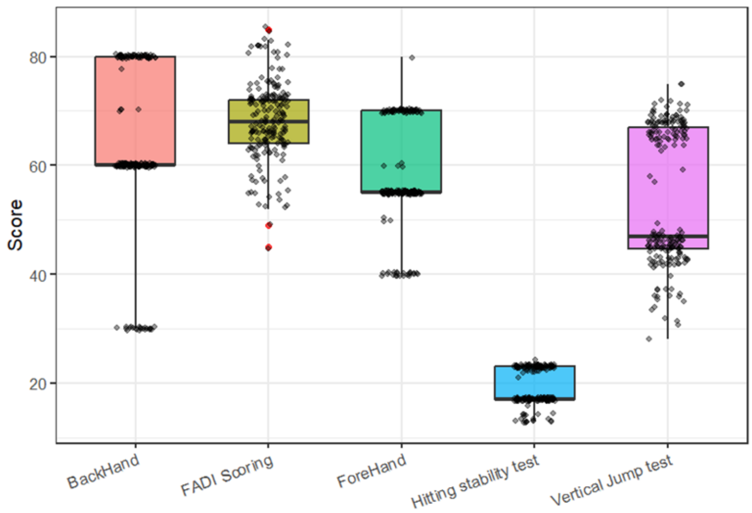

Fig III. Performance Comparison

4. RESULT

Table I illustrates that A total of 200 elite tennis players with chronic ankle instability participated in the study. The majority of participants were male (71.0%, n = 142), while 29.0% (n = 58) were female. Based on the FADI classification, nearly half of the participants (44.5%, n = 89) demonstrated poor function/marked disability, followed by 37.0% (n = 74) with fair function/moderate disability. A smaller proportion had severe disability (10.5%, n = 21), whereas only 8.0% (n = 16) exhibited good function/mild disability. For the Vertical Jump Test, 44.0% (n = 88) of participants demonstrated average jump performance, while 41.5% (n = 83) achieved a very good rating. Relatively few participants were classified as below average (8.5%, n = 17), excellent (4.0%, n = 8), good (1.5%, n = 3), or poor (0.5%, n = 1). Regarding dynamic stability, more than half of the participants (54.0%, n = 108) exhibited fair stability, whereas 46.0% (n = 92) demonstrated good dynamic stability. For the Hitting Stability Test, almost equal proportions of participants achieved very good (45.5%, n = 91) and excellent (44.5%, n = 89) performance, while only 9.5% (n = 19) were categorized as good and 0.5% (n = 1) as poor.

Table II illustrates that The participants had a mean age of 21 ± 2 years, with ages ranging from 18 to 26 years. The mean FADI score was 68 ± 7, with scores ranging from 45 to 85, indicating a moderate level of self-reported ankle function among the participants. The Vertical Jump Test showed a mean jump height of 54 ± 13 cm, with values ranging from 28 to 75 cm, suggesting considerable variability in lower-limb explosive performance. The mean Dynamic Stability Test score was 2.1 ± 0.6, with scores ranging from 1.0 to 3.0, indicating that most participants demonstrated fair to good dynamic balance. The mean Hitting Stability Test score was 19 ± 3, with values ranging from 13 to 24, reflecting generally good hitting stability among the participants. The average Forehand performance score was 58 ± 9, with scores ranging from 40 to 80, while the average Backhand performance score was 63 ± 15, with scores ranging from 30 to 80, indicating that backhand performance was slightly higher on average than forehand performance.

Table III states that The normality of continuous variables was assessed using the Kolmogorov–Smirnov and Shapiro–Wilk tests. All study variables demonstrated significant departures from normality ($p < 0.05$), indicating non-normal distributions. Therefore, non-parametric statistical tests were employed for subsequent analyses.

Table IV illustrates that Spearman's rank correlation analysis demonstrated significant associations among all study variables ($p < 0.001$). FADI scoring showed a strong positive correlation with the Vertical Jump Test ($\varrho = 0.856$) and Hitting Stability Test ($\varrho = 0.870$), whereas it demonstrated a strong negative correlation with the Dynamic Stability Test ($\varrho = -0.896$). Forehand and Backhand performance exhibited a very strong positive correlation ($\varrho = 0.988$), indicating a high degree of association between the two stroke performance measures.

5. DISCUSSION

In this study, we demonstrated the associated factors of chronic ankle instability. Lateral ankle sprains are recurrent among high-intensity sporting activities involving sudden acceleration, deceleration, cutting, and jumping movements. In most sporting activities, rehabilitation following an ankle sprain is primarily focused on the injured ankle, while other potential associated factors that contribute to impaired function and performance are often overlooked.

