The Influence of Soccer-specific Metrics on The Interindividual Variance in Response to Plyometric Training on Jump Performance in Elite Youth Soccer Players

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Abstract

Aim: The aim of this study was to explore the association between weekly soccer-specific metrics and the individual variance in response on the Reactive Strength Index (RSI) and Countermovement Jump (CMJ) among elite youth soccer players (U15) during the in-season implementation of low-volume, high-intensity plyometric training.

Method: Twelve subjects from the U15 elite youth soccer team from AaB Academy participated in the study. Subjects performed two specific plyometric training sessions per week, in addition to their regular training session for eight weeks. The intervention protocol consisted of three exercises including Drop Jump, Countermovement Jump, and Squat Jump starting at three sets of three repetitions. Progression occurred throughout the intervention. A pre- (T1) and post- (T2) tests were utilized to examine changes in outcome measurements (RSI and CMJ) and compared to previous assessments (RSI and CMJ) functioning as a baseline test (T0). Multiple soccer-specific metrics (Total Time Played, Total Distance, Total High-speed Running, and Total Sprints) were gathered and included for multiple regression analysis.

Results: Two multiple regression analyses were conducted to predict RSI and CMJ based on readiness, RPE, TTP, TD, THSR, and TS. The regression models could not significantly predict RSI ($F(6,4) = 0.660$, $p = 0.692$) or CMJ ($F(6,4) = 0.472$, $p = 0.804$). A one-way repeated measures ANOVA was conducted to examine potential differences in RSI and CMJ across three timepoints (T0, T1, T2). The exercise intervention led to significant changes in RSI ($F(2, 22) = 12.699$, $p < 0.001$) and CMJ ($F(2, 22) = 9.173$, $p = 0.001$). A Pearson's product-moment correlation was conducted to examine the association between changes in RSI and changes in CMJ from T1 to T2. The correlation analysis indicated a nonsignificant correlation between changes in RSI and changes in CMJ, $r(10) = 0.59$, $p = 0.854$.

Conclusion: In conclusion, this study found that the weekly soccer-specific metrics (TTP, TD, THSR and TS), readiness and RPE do not affect the individual responses to nine plyometric training sessions conducted over eight weeks during the in-season for elite youth soccer players. Significant improvements in means from T1 to T2 were found in both RSI and CMJ. No correlation was found between changes in RSI and CMJ, which leads to the conclusion that the plyometric training program can provide different outcomes. This shows the presence of inter-individual variance in response to training.

Introduction

Soccer is the most popular sport in the world (based on active players) (Dvorak et al., 2004; Stølen et al., 2005). The performance of a soccer player depends on numerous factors such as tactical, technical, mental, and physiological abilities (Stølen et al., 2005). For instance, a soccer player covers 10-12 km during a match and performs 1000-1400 small activity outbursts, which requires high thresholds for both aerobic and anaerobic capacities**,** especially at elite level (Stølen et al., 2005). Even though soccer is primarily dominated by the aerobic energy system, the decisive actions (sprinting, jumping, tackles) are covered by the anaerobic energy system. The utilization of the anaerobic energy system and thereby the release of lactate seems to be one of the points where the elite differs from the sub-elite, where elite soccer players tax the anaerobic energy system to a higher degree and therefore perform these decisive actions superior to the sub-elite players (Stølen et al., 2005). Presently, soccer academies prioritize the early development of soccer athletes to ensure that they meet the rigorous demands of elite competition (Morris, 2000; Strøyer et al., 2004). Various training regimes and methods are used to enhance these anaerobic abilities such as strength, power, change of direction ability, jumping height, speed, running acceleration and repeated sprint ability in highly trained soccer players (Silva et al., 2015). Arnason and colleagues (2004) shows a positive relationship between the success of a team (final league standing), jumping ability, and leg extensor power measured in the extension phase of a squat, suggesting that the speed and acceleration of leg movement is crucial to be at the top of the league (Arnason et al., 2004). All the above drives the conclusion that even though soccer is primarily an aerobic sport, the elite soccer player needs to have an excellent anaerobic system to perform decisive and repetitive actions like acceleration, sprinting, high jumps, and other outbursts to compete at the highest level (Stølen et al., 2005; Silva et al., 2015; Arnason et al., 2004). These outbursts require the ability to swiftly transition from eccentric to concentric muscle contractions. This transition containing an eccentric pre-stretch of the muscle, followed by a concentric contraction is often referred to as the stretch-shortening-cycle (SSC) (Flanagan et al., 2008)**.** One way to quantify the effectiveness of the SSC is by using the reactive strength index (RSI). The RSI-score can be calculated by dividing jump height (cm) with ground contact time (s), for instance performing a drop jump (Flanagan et al., 2008; Rebelo et al., 2022). Plyometric training interventions have shown to significantly increase various athletic abilities, such as kicking distance, jumping ability, and agility in youth soccer athletes (Bedoya et al., 2015; Meylan & Malatesta, 2024). Plyometric training has also shown to be superior, when compared with resistance training or a combination of the two, when the goal is to enhance RSI (Rebelo et al., 2022). For instance, Ramirez-Campillo and colleagues (2014) has shown that a 7 week, in-season, low-volume, high-intensity plyometric training program increases the RSI in youth amateur soccer players with no experience in plyometric or resistance training (Ramírez-Campillo et al., 2014). Furthermore, a meta-analysis by Oliver and colleagues (2023) shows that highly trained youth soccer players (<18 years) experience small to moderate gains in strength, power, and speed after short (>12 weeks) interventions of strength training, combined training or plyometric training (Oliver et al., 2023). These findings support the tracking and testing of the RSI and implementation of plyometric training to enhance this. However, a problem with plyometric training and training in general is that every individual responds differently to the same identical training protocol (Carpinelli, 2017; Karavirta et al., 2011; Radnor et al., 2016; Ramirez-Campillo et al., 2018). Ramirez-Campillo et al. (2018) explore inter-individual variability in the response to plyometric training. Following a RCT design using an experimental group (plyometric jump training) and a control group (usual soccer training) 18 out of 38 (47,4%) subjects responded positively to the training intervention when measuring performance in CMJ. When measuring performance in RSI20 (20cm drop height) and RSI40 (40cm drop height) 33 (86,8%) and 29 (76,3%) subjects responded positively. Noticeable is sprinting performance where only 4 (10,5%) subjects responded positively highlighting the individual variance in response to in-season plyometric training. The reasoning behind the individual variance in response might be due to various reasons including genetics, prior experience regarding numerous training protocols, quality of sleep, habitual physical activity level resulting in different amount of recovery, and mental fortitude thus ability to execute high intensity training (Carpinelli, 2017; (Bouchard et al., 2010; Hautala et al., 2023; Lamberts et al., 2010; McPhee et al., 2010)**.**

