



Exploring the associations between ankle dorsal and plantar flexion strength, reactive strength index, and balance in elite youth soccer players

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Abstract

Background Enhanced muscular strength has been widely acknowledged as a fundamental determinant of improved performance in the lower extremities. However, the specific impact of ankle strength on explosive strength and balance remains inadequately elucidated. Consequently, this study aims to (a) evaluate balance, reactive power, and flexor–extensor muscle balances in soccer players, and (b) evaluate ankle dorsal and plantar flexion muscle strength as predictive factors for reactive strength index and balance performance.

Methodology A cohort comprising 38 actively engaged Turkish National League soccer players participated in the study. The assessment encompassed explosive power through a drop jump, dynamic balance utilizing a moving disc, and ankle strength measured with a handheld dynamometer.

Results The findings revealed that dominant lower limb dorsal flexion strength emerged as a significant predictor of both reactive strength ($R^2=0.106$, $p<0.05$) and balance ($R^2=0.121$, $p<0.05$). Similarly, non-dominant lower limb dorsal flexion strength was identified as a significant predictor of reactive strength ($R^2=0.362$, $p<0.05$). Furthermore, the study established that dominant lower limb plantar flexion strength significantly predicted balance ($R^2=0.121$, $p<0.05$), while non-dominant lower limb plantar flexion strength served as a significant predictor of both reactive strength ($R^2=0.148$, $p<0.05$) and balance ($R^2=0.179$, $p<0.05$).

Conclusions Consequently, these findings emphasize the significance of incorporating targeted exercises designed to enhance intrinsic foot musculature, thereby augmenting both explosive strength and balance in athletes. While acknowledging the persistent importance of strength assessment in evaluating lower extremity performance, our results underscore the critical role played by ankle muscle strength in the execution of explosive strength and balance.

Keywords Ankle strength · Reactive strength index · Balance · Soccer · Asymmetry index

Introduction

Considering the lower extremities, ankle stability assumes a pivotal role in facilitating mobility and reducing the susceptibility to ankle injuries during sports engagement [1]. Given the range of motion and force exerted upon the ankle during diverse sporting actions (jumping, running, changing direction, etc.), this assumes an ascending significance within the context of sports performance [2]. The ankle joint serves as a pivotal, mobile point of articulation during weight-bearing activities. It is imperative that movements of this joint in

all planes produce minimal displacement of the center of gravity [3]. Consequently, the preservation of equilibrium and efficient energy expenditure hinge upon the effective functioning of the foot and ankle complex [4]. Moreover, the pivotal ankle joint contributes to dynamic movement, static support, and load-bearing functions [5]. When any circumstance exceeds the stable load threshold, the inversion torque acting on the muscles experiences a rapid escalation, potentially resulting in a state of “loss of control” of the ankle [6]. For this reason, the ankle assumes a vital role in mitigating multifaceted conditions characterized by intricate mechanical and neuromuscular elements.

The human foot serves a dual role as both a flexible structure for energy absorption and a rigid lever for energy

Extended author information available on the last page of the article

generation during weight-bearing activities, owing to its composite of passive elastic and active components [7, 8]. A pivotal anatomical attribute of the foot lies in its function as a medial longitudinal spring, undergoing compression and elongation to store potential energy within its passive constituents, including the plantar ligaments and aponeurosis, prior to its release during the stance phase of locomotion [9]. It is noteworthy that these spring-like characteristics are not confined solely to passive structures, as compression of the plantar ligaments and aponeurosis also results in energy storage through the tendinous tissues of the intrinsic foot muscles [10]. This intricate mechanism enables the foot to function as a dynamic modulator, capable of both dissipating and augmenting mechanical energy in stable [10, 11] and unstable movements, as well as facilitating acceleration and deceleration movements [12]. Consequently, ankle muscle strength emerges as a critical determinant that can exert a substantial impact on the athletic performance of individuals engaged in activities that entail frequent jumping and acceleration/deceleration actions [13, 14], such as soccer. To execute an effective jump, it is imperative that joints are flexed at optimal angles. This facilitates maximal muscle contractions during extension and the dynamic application of force, thereby enhancing jumping efficiency [15]. Assessing the range of dorsiflexion and plantar flexion movements at the ankle joint across specific velocities offers insights into the strength generated during a jump. Furthermore, Lalevée et al. [6] considered the ankle's involvement in balance disorders and muscle weakness as primary risk factor for ankle injuries. Additionally, several studies have demonstrated that conditions leading to ankle injuries may arise from deficiencies in proprioceptive control, balance, and muscular strength, even in the presence of distinct combinations of deficits [16, 17]. Thus, a model aimed at elucidating the associations between ankle dorsal and plantar flexion strength and balance is warranted.

The game of soccer demands not only significant endurance but also optimal muscle strength, crucial for executing various soccer-specific explosive movements. Specifically, robust lower extremity muscle strength is vital for actions like sprinting, jumping, directional shifts, passing, tackling and shooting [18]. Diminished muscle strength can lead to lower athletic performance and increase the risk of muscular injuries [19]. Numerous studies have highlighted the potential risks of ankle and knee injuries associated with muscle strength or imbalances [1, 20–22]. Hence, the regular assessment of functional parameters holds substantial importance in establishing the foundation for injury prevention programs [23, 24]. Soccer is associated with a very high injury rate at both professional and amateur levels [22]. As these injuries can lead to reduced physical activity and endurance levels, lost playing time and healthcare costs, it is important to provide appropriate intervention to increase the stability of the