The ankle joint serves as a fundamental component in transferring ground reaction forces, regulating the body's centre of mass over the base of support, efficiently storing and releasing elastic energy, generating plantarflexion torque for propulsion, and absorbing impact forces during landing. In tennis, the ankle serves as the foundation of the kinetic chain, allowing effective transfer of ground reaction forces through the lower limbs, trunk, and upper extremities to produce powerful and accurate strokes.20–24 Therefore, optimal ankle function is fundamental to elite tennis performance.

Chronic ankle instability is characterized by repeated episodes of ankle sprain and is not merely a consequence of mechanical ligament laxity but rather a complex sensorimotor disorder involving mechanical insufficiency, proprioceptive deficits, neuromuscular dysfunction, altered movement biomechanics, and central nervous system adaptations.16–17 Chronic ankle instability develops following recurrent ankle sprains, which cause structural disruptions to the anterior talofibular and calcaneofibular ligaments. These structural changes reduce afferent proprioceptive input to the central nervous system, resulting in impaired sensorimotor integration, delayed reflexive activation of the peroneal muscles, compromised dynamic joint stabilization, and altered motor control strategies during functional activities. Furthermore, chronic ankle instability impairs the biomechanics of the initial phases of jumping and landing, increasing joint loading, reducing movement efficiency, and contributing to recurrent injuries while negatively affecting athletic performance.18–19

Hertel and Corbett (2019) and Gribble et al. (2016) reported that tennis players require rapid acceleration, deceleration, cutting, and pivoting movements, and that individuals with chronic ankle instability exhibit impaired neuromuscular control and altered lower-extremity biomechanics during these activities. Consistent with these findings, the results of the present study demonstrated that chronic ankle instability exhibited a strong positive correlation with vertical jump performance ($p < 0.001$) and hitting stability, while showing a strong negative correlation with dynamic stability. Additionally, forehand and backhand performance demonstrated a very strong positive correlation ($\varrho = 0.988$), indicating a high degree of association between the two stroke performance measures.

The observed relationship between chronic ankle instability and vertical jump performance is biomechanically plausible because efficient jump performance depends on adequate ankle dorsiflexion, plantarflexor strength, proprioceptive function, and effective utilization of the stretch-shortening cycle. Individuals with chronic ankle instability frequently demonstrate impaired force generation and altered landing mechanics, thereby reducing jump efficiency. Similar findings were reported by Simpson et al. (2019), who demonstrated altered unilateral landing biomechanics and reduced neuromuscular control in individuals with chronic ankle instability. Likewise, Doherty et al. (2022) concluded that chronic ankle instability adversely affects lower-extremity biomechanics during jump-landing tasks. However, Markovic (2007) emphasized that vertical jump performance is also influenced by muscle strength, tendon stiffness, and training status, suggesting that ankle function alone does not fully explain explosive performance.

Similarly, Simpson et al. (2019) and Dejong et al. (2020) stated that dynamic balance deficits are not solely attributable to ankle instability, as proximal neuromuscular adaptations involving the hip and trunk also contribute substantially to postural regulation. Likewise, Kibler et al. (2006) emphasized that deficiencies in any segment of the kinetic chain reduce energy transfer and compromise stroke performance. However, Elliott et al. (2009) argued that stroke performance is also influenced by technical proficiency, racket mechanics, and tactical decision-making, indicating that ankle function represents only one component of successful tennis performance. Although the present study demonstrated significant correlations between ankle function and sport-specific performance, overall athletic performance continues to depend on multiple interacting factors, including technical skills, tactical ability, decision-making, lower-limb strength, core stability, psychological readiness, fatigue, and training history.

Despite the fundamental role of ankle function in elite tennis performance, rehabilitation programmes frequently prioritize symptom relief and restoration of ankle mobility, with comparatively less emphasis on comprehensive exercise interventions targeting neuromuscular control, balance, explosive power, and sport-specific performance. Likewise, clinical assessment remains largely impairment-based rather than performance-oriented. A multidimensional evaluation incorporating dynamic balance, jump performance, and tennis-specific functional tasks may better identify residual deficits, allowing clinicians to design individualized rehabilitation strategies that enhance performance while reducing the risk of recurrent injury.

6. CONCLUSION

This study concludes that chronic ankle instability significantly correlates with jumping performance, hitting stability, forehand and back hand stroke performance, where it negatively correlates with dynamic stability.

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