In elite soccer, in-season training holds great importance for strength and conditioning coaches. Therefore, careful management is crucial to optimize performance outcomes and mitigate the risk of over-training, which could otherwise diminish overall performance levels. A study by Kreamer and colleagues (2004) followed 25 players during 11 weeks of in-season. The study suggests that players who enter the season with a catabolic environment in the neuromuscular system due to high intensity pre-season training are likely to experience a decrease in strength and performance during the in-season period (Kraemer et al., 2019). Similarly, Filaire and colleagues (2003) examined 20 players for a whole year, focusing on both biological, hormonal, and physiological parameters at four different timepoints, showing that when being in-season and performing moderate-volume, high-intensity training, biomarkers (cortisol and uric acid) for a catabolic environment was increased. At the end of the season where strength training volume was reduced, so was the cortisol levels (Filaire et al., 2003). These findings indicate that additional in-season training should be carefully evaluated during implementation. Moreover, they underscore the significance of balancing overall soccer training, strength training, and match volume to optimize performance outcomes. This variation in different training intensities and training methods might contribute to the explanation of the earlier mentioned variations in response to in-season training.

Despite the clear importance of balancing the overall training methods, volume and intensity when dealing with elite soccer players there is to our knowledge only one study (Collins et al., 2024) that describes the influence of soccer-specific metrics on the variation of adaptation to plyometric training. However, this particular study is a preprint under review. The increasing use of GPS-trackers in soccer provides metrics on the individual players' workload during the season and makes it possible to track different match metrics and intensities, such as Time Played, Running Distance, High-speed Running, and Sprints (Hennessy & Jeffreys, 2018). The unresolved question involves the impact of these different soccer-specific metrics during the competitive season on the potential effectiveness of structured and periodized plyometric training characterized by low-volume and high-intensity. It is of scientific interest to explore whether players with variations in weekly volume and intensity from combined soccer training and competitive matches demonstrate variance in response to such plyometric strength training. This information could be important for strength and conditioning coaches when planning periodized individual training for youth elite soccer players.

Therefore, the aim of this study was to explore the association between weekly soccer-specific metrics and the individual variance in response on the RSI and countermovement jump (CMJ) among elite youth soccer players during the in-season implementation of low-volume, high-intensity plyometric training.

Methods

Experimental design

A group of 18 youth soccer players from the U15 team at AaB Academy were recruited for an eight-week in-season plyometric training program. Originally planned for six weeks, the intervention was extended due to in-season commitments such as matches and a training camp. The week before and after the training intervention, pre- (T1) and post- (T2) testing sessions were conducted. Additionally, eight weeks prior to the intervention, the same tests were administered (T0) as no control group was employed. T0 was executed by the Head of strength and condition coach and was not a part of the present study's training intervention. T0 was solely used as a comparison group to see if the training executed in the present study's intervention was the cause behind any significant changes. The evaluation included two tests: RSI and CMJ. Throughout the intervention, participants assessed their readiness before each plyometric session, and after each session, they rated their Rate of Perceived Exertion (RPE). Soccer-specific metrics were gathered for competitive matches and soccer training during the intervention period using GPS trackers, consisting of Total Time Played (TTP), Total Running Distance (TRD), Total High-Speed Running (THSR), and Total Sprints (TS). All collected data were analyzed statistically to address the following inquiries: whether match metrics, RPE, and readiness could predict the interindividual response of the 8-week in-season plyometric training intervention measured on RSI and CMJ; whether the intervention had an effect by comparing performance in RSI and CMJ at three timepoints T0, T1, T2; whether there were individual variations in adaptation to the intervention.

Subjects

This study focused on the U15 team (n=18) from the local soccer club AaB Academy, participating in the premier Danish youth league. However, only data from 12 players were included in the descriptive statistics and statistical analysis regarding improvements in RSI and CMJ. 11 players were included in the multiple regression. This exclusion was due to some players not utilizing GPS trackers (such as goalkeepers) and others experiencing injuries during the intervention period, though these injuries were not related to the intervention. On average, all players engaged in 9.07 ± 0.52 hours of weekly exercise, consisting of a combination of regular soccer practice sessions and competitive matches. Typically, this weekly amount of exercise was divided into five regular training sessions and one competitive match per week. Additionally, each player underwent an average of 0.58 ± 0.06 hours of plyometric strength training per week. Before the intervention, none of the players had previously undergone a periodized plyometric training regimen specifically targeting the RSI. The testing and training protocols were conducted in collaboration with the Head of Strength and Conditioning coach at AaB Academy. Table 1 presents descriptive data for all 12 participants included in the analysis.

TABLE 1. Descriptive Statistics (Mean ± SD).*

Age (y)	Height (cm)	Weight (kg)
14.80 ± 0.19	173.65 ± 6.96	59.48 ± 6.48

* Mean ± SD for all included players (n=12)

Tests

Anthropometrics

Anthropometric measurements were gathered before the pretesting protocols and consisted of age (y), height (cm), and weight (kg). Height was quantified using the Seca 217 stadiometer (Seca, Germany), and weight using the MPK 200K-1P scale (Kern & Sohn, Germany).

Reactive Strength Index and Countermovement jump

Testing occurred five days prior to the intervention and five days post the last training session. Prior to conducting the RSI30 and CMJ tests, participants completed a seven-minute warm-up routine. This warm-up included four minutes of general, self-selected warm-up activities followed by three minutes of dynamic stretching. This standardized warm-up protocol is regularly employed on test days at the academy, ensuring consistency across testing sessions at T0, T1, and T2.

Following the warm-up, the RSI test was conducted. Participants performed drop jumps from a 30 cm height box to assess RSI. Each player completed three attempts with 3-minute rest intervals between sets, and the best RSI value was selected for further analysis. Players were instructed to minimize ground contact time and maximize jump height with arms akimbo. During testing, an optical system comprising a transmitting and receiving bar (Optojump, Microgate, Italy) recorded ground contact time (s) and flight time (s). The RSI30 was calculated by dividing jump height by ground contact time. Jump height was calculated using the formula: jump height = (flight time^2 × gravity)/8.

Following a 3-minute break, participants proceeded to the CMJ test. Each participant performed three attempts, with the option for additional attempts if performance improved, until a decline in performance was observed. Three-minute rest periods were provided between attempts. Players were instructed to initiate a slight downward movement before swiftly pushing themselves upward, maintaining arms akimbo and extended knees and hips throughout the jump. During testing, an optical system comprising a transmitting and receiving bar (Optojump, Microgate, Italy) recorded flight time. Jump height was calculated with the earlier mentioned formula.