entire lower extremity to prevent injuries [22]. Ankle injuries are common among athletes, and their prevalence varies depending on the type of sport. Approximately 70–80% of ankle injuries occur in team sports [20]. Ankle instability, explained by functional or mechanical factors, is one of the most common causes of ankle sprains in soccer players [22]. Muscle fatigue is known to cause chronic ankle instability and affect joint proprioception and kinesthetic properties [25]. Fatigue increases the threshold of muscle spindle discharge, impairing afferent feedback that alters joint awareness and reduces postural control [25]. Additionally, changes in postural control due to ankle muscle fatigue may be worsened by changing joint position and force perception and kinesthesia [21]. Therefore, it can be said that evaluation of ankle strength is of critical importance in soccer. Previous research has shown that balance, proprioception, and neuromuscular feedback mechanisms play a role in the development and maintenance of functional joint stability [1]. In this context, the evaluation of ankle strength, which is believed to impact fundamental athletic qualities such as jumping and balance, holds relevant significance. While existing literature does feature studies comparing ankle range of motion and isokinetic muscle strength values with various physical fitness parameters [26, 27], investigations examining the strength of both agonist and antagonist ankle muscles, and any correlation with reactive strength index and balance in youth soccer players competing in the national league, is scant.

Therefore, the aims of this study are: (1) to analyze ankle strength, reactive power, and flexor–extensor muscle balances in soccer players, and (2) to assess the impact of ankle dorsal and plantar flexion muscle strength as predictors of reactive strength and balance performance. The study hypotheses are as follows: (i) Dynamic balance (H_1) and re-active strength (H_2) is influenced of ankle dorsal and plantar flexor strength, (ii) a negative correlation, indicative of enhanced balance, between dynamic balance (H_3) and ankle dorsal and plantar flexion strength and a positive relationship between reactive strength (H_4) and ankle dorsal and plantar flexion strength is evident.

Material and methods

Participants

This study examined youth Turkish soccer players that compete in the Turkish National league. A total of 38 male soccer players, were included in the study. The inclusion criteria for the study were as follows: (i) absence of acute or chronic ankle pain, (ii) no lower extremity injury within the last 6 months prior to testing, (iii) between 18 and 19 years of age and volunteered to participate in the study, (iv)

minimum four years of active participation in soccer, and (v) currently engaged in a minimum of two training sessions per week. Only participants that read and voluntarily signed the consent form were considered for inclusion. The sample size was determined using G*Power software, conducting an a priori analysis. With a power of 0.80, a significance level of 0.05, a correlation coefficient of 0.5, nonsphericity correction of 1, and an effect size of 0.84, a sample of 38 participants was calculated. The sample calculation followed the procedures recommended by Otsuka et al. [28]. The study was conducted according to the requirements of the Declaration of Helsinki and was approved by the local Non-interventional Ethics Committee of Recep Tayyip Erdogan University and the Turkish club from which the participants volunteered. To ensure confidentiality, all data were anonymized prior to analysis.

Procedure

The research was designed utilizing a quantitative research design, employing the descriptive relational method. The primary aim was to assess causal relationships between the variables (balance and reactive strength with ankle strength). Accordingly, measurements of dorsal and plantar flexion strength, reactive strength, and balance were conducted on the participants, and any interrelationship between these parameters were examined. The conceptual model's framework is depicted in Fig. 1.

Measurements

Participants wore sports clothing (shorts and t-shirts) for the tests. To ensure the tests were conducted under optimal conditions, measurements were taken in a designated area adjacent to the soccer field between 16:00 and 18:00 p.m. All measurements were conducted by the authors of this study. Each player's measurements were taken twice within a 10-min interval and recorded, respectively.

Following the assessment of height and body weight, a warm-up routine consisting of an 8-min run and eight

minutes of dynamic exercises was conducted. A 2-min rest period was provided between tests.

Balance performance

The Togu Challenge Disc (German Togu Company: Germany) was utilized to evaluate balance proficiency. Participants stood at the center of the disc, barefoot and with arms free for balance support, on one leg (right-left) for a duration of 20 s. The measurements were repeated twice with 2-min intervals, and the best score was recorded. In instances where participants were unable to maintain balance on the disc, the attempt was considered erroneous, and the test was repeated [29]. Evaluation of balance was conducted using a scoring system ranging from 1 to 5, representing the stability index (1-very good/2-good/3-moderate/4-poor/5-very poor) as per the Togu Challenge recommended guidelines. In balance measurements, the procedures used by Hildebrandt [29] were used.

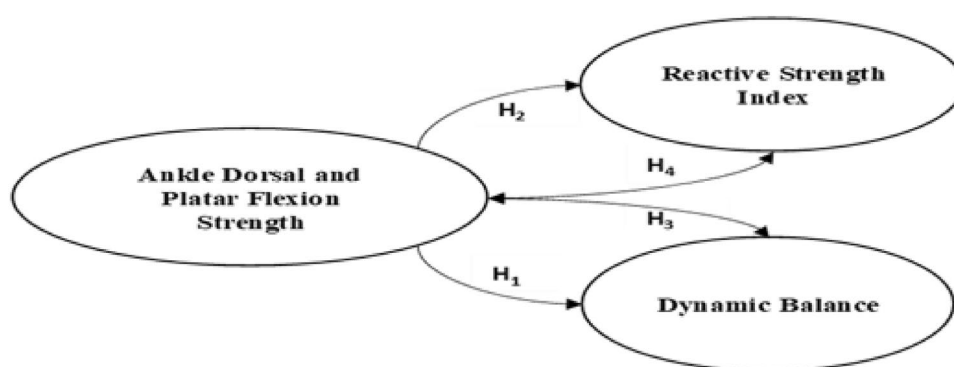
Reactive strength index

The Reactive Strength Index (RSI) was determined using the Jump Mat Pro device (Bolzano, Bozen, Italy) with drop jump test. The athlete was instructed to free-fall from a 30 cm box with one foot (right-left) onto an electronic jumping mat and rapidly jump vertically with maximum speed [30]. Any movement involving raising the knee while in flight or failing to land on the mat was considered invalid and the test was repeated for any such movements. The test was repeated twice with a 30-s rest interval, and the highest RSI (m/s), ground contact time, and flight-time were recorded. In reactive strength index measurements, the procedures used by Kenny et al. were used [30].