Readiness and Rate of Perceived exertion

Readiness was evaluated through a subjective questionnaire comprising four questions that assessed sleep quality, stress level, fatigue, and muscle soreness. Each topic was rated on a scale from 1 to 10, where 1 indicated the best condition (e.g., good sleep, low stress, no fatigue, and no muscle soreness), and 10 represented the worst condition (e.g., poor sleep, high stress, extreme fatigue, and severe muscle soreness). Participants were familiarized with the scales and asked to rate their current subjective feeling right before each training session. The readiness score for each player was computed as the total sum of the ratings for the four topics, with a score of 4 indicating the best possible readiness and 40 indicating the worst (Moalla et al., 2016). The average readiness score for each player throughout the intervention period was determined by summing the readiness scores for all training sessions and dividing by the individual attendance. After each plyometric strength training session, players were required to assess the subjective intensity using the Rate of Perceived Exertion (RPE) scale, which ranges from 0 to 10 (CR10), with 0 representing hardly any exertion and 10 signifying maximum effort. The average RPE score was calculated using the same method applied for readiness assessment (Moalla et al., 2016).

Match and training data

Match and training data was gathered by GPS-trackers (Fieldwiz, Insiders, Suisse) to monitor soccer-specific metrics from pre- to posttesting. The metrics included TTP (h), TD (m), THSR (distance (m) covered at speeds between 19.8-25.1 km/t), TS (distance (m) covered at ≥25.2 km/h). The total weekly volume for each metric was calculated by summing up the daily values of the respective metric lasting from pre- to posttesting divided by weeks during the intervention period.

Intervention

Integrating a progressive and periodized training protocol as an intervention during the competitive season (in-season) presents challenges. The competitive season revolves around weekly matches, typically held on weekends, with occasional midweek fixtures. When midweek matches occur, the standard weekly periodization involving both soccer and strength training may need adjustments, potentially shortening or extending the intended periodization. The current study's intervention period was disrupted by midweek matches, a training camp, and a school camp. As a result, the intervention had to be extended to accommodate completing as many training sessions as possible out of the initially planned 12. The subsequent sections will outline the initial intervention periodization and the actual structure that unfolded due to these adjustments.

Participants were scheduled to undergo indoor plyometric training sessions twice per week, specifically on Mondays and Wednesdays, preceding their regular soccer training. These sessions took place at the academy’s fitness facilities. The intervention was set to span six consecutive weeks during the competitive season. However, due to the competitive nature of the season, the intervention had to accommodate weekly periodization. The team encountered three midweek matches, followed by a six-day training camp and a seven-day school camp, extending the intervention period by three weeks. Consequently, the number of training sessions were fewer than initially intended. On average, players attended 7.11 ± 1.88 out of the 9 possible sessions. The final structure of the intervention period deviated from the initial plan and is detailed in the model below (Figure 1).

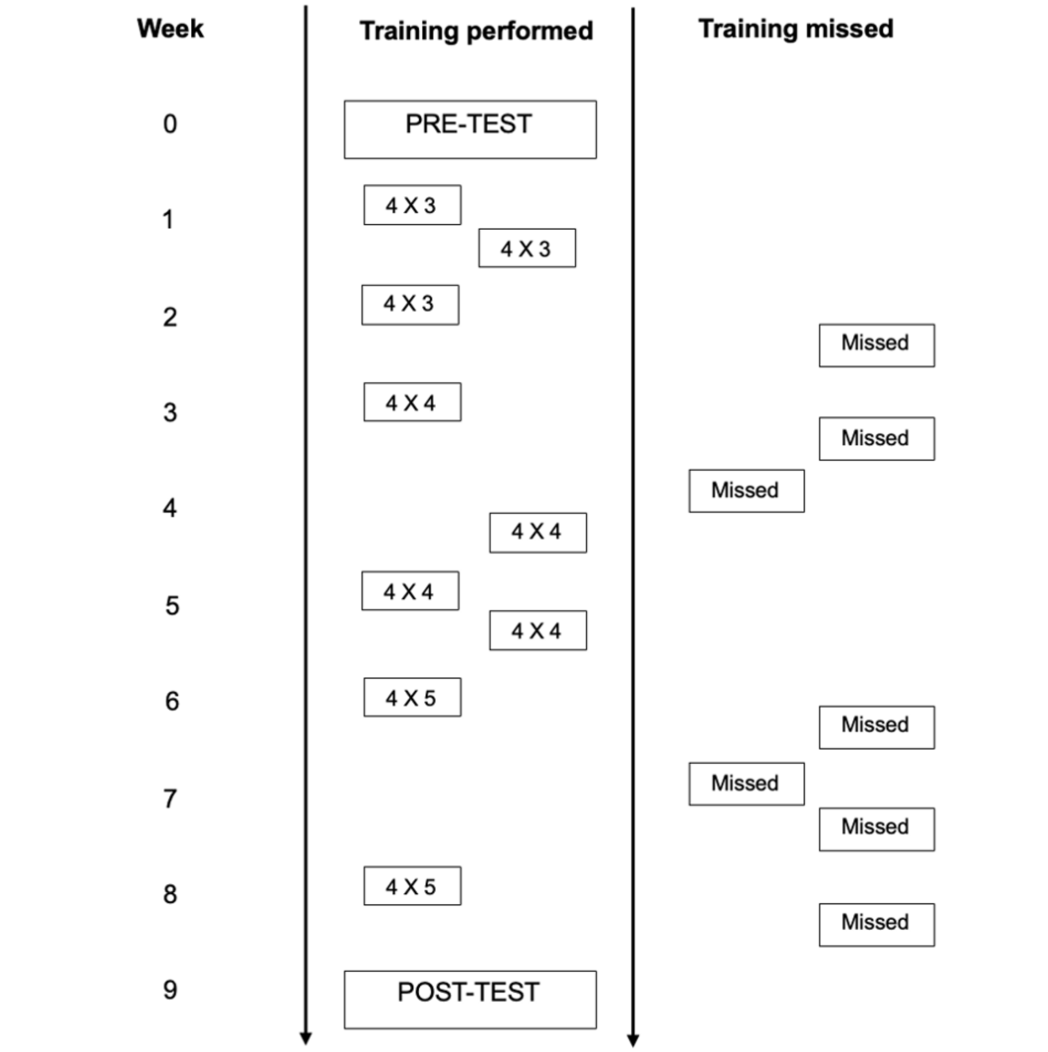

Figure 1. Completed and missed training sessions during the intervention, including the set- and repetition scheme for each training (set X repetition)

Plyometric training

Throughout the intervention, strict supervision and specific instructions on exercise execution was imposed during all training sessions. Before training, players performed a standardized warm up consisting of four exercises including legswings (front-to-back), legswings (side-to-side), tip-toe squats and pogo jumps. The training program consisted of three different plyometric exercises, 40cm drop jump (DJ40), CMJ and squat jumps (SJ) each done with identical sets and repetitions. Throughout the seven-week intervention period, the nine total training sessions followed a progression scheme (Figure 1). Players were allocated two minutes to complete each set of the respective exercise and to secure adequate rest between following sets. Typically, this resulted in performance durations of 10-30 seconds and rest periods of 90-110 seconds, with the performance duration increasing progressively and the rest duration decreasing. The subjects were given identical, standardized instructions that matched those delivered during the testing protocol for DJ and CMJ. For SJ players were instructed to perform a slight downward movement before quickly reversing themselves into the air. Arms held in front of the torso during the lowering phase and intuitively on the upward phase. Knees and hips extended during the jump. Repetitions were done repetitively with no rest between reps.

Statistical analysis

Data analysis was conducted using IBM SPSS Statistics (Version 29.0, IBM Corp). A significance level of 0.05 was applied to all tests, rendering p-values below this threshold as significant. Normality of the data was assessed through both the Shapiro-Wilk test and Q-Q plots, with potential outliers observed using boxplots (equation 1a,b-2a,b) (*Lab 5: Testing Our Way to Outliers*2013).

Outliers

$$1a = 3rd\ quartile\ +\ 1.5 * interquartile\ range$$
$$1b = 1st\ quartile\ -\ 1.5 * interquartile\ range$$

Extreme outliers

$$2a\ =\ 3rd\ quartile\ +\ 3 * interquartile\ range$$
$$2b\ =\ 1st\ quartile\ -\ 3 * interquartile\ range$$

The primary statistical method employed was a multiple regression analysis, with one dependent variable (RSI or CMJ) and several independent variables (TTP, TD, THSR, and TS). Assumption testing (such as linearity, homoscedasticity, and multicollinearity) preceded the finalization of the multiple regression analysis. The purpose of the multiple regression analysis was to evaluate the prediction of the dependent variable based on multiple independent variables. The fit of the model was assessed based on the adjusted R-square, while statistical significance was determined by the p-value. The adjusted R-square also functioned as an estimate of effect size, following Cohen's (1992) classification, with values of 0.10, 0.30, and 0.50 considered small, medium, and large (Cohen, 1992). The secondary statistical analysis was a one-way repeated measures ANOVA which was employed to determine if there was a statistically significant difference between the mean values of three levels of a within-subject factor. This statistical analysis was specifically conducted on the two outcome variables, RSI and CMJ. Given that the intervention only involved pre- (T1) and post-tests (T2), the prior assessment (T0) on both RSI and CMJ served to determine if any significant changes in means resulted from the intervention executed in this study. The prior assessment was done 8 weeks before T1. This ensures that the gap between each of the three test days (T0, T1, T2) is comparable in terms of time. The effect size between the changes was calculated using the Cohen's d equation, which consists of the mean value of two timepoints (T0-T1, T-1-T2, T0-T2) and the respective standard deviation (equation 3) since the pairwise comparisons in a repeated measures ANOVA do not incorporate effect size values. Values of 0.20, 0.50, and 0.80 are considered small, medium, and large.

$$d = \frac{mean_a - mean_b}{SD}$$

At last, a Pearson's product-moment correlation was conducted to assess the relationship between changes in RSI and CMJ, in which *r* will function as both the correlation coefficient and a value for effect size. Values of 0.10, 0.30, and 0.50 are considered small, medium, and large. If any outliers are found during testing of assumptions, these will be evaluated.

Results

Questionnaire and soccer-specific metrics

On average, players attended 8.17 ± 0.83 out of the 9 possible sessions. Resulting in 90.74% compliance. The results of the questionnaire regarding readiness and RPE at each training and the total weekly volume of soccer training are shown in Table 2.

TABLE 2. Readiness, Rate of Perceived Exertion and soccer-specific metrics

	Mean ± SD	95% CI	
		LL	UL
Readiness	14.37 ± 3.29	12.16	16.58
RPE	4.32 ± 1.30	3.45	5.20
TTP (h)	9.07 ± 0.52	8.72	9.42
TD (m)	44195.94 ± 5244.47	40672.65	47719.22
THSR (m)	1411.34 ± 587.44	1016.69	1805.99
TS (m)	181.72 ± 139.11	94.26	281.17

LL = Lower Limit, UL = Upper Limit, RPE = Rate of Perceived Exertion, TTP = Total Time Played, TD = Total Distance, THSR = Total High-speed Running (19.8-25.1 km/h), TS = Total Sprints (≥25.2 km/h)

Influence of soccer-specific metrics

Two multiple regression analyses were conducted to predict RSI and CMJ based on readiness, RPE, TTP, TD, THSR, and TS. However, the regression models could not significantly predict RSI ($F(6,4) = 0.660$, $p = 0.692$) or CMJ ($F(6,4) = 0.472$, $p = 0.804$). None of the six variables made a statistically significant contribution in predicting either RSI or CMJ ($p > 0.05$) (Table 2A-2B).

TABLE 3A. Multiple regression results for RSI

RSI	*B*	95% *CI for B*		*SE B*	*β*	R^2	ΔR^2
		LL	*UL*				
Model						.497	-.257
Readiness	-.008	-.103	.088	.034	-.103		
RPE	-.005	-.385	.376	.137	-.024		
TTP	-.001	-.005	.002	.001	-1.395		
TD	<.001	-.000	.000	.000	1.701		
THSR	<.001	-.000	.000	.000	.424		
TS	-.001	-.002	.001	.001	-1.057		

TABLE 3B. Multiple regression results for CMJ

CMJ	*B*	95% *CI for B*		*SE B*	*β*	R^2	ΔR^2
		LL	*UL*				
Model						.414	-.464
Readiness	-.140	-1.080	.801	.339	-.200		
RPE	-.928	-4.674	2.818	1.349	-.523		
TTP	.020	-.014	.054	.012	2.865		
TD	<.001	-.001	.000	<.001	-3.129		
THSR	.001	-.003	.005	.001	.615		
TS	.002	-.013	.016	.005	.365		

Model = overall fit; *B* = unstandardized regression coefficient; *CI* = confidence interval; *LL* = lower limit; *UL* = upper limit; *SE B* = standard error of the coefficient; *β* = standardized coefficient; R^2 = coefficient of determination; ΔR^2 = adjusted R^2.