Ankle muscle strength

Dorsiflexion and plantar flexion measurements were conducted using an Active Force Dynamometer (Version: 2, Digital Dynamometer, San Diego, United States). During

Fig. 1 Model of the study



the measurement, the participants assumed a seated position on a standard-height chair without armrests, with the hip and knee joints flexed at 90 degrees [31]. One foot was positioned perpendicular to the ground, with the heel in contact with the ground. Measurements were taken for both the dominant and non-dominant side. In ankle muscle strength measurements, the procedures used by Aramaki et al. were used [31].

Muscle strength in dorsiflexion

The player was instructed to dorsiflex the ankle to the full extent and maintain this position. With the hand-held dynamometer placed dorsally to the metatarsal head, the athlete gradually exerted maximal force against the dynamometer, sustaining it for at least 5 s [32]. Two measurements were taken with a 1-min rest interval, and the highest value was recorded in kilograms. In muscle strength in dorsiflexion measurements, the procedures used by Kimura et al. were used [32].

Muscle strength in plantar flexion

The participant was instructed to perform maximal plantar flexion and sustain this position. With the hand-held dynamometer placed on the plantar surface of the metatarsal heads, the athlete gradually applied maximal muscle strength against the dynamometer, holding it for at least 5 s [33]. Two measurements were taken with a 1-min rest interval, and the highest value was recorded in kilograms. In muscle strength in plantar flexion measurements, the procedures used by Spink et al. were used [33].

Statistical analysis

The data were analyzed using the SPSS 27.0.1 statistical package. The data's normality was confirmed through Shapiro–Wilk test results ($p > 0.05$), indicating adherence to normal distribution assumptions. Descriptive statistics were applied to the dataset. The association between dynamic balance, RSI, and ankle strength was assessed through Pearson correlation analysis. In addition, the effect of force on balance was investigated using reactive force Linear Regression analysis after the regression assumptions were met. The data were assessed at a significance level of 0.05.

Results

In our study, the mean age of the participating athletes was determined to be 18.56 ± 0.50 years, with a mean body weight of 67.80 ± 1.07 kg, an average height

of 1.76 ± 0.85 m, and a mean body fat percentage of 10.61 ± 3.64 .

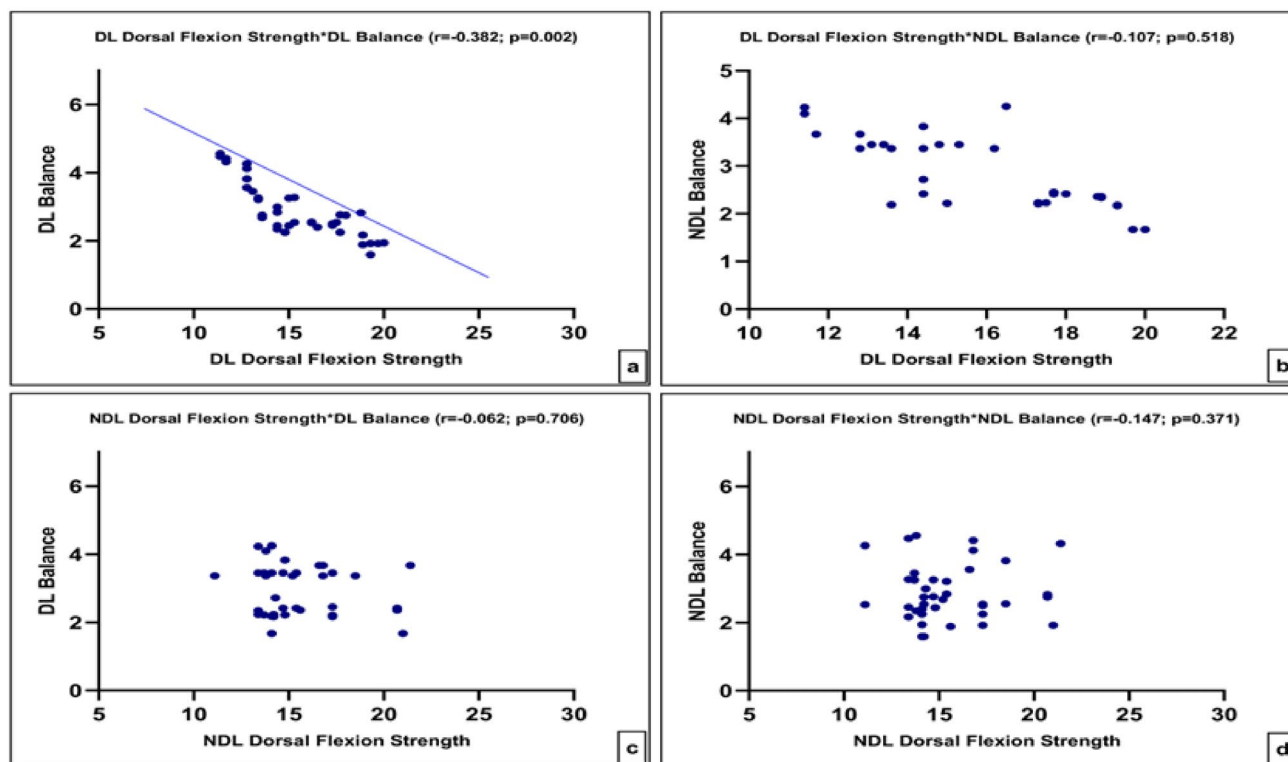
In Fig. 2, a Pearson correlation test was employed to ascertain the potential relationship between ankle dorsal flexion strength and balance. The results of the test revealed a negative correlation ($r = -0.382$; $p = 0.002$) between dorsal flexion strength of the dominant leg and the corresponding balance score (a). However, no significant relationship was found in other variables (b, c, d).