RPE = Rate of Perceived Exertion; TTP = Total Time Played; TD = Total Distance; THSR = Total High-speed Running; TS = Total Sprints.

p <.05

Response to plyometric training

A one-way repeated measures ANOVA was conducted to examine potential differences in RSI and CMJ across three timepoints (T0, T1, T2) spanning approximately four months. Despite two outliers in the T2 group, these were retained in the analysis since adjusting these values did not significantly alter the group mean ($p = 0.166$). Although the data deviated from normality (Shapiro-Wilk test, $p = 0.039$), the ANOVA is robust against such violations (Blanca et al., 2017). Notably, there were no outliers in the other groups, and their data was normally distributed ($p > 0.05$), confirmed via boxplot and Shapiro-Wilk test, respectively. The assumption of sphericity was met as indicated by Mauchly's test of sphericity for both RSI ($\chi 2(2) = 1.20$, $p = 0.548$) and CMJ ($\chi 2(2) = 2.19$, $p = 0.334$). The exercise intervention led to significant changes in RSI ($F(2, 22) = 12.699$, $p < 0.001$) and CMJ ($F(2, 22) = 9.173$, $p = 0.001$). Post hoc analysis using Bonferroni adjustment revealed that RSI did significantly differ between T0 (1.67 ± 0.45) and T2 (1.95 ± 0.38) ($p = 0.024$, effect size = -0.936) and between T1 (1.53 ± 0.38) and T2 ($p < 0.001$, effect size -1.691), with no significant difference between T0 and T1 ($p > 0.05$) (Figure 2). Similarly, for CMJ a significant difference was noted between T0 (35.65 ± 4.05) and T2 (38.80 ± 4.07) ($p = 0.002$, effect size = -0.375) and between T1 (36.81 ± 4.18) and T2 ($p = 0.028$), with no significant difference between T0 and T1 ($p > 0.05$, effect size = -0.909) (Figure 3).

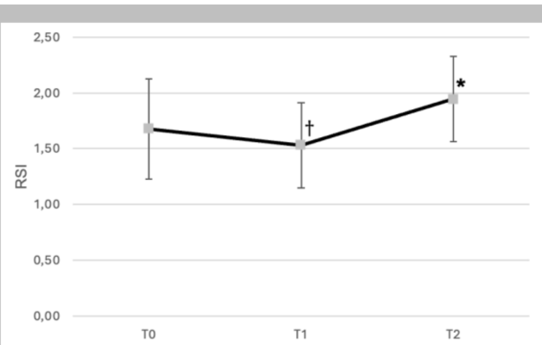

Figure 2. Mean RSI score at three timepoints (T0, T1, T2).
* = significantly different from T0 and T1 (p > .05)
† = significantly different from T2 (p > .05)

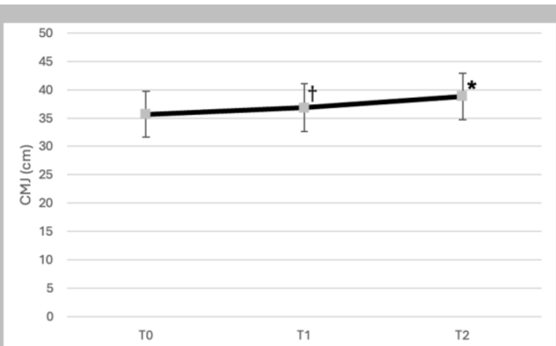

Figure 3. Mean CMJ score at three timepoints (T0, T1, T2).
* = significantly different from T0 and T1 (p > .05)
† = significantly different from T3 (p > .05)

Correlation in response

Despite a significant change in means across T1-T2, the individual changes in RSI and CMJ showcase the interindividual variance in response to training. In the present study, the percentage of change in RSI ranged from 1.73 to 70.41% and for CMJ from -7.45 to 14.24%. A Pearson's product-moment correlation was conducted to examine the association between changes in RSI and changes in CMJ from T1 to T2. The correlation analysis indicated a nonsignificant correlation between changes in RSI and changes in CMJ, r(10) = 0.59, *p* = 0.854 (Figure 4). Included in figure 4 is also the TD, to showcase the non-relation between a match metric and the differences in RSI and CMJ.

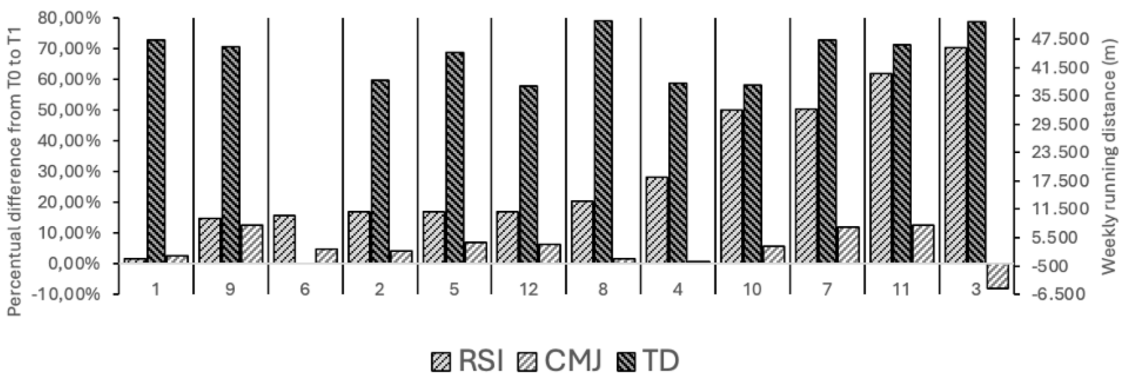

Figure 4. Percentual differences in RSI and CMJ from pre- to posttest with total running distance (weekly) for each individual player. RSI = Reactive Strength Index, CMJ = Countermovement Jump, TD = Total Distance (weekly), 1-12 = Player number.
No running distance available for player 6 (goalkeeper).

Discussion

The aim of this study was to investigate the relationship between weekly soccer-specific metrics and individual variations in RSI and CMJ among elite youth soccer players during the implementation of low-volume, high-intensity plyometric training within the competitive season. Despite employing multiple statistical tests, the primary finding from the multiple regression analyses revealed no ability to predict the dependent variables, RSI and CMJ based on the independent variables (Readiness, RPE, TTP, TD, THSR, and TS). This indicated that in-season volume and intensity of soccer-specific activities (training sessions and competitive matches) were unrelated with the improvements observed in RSI and CMJ.