In Table 1, a linear regression model was established to predict the balance level of the dominant leg based on dorsal flexion strength of the dominant leg. The computed regression model demonstrated statistical significance ($F_{(1,37)} = 4.797$, $p = 0.002$). The dorsal flexion strength of the dominant leg accounts for 12% of variance in balance of the dominant leg ($r = 0.382$; $R^2 = 0.121$). It was observed that a one-unit increase in dominant leg dorsal flexion strength led to a -0.137 unit decrease in balance of the dominant leg.

In Fig. 3, a Pearson correlation test was conducted to examine the potential relationship between ankle dorsal flexion strength and RSI. The results indicated a positive correlation between dorsal flexion strength of the dominant leg and RSI of the dominant ($r = 0.326$; $p = 0.043$) (a). Furthermore, a positive correlation was observed between dorsal flexion strength of the non-dominant leg and RSI of both the dominant ($r = 0.602$; $p = 0.000$) (c) and non-dominant leg ($r = 0.602$; $p = 0.000$) (d). The results showed that there was no correlation between the dorsal flexion strength of the dominant leg and the RSI of the non-dominant leg (b).

In Table 2, multiple linear regression models were constructed to predict the RSI of the dominant and non-dominant leg based on dorsal flexion strength of both sides. The regression model for dorsal flexion strength and RSI of the dominant leg ($F_{(1,37)} = 4.406$, $p = 0.043$), as well as the regression model for dorsal flexion strength of the non-dominant leg ($F_{(1,37)} = 20.990$, $p = 0.000$) and dominant ($F_{(1,37)} = 20.637$, $p = 0.000$) RSI were found to be statistically significant. The dorsal flexion strength on the dominant leg accounts for 10% of the variance in the dominant leg RSI ($R = 0.326$; $R^2 = 0.106$), while the non-dominant leg dorsal flexion strength explains 36% of non-dominant leg RSI ($R = 0.602$; $R^2 = 0.362$), and 35% of the dominant leg RSI ($R = 0.598$; $R^2 = 0.358$). It was also observed that a one-unit increase in dorsal flexion strength of the dominant leg led to an increase of 0.051 units in dominant RSI, while a one-unit increase in dorsal flexion strength of the non-dominant leg resulted in an increase of 0.108 units in non-dominant RSI, and 0.098 units in dominant RSI.

In Fig. 4, a Pearson correlation test was conducted to explore the relationship between ankle plantar flexion strength and balance. The results indicated a negative correlation between plantar flexion strength of the dominant leg and corresponding balance ($r = -0.348$; $p = 0.030$) (a).



DL: Dominant Leg, NDL: Non-Dominant Leg

Fig. 2 Relationship between ankle dorsal flexion strength and balance

Table 1 The effect of ankle dorsal flexion strength on balance

Predictive variable	Predicted variable	B	Std. error	(β)	t	R	R ²	F	p
DL dorsal flexion strength	DL balance	-0.137	0.446	-0.382	-2.893	0.382	0.121	4.797	0.002*