Although the multiple regression analyses did not yield predictive results, the secondary finding from the One-way repeated measures ANOVA indicated significant differences in means across three timepoints (T0, T1, T2) for both RSI and CMJ. Specifically, there was a substantial 27.5% change from T1-T2 in RSI and for CMJ, a 5.41% change from T1-T2 was found, with no significant change from T0-T1 in both RSI and CMJ highlighting the meaningful impact of the intervention protocol on both RSI and CMJ.

Furthermore, the tertiary finding from Pearson's product-moment correlation demonstrated no significant correlation between the percentage change in RSI and the percentage change in CMJ. This suggests that individuals who experienced the greatest improvement in RSI did not necessarily exhibit similar improvements in CMJ.

Overall, these results underscore the effectiveness of the plyometric training intervention in enhancing RSI and CMJ among elite youth soccer players, despite the lack of predictability from the analyzed soccer-specific metrics. Despite significant change in RSI and CMJ, it is important to highlight the interindividual difference shown by the notable range in percentage of change in both RSI (1.73 to 70.41%) and CMJ (-7.45 to 14.24%).

When comparing the results of the multiple regression analyses with the results by Los Arcos and colleagues (2015), whose aim was to examine the usefulness of the rating of perceived exertion training load (sRPE) on neuromuscular performance variables during 9 weeks of soccer training in young professional players, similarities appear (Los Arcos et al., 2015). Los Arcos and colleagues (2015) intervention ran through the pre- (5 weeks) and in-season (4 weeks), which might influence the comparison, however, when comparing training volumes for both the present study (4897.8 min) and Los Arcos et al. (2015) (4600 min), the comparison might be practical. The result of a Pearson's product-moment correlation between changes in CMJ and training volume (min) showed r = -0.42, however the test was nonsignificant (Los arcos et al., (2015). Furthermore, when considering RPE measures in relation to leg musculature (RPEmus) effort and sumRPEmus (sum of all muscular perceived efforts) the perception of increase in training load and intensity correlates negatively with physical attributes such as single leg dominant (r = -0.54) and non-dominant (r = -0.52) CMJ height. A paired sample t-test between pre- and posttest (CMJ), respectively 41.9 ± 4.3 and 42.9 ± 4.2 showed non statistical significance too (Los arcos et al., 2015) This might indicate that the sole increase in training load and intensity do not affect performance negatively, if certain adjustments for both volume and intensity during a periodization is present, and that the negative correlation seen in Los Arcos et al. (2015) primarily is due to the individual's perception of increasing volume, which might translate into a more significant feeling of accumulated fatigue. Another study done by Collins et al. (2024) investigates the association between internal and external training load on neuromuscular performance (NMP) on elite soccer players. A multiple regression of force time curve metric (the method used to measure jump height and time to take off, which are the metrics used in a modified reactive strength index (RSI-mod)) and internal (sRPE x duration) and external training (GPS metrics) load for a 7-day training window was not able to predict changes in RSI based on training load (p = 0.210), High-speed running (p = 0.118), and Sprint distance (p = 0.560). The regression was however able to statistically significantly predict changes in RSI-mod based on Total distance (0.049), which is a contradicting finding compared to the findings of the present study. The multiple regression analysis was done for a 7-, 14-, and 28-day training window. For all the training windows, only Total distance (7-day) and High-speed running (14-day) was able to statistically significantly predict RSI-mod, while all other external training metrics (Training load, Sprint distance, Accelerations, Decelerations) failed to statistically significantly predict RSI-mod (p > 0.05) (Collins et al., 2024). These findings are contradicting when comparing the influence of soccer-specific metrics found in the present study. The reason for opposite results could be due to the difference in sample sizes or the subjects recruited. The subjects in the study by Collins and colleagues (2024) performed two weekly strength training sessions, where in the present study two plyometric training sessions were performed. This could indicate that if elite players perform training targeting NMP and especially RSI-training, the decrease in RSI performance due to soccer training might not be present.

The plyometric strength training employed in the present study, resulted in a significant change in both RSI and CMJ. De Hoyo and colleagues (2016), found similar changes in CMJ following plyometric training on elite U19 soccer players in-season. De Hoyo and colleagues (2016) find a statistically significant increase of 7.2% in CMJ height from pre- to posttest (8 weeks) compared to the increase in CMJ from the present study (5.41%) (De Hoyo et al., 2016). A study done by Ramírez-Campillo et al. (2014) finds changes in RSI20 (20 cm) and RSI40 (40 cm) as the present study. Ramírez-Campillo and colleagues (2014) found a 22.2% increase in RSI20 and 16.0% increase in RSI40 following a 7-week intervention period consisting of plyometric training. The study by Ramírez-Campillo et al. (2014) was done on amateur soccer players (age 10-16) with a weekly schedule of two soccer training sessions and one competitive match (pre-season), which deviate from the players recruited in the present study, having a weekly schedule of five soccer training sessions and one competitive match. This might indicate that the potency of plyometric training and thus a new training stimulus potentially have the ability to change certain physical abilities in both elite and amateur soccer players both in-season and pre-season.

When comparing the results of the Pearson's product-moment correlation with the results by Ramírez-Campillo et al. (2018) the phenomenon of interindividual variability to strength training seems inevitable. Ramírez-Campillo and colleagues (2018) find an increase of 4.4 ± 3.8, 23.3 ± 17.3, and 16.7 ± 13.2 (%) on CMJ, RSI20, and RSI40, respectively. However, only 18 out of 38 soccer players in the experimental group responded to plyometric training, implying that out of the 18 responders, some responded significantly better to the induced stimuli caused by the intervention protocol than others, while some of the 20 nonresponders got worse in CMJ. In the present study, the reasoning behind why some individuals improved significantly more in RSI than CMJ might be due to some players having less experience with plyometric training and the SSC than other players. For example, the player with the highest RSI-score at T1 improved 14.66% while the player with the lowest RSI-score improved 61.70%.

The interindividual variance in response to training reported in this study, matches results of similar studies on this phenomenon in relation to plyometric training (Ramírez-Campillo et al., 2018, Radnor et al., 2016). Furthermore, this variance is reported to occur when performing endurance training (Karavirta et al., 2011) or other forms of resistance strength training (Radnor et al., 2016; (Beaven et al., 2008); Carpinelli, 2007). It has also been shown that the inter-individual variance in response can be detected in all age group and in both males and females (Radnor et al., 2016, Beaven et al., 2008, Carpinelli, 2007, Ramírez-Campillo et al., 2018, Karavirta et al., 2011). The explanation of the interindividual response to training seems to be multifactorial, as genetics (Bouchard et al., 2011), maturity status (Radnor et al., 2016), base-line fitness (Hautala et al., 2003), perception of training intensity (McPhee et al., 2010), inter-individual recovery rates (Lamberts et al., 2010) and stress (Bartholomew et al., 2008) all seem to influence the response to training. Based on the results of the present study, these soccer-specific metrics do not seem to influence the change in RSI and CMJ, thus these changes might be explained by various other factors. In the present study all of the above-mentioned factors could be confounding resulting in the interindividual response to the current plyometric training program, however some factors may have been accounted for. In the present study stress and recovery is accounted for through the questionnaire and is a part of the readiness score, which was included in the multiple regression analysis, showing that readiness was a non-predictive factor explaining the changes in the outcome-measures (RSI and CMJ), even though this was not physiological tested for. The perception of training intensity could maybe explain some of the variance in this study as the players did not receive feedback during the execution of each exercise and therefore there could be differences in intensities for each subject. It is also well known that maturity status effects the response to training (Radnor et al., 2016; Cumming et al., 2017; (Malina et al., 2007), and working with youth soccer players it seems unavoidable that this has had an influence on the interindividual response in the current study. The age of the subjects in this study (14.80 ± 0.19), is near the age of the growth spurt occurring (Peak Height Velocity, PHV, age 13.80-14.20) for Danish boys (Philippaerts et al., 2007). Another important highlight is that sample size and lack of variance across the independent variables due to highly similar training protocols might have influenced the multiple regressions analyzes negatively.

Another finding in the present study is the mean improvement in both RSI and CMJ. To enhance the RSI, as seen from T1 to T2, it requires an athlete to shorten ground contact time and/or enhance the jumping height as the RSI is the calculated by the jump height divided by ground contact time (Rebelo et al., 2022, Flanagan & Comyns, 2008). The same factors are not present when performing a CMJ, because this is only reported by jumping height. This is also why the two exercises are categorized in two, the RSI as being a fast SSC exercise and the CMJ being a slow SSC exercise (Flanagan & Comyns, 2008). The plyometric training program performed in the current study was more fast SSC-focused, which might explain the greater enhancement in RSI compared to CMJ. The subjects in the present study were used to the testing protocol and performed this several times a year at the academy, but none of the players specifically trained this during the year, which is why the phenomenon known as specificity of training might have been a root cause in the change in RSI and CMJ (Flanagan & Comyns, 2008).

The present study has several limitations that should be acknowledged. Firstly, the experimental design did not include a control group to compare the effects of the intervention protocol. Although previous measures of RSI and CMJ were available for comparison, the strength training performed between T0 and T1 varied based on the individual player's strengths and weaknesses. This variation means that some players might have engaged in plyometric training, potentially causing a bias towards weaker progression compared to players who did not do any plyometric training. However, since the measurements of RSI and CMJ previously done (T0) have been systematically and identical as the approach of the present study, it is fair to acknowledge that the changes seen in RSI and CMJ primarily are mediated by the intervention protocol. Secondly, the extension of the initial intervention protocol might have influenced the changes in RSI and CMJ. For some players, the unstructured progression in volume and the extended break from plyometric training could have led to greater progression due to accumulated external load caused by higher values of the soccer-specific metrics. Conversely, for other players, this lack of structure might have resulted in weaker progression in intramuscular coordination, leading to weaker results. This variability might explain some of the variation in the nonsignificant correlation between RSI and CMJ. Thirdly, the considerable small number of players participating in this study, thus a small sample size together with a potentially significant lack of variability in the independent variables makes it difficult to, at least with some amount of certainty, generalize the findings of the multiple regression analyzes with the belonging population. To strengthen the ability to generalize the findings of a multiple regression analysis, multiple teams across multiple age groups from different clubs and regions should be included in such analysis, since this would heighten the possibility of variability within the dataset.

Conclusion

In conclusion, this study found that the weekly soccer-specific metrics (TTP, TD, THSR and TS), readiness and RPE do not affect the individual responses to nine plyometric training sessions conducted over eight weeks during the in-season for elite youth soccer players. Significant improvements in means from T1 to T2 were found in both RSI and CMJ. No correlation was found between changes in RSI and CMJ, which leads to the conclusion that the plyometric training program can provide different outcomes. This shows the presence of interindividual variance in response to training.

Practical application

Strength and conditioning coaches at elite youth academies can use these findings when planning in-season plyometric training to target RSI or CMJ. The current findings show that it is possible to enhance both RSI and CMJ in-season with two weekly plyometric training sessions. The periodization, rep scheme, and intensity used in this study's protocol can serve as a guide. The present study also finds that it is not possible to predict in which measure (RSI and CMJ) the enhancement occurs, and that the benefits of this plyometric training program is highly individual. This underscores that, at least based on the findings of the present study, that individual training based on weekly volume from regular soccer training and competitive matches is not rewarding. The importance of regular evaluation and testing of individual responses to specific training protocols to ensure the desired adaptations occur for each player might be a better investment of time.

References

Arnason, A., Sigurdsson, S. B., Gudmundsson, A., Holme, I., Engebretsen, L., & Bahr, R. (2004). *Physical Fitness, Injuries, and Team Performance in Soccer*. Ovid Technologies (Wolters Kluwer Health). 10.1249/01.mss.0000113478.92945.ca

Bartholomew, J. B., Stults-Kolehmainen, M. A., Elrod, C. C., & Todd, J. S. (2008). *Strength Gains after Resistance Training: The Effect of Stressful, Negative Life Events*. National Strength and Conditioning Association.

Beaven, C. M., Cook, C. J., & Gill, N. D. (2008). *Significant Strength Gains Observed in Rugby Players after Specific Resistance Exercise Protocol Based on Individual Salivary Testosterone Response*. National Strength and Conditioning Association.

Bedoya, A. A., Miltenberger, M. R., & Lopez, R. M. (2015). *Plyometric Training Effects on Athletic Performance in Youth Soccer Athletes: A Systematic Review*. National Strength and Conditioning Association.

Bouchard, C., Sarzynski, M. A., Rice, T. K., Kraus, W. E., Church, T. S., Sung, Y. J., Rao, D. C., & Rankinen, T. (2010). *Genomic predictors of the maximal O uptake response to standardized exercise training programs*. American Physiological Society. 10.1152/japplphysiol.00973.2010:10.1152/japplphysiol.00973.2010

Carpinelli, R. N. (2017). *Interindividual Heterogeneity of Adaptations to Resistance Training*. Medicina Sportiva.