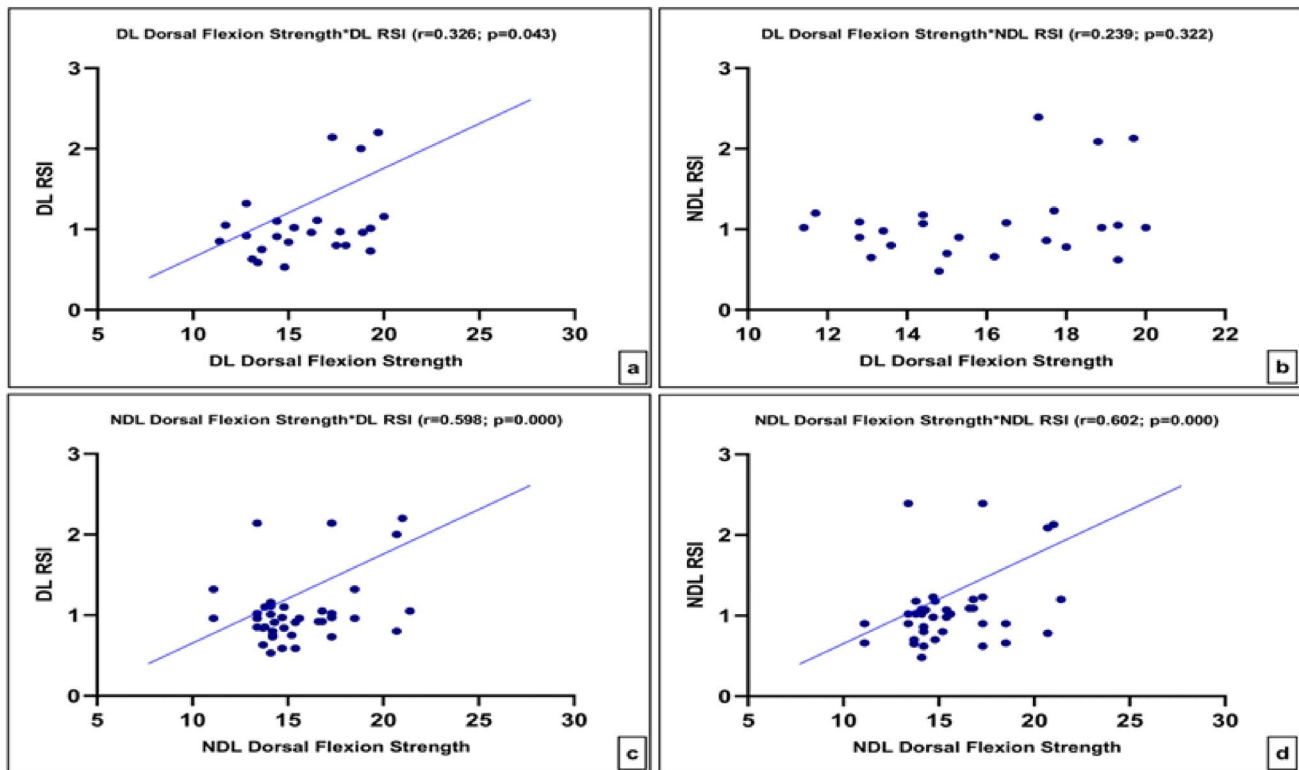
DL Dominant Leg

Additionally, a negative relationship was observed between plantar flexion strength of the non-dominant leg and balance of both the dominant ($r = -0.319$; $p = 0.046$) (c) and non-dominant leg ($r = -0.280$; $p = 0.048$) (d). The results indicated that there was no correlation between the plantar flexion strength of the dominant leg and the balance of the non-dominant leg (b).

In Table 3, multiple linear regression models were developed to predict balance of the dominant and non-dominant leg based on the plantar flexion strength of both legs. The regression model for plantar flexion strength of the dominant leg and balance ($F_{(1,37)} = 5.108$, $p = 0.030$), and non-dominant plantar flexion strength ($F_{(1,37)} = 4.159$, $p = 0.046$) and dominant ($F_{(1,37)} = 4.195$, $p = 0.048$) balance were found to be statistically significant. Plantar flexion strength of the dominant leg accounts for 12% of the variance in balance ($R = 0.348$; $R^2 = 0.121$), while non-dominant plantar flexion strength explains 17% of non-dominant leg balance

($R = 0.280$; $R^2 = 0.179$), and 10% of dominant leg balance ($R = 0.319$; $R^2 = 0.102$). It was also determined that a one-unit increase in plantar flexion strength of the dominant leg resulted in a decrease of -0.047 units in the dominant balance. Additionally, a one-unit increase in plantar flexion strength of the non-dominant leg led to an increase of -0.030 units in non-dominant balance and -0.034 units in dominant balance.

In Fig. 5, a Pearson correlation test was conducted to explore the potential relationship between ankle plantar flexion strength and RSI. The results indicated a positive correlation between plantar flexion strength of the dominant leg and the RSI of the non-dominant leg ($r = 0.309$; $p = 0.047$) (b). Furthermore, a positive relationship was observed between plantar flexion strength of the non-dominant leg and RSI of both the dominant ($r = 0.446$; $p = 0.004$) (c) and the non-dominant leg ($r = 0.384$; $p = 0.016$) (d). The results demonstrated that there was no correlation between



DL: Dominant Leg, NDL: Non-Dominant Leg, RSI: Reactive Strength Index

Fig. 3 The relationship between ankle dorsal flexion strength and RSI

Table 2 The effect of ankle dorsal flexion strength on RSI

Predictive variable	Predicted variable	B	Std. error	(β)	t	R	R ²	F	p
DL dorsal flexion strength	DL reactive strength index	0.051	0.024	0.326	2,099	0.326	0.106	4.406	0.043*
NDL dorsal flexion strength	NDL reactive strength index	0.108	0.024	0.602	4,582	0.602	0.362	20.990	0.000*
	DL reactive strength index	0.098	0.022	0.598	4,543	0.598	0.358	20.637	0.000*

DL Dominant Leg, NDL Non-Dominant Leg

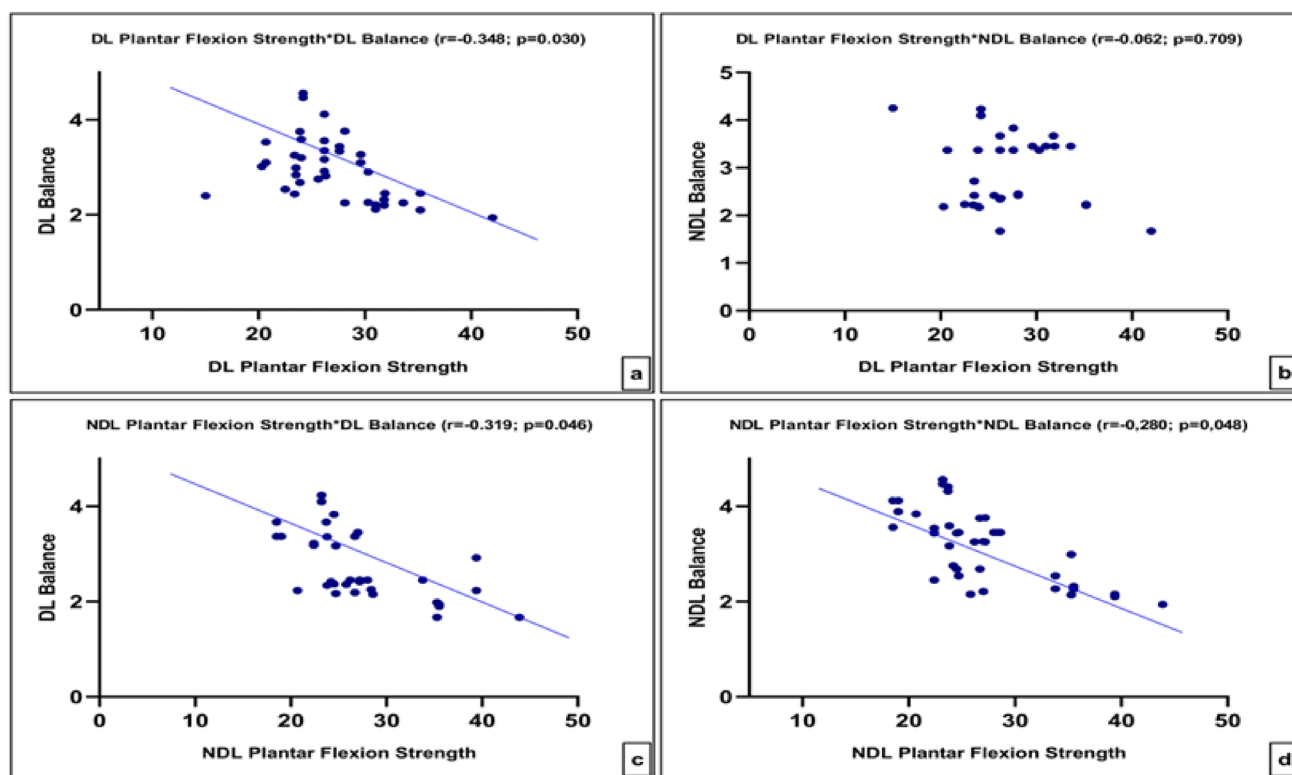
the plantar flexion strength of the dominant leg and the RSI of the dominant leg (a).

In Table 4, multiple linear regression models were established to predict the RSI of the dominant and non-dominant leg based on plantar flexion strength of both legs. The regression model for plantar flexion strength of the dominant leg and non-dominant RSI ($F_{(1,37)}=3.892$, $p=0.048$), as well as the regression model for plantar flexion strength of the non-dominant leg ($F_{(1,37)}=6.404$, $p=0.016$) and dominant ($F_{(1,37)}=9.178$, $p=0.004$) RSI were found to be statistically significant. Plantar flexion strength of the dominant leg accounts for 19% of variance in the non-dominant leg RSI ($R=0.309$; $R^2=0.195$), while plantar flexion strength of the non-dominant leg explains 14% of non-dominant RSI ($R=0.384$; $R^2=0.148$), and 19% of the dominant leg RSI

($R=0.446$; $R^2=0.199$). It was also determined that a one-unit increase in plantar flexion strength of the dominant leg led to an increase of 0.028 units in the non-dominant leg RSI, while a one-unit increase in plantar flexion strength of the non-dominant leg resulted in an increase of 0.028 units in the non-dominant leg RSI and 0.030 units in the dominant leg RSI.

Discussion

The present study aimed to investigate the potential relationship between ankle strength, RSI, and flexor–extensor muscle balance in youth soccer players from the Turkish national league. Additionally, it sought to ascertain whether