Cohen, J. (1992). *A Power Primer*. The American Psychological Association.

Collins, J. J., Malone, S., & Collins, K. D. (2024). *Relationship between internal and external training load metrics on neuromuscular performance*. Research Square Platform LLC. 10.21203/rs.3.rs-4228563/v1

De Hoyo, M., Gonzalo-Skok, O., Borja, S., ˜udo, Carrascal, C., Plaza-Armas, J. R., Camacho-Candil, F., & Otero-Esquina, C. (2016). *Comparative Effects of In-Season Full-Back Squat, Resisted Sprint Training, And Plyometric Training on Explosive Performance in U-19 Elite Soccer Players*. National Strength and Conditioning Association.

Dvorak, J., Junge, A., Graf-Baumann, T., & Peterson, L. (2004). *Editorial*. SAGE Publications. 10.1177/0363546503262283

Filaire, E., Lac, G., & Pequignot, J. (2003). *Biological, Hormonal, And Psychological Parameters in Professional Soccer Players Throughout a Competitive Season*. Perceptual & Motor Skills.

Flanagan, E. P., Comyns, T. M., & U M M A R Y, S. (2008). *The Use of Contact Time and the Reactive*

Strength Index to Optimize Fast Stretch-Shortening Cycle Training. National Strength and Conditioning Association.

Hautala, A. J., Ma ¨kikallio, T. H., Kiviniemi, A., Laukkanen, R. T., Nissila, S., Huikuri, H. V., & Tulppo, M. P. (2023). *Cardiovascular autonomic function correlates with the response to aerobic training in healthy sedentary subjects*. American Physiological Society.

Hennessy, & Jeffreys. (2018). *The Current Use of GPS, Its Potential, and Limitations in Soccer*. Ovid Technologies (Wolters Kluwer Health). 10.1519/ssc.0000000000000386

Karavirta, L., Häkkinen, K., Kauhanen, A., Arija-Blázquez, A., Sillanpää, E., Rinkinen, N., & Häkkinen, A. (2011). *Individual Responses to Combined Endurance and Strength Training in Older Adults*. Ovid Technologies (Wolters Kluwer Health). 10.1249/mss.0b013e3181f1bf0d

Kraemer, French, Paxton, Häkkinen, Volek, Sebastianelli, Putukian, Newton, Rubin, Gómez, Vescovi, Ratamess, Fleck, Lynch, & Knuttgen. (2019). *Changes in Exercise Performance and Hormonal Concentrations Over a Big Ten Soccer Season in Starters and Nonstarters*. Ovid Technologies (Wolters Kluwer Health). 10.1519/1533-4287(2004)018<0121:ciepah>2.0.co;2

Lab 5: Testing Our Way to Outliers (2013).

Lamberts, Swart, Capostagno, Noakes, & Lambert. (2010). *Heart rate recovery as a guide to monitor fatigue and predict changes in performance parameters*. Wiley. 10.1111/j.1600-0838.2009.00977.x

Los Arcos, A., Martínez-Santos, R., Yanci, J., Mendiguchia, J., & Méndez-Villanueva, A. (2015). *Negative Associations between Perceived Training Load, Volume and Changes in Physical Fitness in Professional Soccer Players*

Malina, Ribeiro, Aroso, & Cumming. (2007). *Characteristics of youth soccer players aged 13–15 years classified by skill level*. BMJ. 10.1136/bjsm.2006.031294

McPhee, J. S., Williams, A. G., Degens, H., & Jones, D. A. (2010). *Inter-individual variability in adaptation of the leg muscles following a standardised endurance training programme in young women*. Springer Science and Business Media LLC. 10.1007/s00421-010-1454-2

Meylan, C. E., & Malatesta, D. (2024). *Effects of In-Season Plyometric Training Within Soccer Practice on Explosive Actions of Young Players*. National Strength and Conditioning Association.

Moalla, W., Fessi, M. S., Farhat, F., Nouira, S., Wong, D. P., & Dupont, G. (2016). *Relationship between daily training load and psychometric status of professional soccer players*. Informa UK Limited. 10.1080/15438627.2016.1239579

Morris, T. (2000). *Psychological characteristics and talent identification in soccer*. Informa UK Limited. 10.1080/02640410050120096

Oliver, Ramachandran, Singh, Ramirez-Campillo, & Lloyd. (2023). *The Effects of Strength, Plyometric and Combined Training on Strength, Power and Speed Characteristics in High-Level, Highly Trained Male Youth Soccer Players: A Systematic Review and Meta-Analysis*. Springer Science and Business Media LLC. 10.1007/s40279-023-01944-8

Philippaerts, Vaeyens, Janssens, Van Renterghem, Matthys, Craen, Bourgois, Vrijens, Beunen, & Malina. (2007). *The relationship between peak height velocity and physical performance in youth soccer players*. Informa UK Limited. 10.1080/02640410500189371

Radnor, J. M., Lloyd, R. S., & Oliver, J. L. (2016). *Individual Response to Different forms of Resistance Training in School-Aged Boys*. National Strength and Conditioning Association.

Ramírez-Campillo, R., Meylan, C., Ìvarez, C. A., Henríquez-Olguín, C., Martínez, C., Canas-Jamett, R., Andrade, D. C., & Izquierdo, M. (2014). *Effects of In-Season Low-Volume High-Intensity Plyometric Training on Explosive Actions and Endurance of Young Soccer Players*. National Strength and Conditioning Association.

Ramirez-Campillo, Alvarez, Gentil, Moran, García-Pinillos, Alonso-Martínez, & Izquierdo. (2018). *Inter-individual Variability in Responses to 7 Weeks of Plyometric Jump Training in Male Youth Soccer Players*. Frontiers Media SA. 10.3389/fphys.2018.01156

Rebelo, Pereira, Martinho, Duarte, Coelho-E-Silva, & Valente-Dos-Santos. (2022). *How to Improve the Reactive Strength Index among Male Athletes? A Systematic Review with Meta-Analysis*. MDPI AG. 10.3390/healthcare10040593

Silva, Nassis, & Rebelo. (2015). *Strength training in soccer with a specific focus on highly trained players*. Springer Science and Business Media LLC. 10.1186/s40798-015-0006-z

Stølen, T., Chamari, K., Castagna, C., & Wisløff, U. (2005). *Physiology of Soccer An Update*

Strøyer, J., Hansen, L., & Klausen, K. (2004). *Physiological Profile and Activity Pattern of Young Soccer Players during Match Play*. Ovid Technologies (Wolters Kluwer Health). 10.1249/01.mss.0000106187.05259.96