DL: Dominant Leg, NDL: Non-Dominant Leg

Fig. 4 Relationship between ankle plantar flexion strength and balance

Table 3 The effect of ankle plantar flexion strength on balance

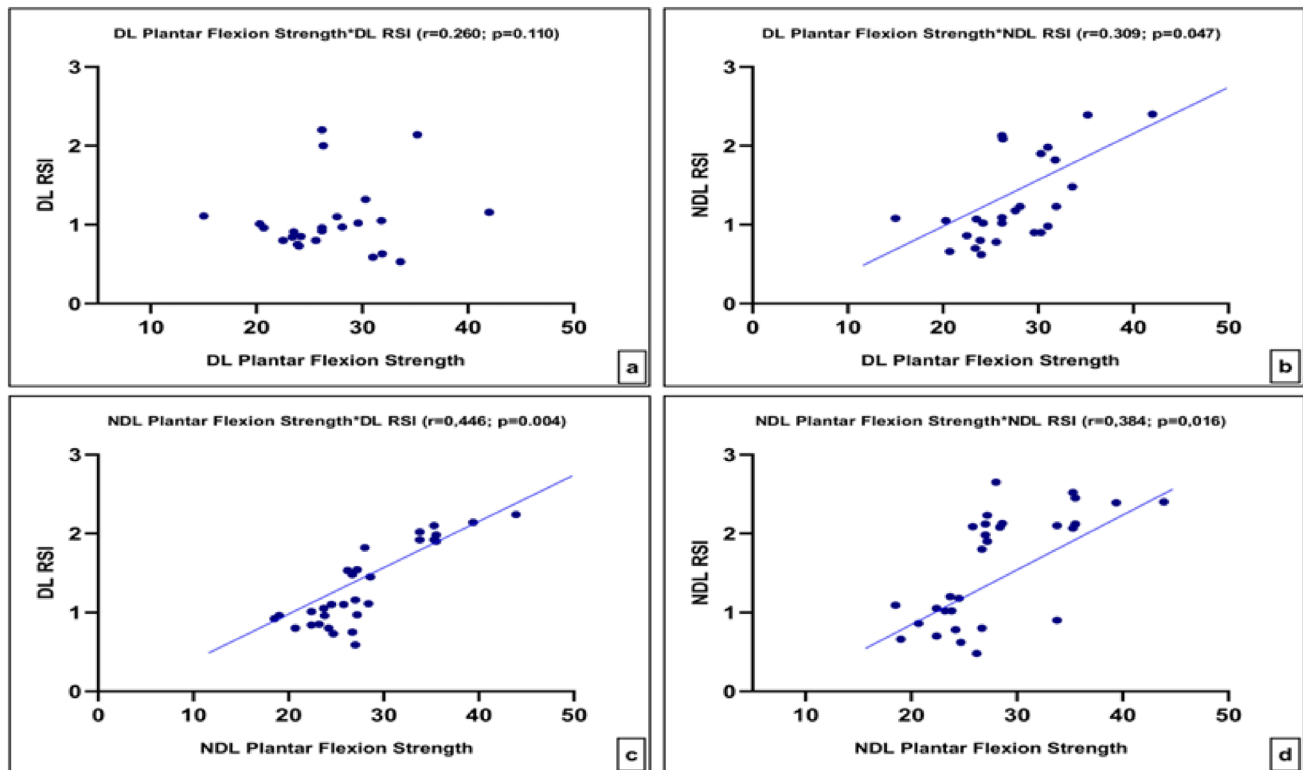
Predictive variable	Predicted variable	<i>B</i>	Std. error	(β)	<i>t</i>	<i>R</i>	<i>R</i> ²	<i>F</i>	<i>p</i>
DL plantar flexion strength	DL balance	−0.047	0.021	−0.348	−2.260	0.348	0.121	5.108	0.030*
NDL plantar flexion strength	NDL balance	−0.030	0.017	−0.280	−2.777	0.280	0.179	4.159	0.046*
	DL balance	−0.034	0.017	−0.319	−2.048	0.319	0.102	4.195	0.048*

DL Dominant Leg, NDL Non-Dominant Leg

ankle dorsal and plantar flexion muscle strength could serve as predictors of reactive strength and balance performance. The primary outcome demonstrated a significant correlation between ankle strength variables and reactive strength as well as balance. Notably, dorsal and plantar flexion strength exerted an impact on both reactive strength and balance.

The initial findings of the study revealed an enhancement in balance performance among this cohort of soccer players with an increase in ankle dorsal flexion strength, particularly in the dominant leg. Furthermore, an improved balance performance was observed with greater ankle plantar flexion strength in both dominant and non-dominant legs. This observation underpins the pivotal role of these muscle groups in ensuring postural stability. Thus, it may be inferred that the foot–ankle complex, being the

sole point of ground contact, functions as a crucial control mechanism in maintaining balance, especially in anatomically neutral positions such as tested in this study. These findings are supported by previous research emphasizing the influence of ankle strength on static postural stability [34, 35]. Moreover, it has been established that balance is reliant on the athlete's muscular strength, with particular emphasis on the role of plantar muscles in influencing foot biomechanics and posture. It has been further asserted that the functionality of foot biomechanics, which establishes ground contact, holds paramount importance in the acquisition of balance proficiency [36–38]. Additionally, Kuczyński et al. [39] have reported that maintaining balance on one leg necessitates precise ankle control.



DL: Dominant Leg, NDL: Non-Dominant Leg, RSI: Reactive Strength Index

Fig. 5 Relationship between ankle plantar flexion strength and RSI

Table 4 The effect of ankle plantar flexion strength on RSI

Predictive variable	Predicted variable	<i>B</i>	Std. error	(β)	<i>t</i>	<i>R</i>	<i>R</i> ²	<i>F</i>	<i>p</i>
DL plantar flexion strength	NDL reactive strength index	0.028	0.017	0.309	2.973	0.309	0.195	3.892	0.047*
NDL plantar flexion strength	NDL reactive strength index	0.028	0.011	0.384	2.531	0.384	0.148	6.404	0.016*
	DL reactive strength index	0.030	0.010	0.446	3.029	0.446	0.199	9.178	0.004*

DL Dominant Leg, NDL Non-Dominant Leg

The critical role of ankle plantar flexor muscles in balance control and movement has been validated by earlier research [40, 41]. Investigations into ankle joint limitations have highlighted the significance of plantar flexion strength in recovering from balance disturbances compared to other muscle groups [42]. The musculo-tendon unit responsible for ankle plantar flexion is the primary site for energy storage and release during movement, making it a key contributor to forward propulsion [43]. Consequently, deficiencies in ankle plantar flexion strength can lead to inefficient propulsion and a reduction in jumping capacity [40]. For instance, Yaggie and McGregor [44] have stated that fatigue in ankle joint muscles may increase postural sway and diminish motor control. Additionally, Gribble et al. [25] proposed that ankle dorsi/plantar flexion

strength could serve as an indicator for evaluating dynamic balance control. The principal conclusion of this finding aligns with previous research, affirming that ankle kinetics exert an influence on dynamic balance characteristics during a range of dynamic tasks, as suggested by previously [40, 41]. In conjunction with our findings, these studies support the pivotal role of ankle mechanics in maintaining balance. Although earlier research [40–45] has laid the foundation, the precise relationship between ankle dorsal and plantar flexion strength and dynamic balance has not been fully elucidated. The present study contributes to the existing body of knowledge by demonstrating that dorsal and plantar flexion strength are indeed correlated with stability during dynamic weight-bearing activities in this cohort of soccer players.

Another finding of our study revealed an increase in RSI as ankle dorsal flexion strength improved in both legs. Additionally, it was observed that an increase in ankle plantar flexion strength in both legs correlated with an increase in RSI. This may be attributed to the active participation of the ankle and knee joints in jump performance. Hence, it may be inferred that intrinsic muscle strength exerts a positive influence on the forceful (explosive) transition from eccentric contraction to concentric contraction during jumping. These findings align with previous research indicating that strength training targeting the ankle flexor muscles leads to a notable improvement in vertical jump performance [45]. Moreover, it has been emphasized that the strength of the ankle flexor muscles plays a crucial role in enhancing dynamic lower extremity functions, including both horizontal and vertical jumps [11, 28, 46]. Additionally, recent studies have highlighted that the ability to generate strength at the ankle joint contributes significantly to the variability observed in single-leg vertical jumps [47–49].

The principal inference drawn from this investigation aligns with prior scholarly works, asserting that ankle kinetics exert a discernible influence on the vertical jump attributes across diverse dynamic tasks [50, 51]. A specific inquiry has demonstrated that the mid-arch of the foot serves as an efficacious conduit for transferring the mechanical power generated by the ankle during propulsion [52]. Notably, antecedent studies have valued the significance of accounting for additional factors pertaining to foot musculature, including arch stiffness [10, 11]. Consequently, it is imperative to recognize that an exclusive focus on dorsal and plantar flexion ankle strength may not suffice to comprehensively explicate the explosive power exhibited during jumping performance. Tourillon et al. [53] accentuated that the isokinetic strength of the ankle plantar flexors furnishes a substantial propulsive impetus during vertical jumping. This concurs with antecedent inquiries that highlight the pivotal role played by ankle plantar flexors in rapidly accelerating during ballistic endeavors [54]. Synthesized with the present study, these investigations note the importance of ankle mechanics in the context of reactive strength. Consequently, ankle strength emerges as a salient parameter necessitating consideration in the evaluation of reactive strength, commensurate with other pertinent variables. While earlier investigations typically employed between-group analyses, the association between ankle dorsal and plantar flexion strength and reactive strength was not examined. In the present study, a correlation between ankle kinetics and strength generation during drop jumps, as assessed by measurements of dorsal and plantar flexion strength was ascertained. In light of these findings, our research contributes clinically relevant insights towards characterizing reactive strength within the framework of ankle strength assessments during jumping conditions.

The study is not without limitations. First, the study was conducted under controlled conditions, and the findings may not fully reflect the complexities of real-world soccer performance in the Turkish national league. Extrapolating these results to competitive match scenarios should be done cautiously, considering the multifaceted nature of soccer dynamics. Second, the study predominantly included male soccer players of a certain age range, namely U18 and U19 youth players. As such, the generalizability of the results to female players and individuals outside this specified age group is limited. Future research should aim to include a more diverse participant pool. Third, in soccer, players can exhibit physical and physiological differences based on playing position, tactical system and style of play and other contextual variables. Therefore, it would be appropriate in future studies to consider these contextual parameters in elite soccer players from varying cohorts, female/male players, players of different age, and different positions and competition standards. This study also only focused specifically on dorsal and plantar ankle flexion strength and the relationship with reactive strength index and balance. Other potential factors, such as ankle range of motion, injury history, and training interventions, were not extensively explored. Future research may consider a more comprehensive examination of these variables. Finally, the study primarily established correlations between dorsal and plantar ankle flexion strength, reactive strength index, and balance performance. While suggestive of associations, establishing causation requires further investigation through controlled intervention studies. Moreover, future research may focus on evaluating force-generating abilities in various lower extremity and trunk joints and any correlation with jumping proficiency. Acknowledging these limitations is crucial for interpreting the results accurately. Future research endeavors should aim to address these limitations for a more comprehensive understanding of the topic.

Conclusions

Our investigation has revealed a significant correlation between ankle dorsal and plantar flexion strength and both RSI and balance performance among youth soccer players. This finding underscores the crucial importance of ankle muscular strength in enhancing both balance and vertical jumping abilities. Proficiency in balance is essential for maintaining optimal body positioning in daily activities and plays a fundamental role in preventing injuries among athletes. Therefore, targeted improvement of ankle strength within this specific cohort could yield positive outcomes in developing postural strategies for soccer players. Furthermore, acknowledging the pivotal role of robust and precise ankle biomechanics in enhancing jumping ability, it is

plausible to suggest that increased ankle strength contributes favorably to the balanced distribution of normal loads and foot displacement.

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Author contribution Conceptualization, R.F.K.; methodology, R.F.K., E.T., S.B., H.İ.C.; formal analysis, R.F.K.; investigation, S.B., H.İ.C.; writing—original draft preparation, R.F.K., E.T., S.B., H.İ.C., R.M., P.T.N.; writing—review and editing, R.F.K., E.T., S.B., H.İ.C., R.M., P.T.N.; supervision, H.İ.C.; All authors have read and agreed to the published version of the manuscript.

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Data availability The data that support the findings of this study are available on request from the corresponding author.

Declarations

Conflict of interest The authors declare no conflict of interest..

Ethics approval and consent to participate The study was approved by the Recep Tayyip Erdogan University Non-Interventional Clinical Research Ethics Committee (Number: E-40465587-050.01.04-148, Date: 24/06/2021). Written informed consent to participate in this study was provided by the participant's legal guardian/next of kin. Informed consent was obtained from all individual participants included in the study.

Consent for publication Not applicable.

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