European Journal of Physical Education and Sport Science
ISSN: 2501 - 1235
ISSN-L: 2501 - 1235
Available on-line at: www.oapub.org/edu

DOI: 10.46827/ejpe.v13i2.6527 Volume 13 | Issue 2 | 2026

EFFECTS OF A 12-WEEK NEUROMUSCULAR TRAINING INTERVENTION ON JUMP HEIGHT, MAXIMAL FORCE, AND POWER IN U-13 MALE SOCCER PLAYERS

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Abstract:
The aim of this study was to investigate the effects of a 12-week structured neuromuscular training intervention on lower-limb explosive performance, specifically jump height, maximal force, and maximal power in U-13 male soccer players. Fifty-seven youth soccer players (mean age = 12.5 ± 0.6 years) from four U-13 teams in Tirana, Albania, were randomly assigned to an intervention group (n = 28) or a control group (n = 29). The intervention group completed a structured neuromuscular training program three times per week (15 minutes per session) focusing on coordination, running technique, reaction time, jumping, and multidirectional sprinting, while the control group continued routine soccer training. Explosive performance was assessed before and after the intervention using the Leonardo force platform during a Single Two-Leg Jump (S2LJ). A two-way repeated-measures ANOVA was used to analyze the effects of Time (pre, post) and Type of Intervention (intervention, control). Significant main effects of Time were observed for jump height, maximal force, and maximal power ($p < .001$), indicating overall improvements across the study period. Significant Time × Type of Intervention interactions were found for all three variables ($p < .05$), demonstrating greater time-related improvements in the intervention group compared with the control group. Jump height showed the largest intervention effect, followed by maximal force, while maximal power exhibited a smaller but still significant interaction effect. Between-subjects effects were significant for jump height, whereas force and power adaptations were primarily reflected in longitudinal interaction effects. A short, low-volume neuromuscular training intervention integrated into regular soccer practice significantly enhances lower-limb explosive performance in U-13 male soccer players. The findings

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highlight that jump height, maximal force, and maximal power respond differently to neuromuscular training during early adolescence and underscore the importance of multidimensional force-platform assessment. Incorporating targeted neuromuscular exercises into youth soccer training programs appears to be an effective strategy for optimizing explosive performance development.

Keywords: youth soccer; neuromuscular training; jump height; maximal force; maximal power; force platform; explosive performance

1. Introduction

Soccer is a high-intensity intermittent sport that requires players to repeatedly perform explosive actions such as jumping, sprinting, accelerating, decelerating, and changing direction. These actions are underpinned by well-developed neuromuscular qualities, particularly lower-limb explosive performance, which plays a critical role in both match performance and long-term athletic development [1,2]. In youth soccer, the development of these qualities is especially important, as early adolescence represents a sensitive period for enhancing coordination, force production, and power-related capacities [3]. Explosive performance is a multidimensional construct commonly assessed through vertical jumping tasks, which provide insight into an athlete's ability to generate force rapidly against the ground. Variables such as jump height, maximal force, and maximal power offer complementary information regarding neuromuscular function. Jump height reflects the overall outcome of force–velocity interactions, maximal force represents the capacity to generate high ground reaction forces, and maximal power integrates both force and movement velocity [4,5]. Assessing these variables together allows for a more comprehensive understanding of training-induced adaptations than relying on a single performance metric.

In youth athletes, improvements in explosive performance are driven primarily by neural and coordinative adaptations, rather than muscle hypertrophy, due to the immaturity of the endocrine system and limited exposure to heavy resistance training [6]. Consequently, training programs emphasizing coordination, technique, plyometric actions, and multidirectional movement are considered particularly effective during pre- and early-pubertal stages [7]. Such approaches align with long-term athlete development models, which advocate for age-appropriate neuromuscular training to establish a foundation for later performance enhancement [8].

Despite this theoretical consensus, traditional youth soccer training often prioritizes technical and tactical components, with limited structured emphasis on neuromuscular development. As a result, routine soccer practice alone may be insufficient to optimally stimulate improvements in explosive performance, especially when training time is constrained [9]. In recent years, several studies have demonstrated that short, targeted neuromuscular or plyometric interventions, when integrated into regular training sessions, can elicit significant gains in jump performance, force production, and power output in youth soccer players [10,11]. However, findings across studies are not always consistent, particularly with respect to maximal force and power outcomes, which may be influenced by maturation status, training content, and assessment methodology.

The use of force-platform technology has enhanced the precision of performance assessment in youth sport. Force platforms allow for the objective quantification of jump height, force, and power, offering greater sensitivity to neuromuscular adaptations than field-based tests alone [12,13]. Nevertheless, relatively few intervention studies in youth soccer have employed force-platform-derived measures to simultaneously examine adaptations in jump height, maximal force, and maximal power within the same experimental framework.

Given these considerations, there remains a need for controlled intervention studies that (a) integrate structured neuromuscular training into youth soccer practice, (b) employ robust biomechanical assessment tools, and (c) examine multiple dimensions of explosive performance concurrently. Such evidence is essential for informing evidence-based training practices and optimizing physical development during early adolescence. Therefore, the aim of this study was to evaluate the effects of a 12-week structured neuromuscular training intervention on jump height, maximal force, and maximal power during a Single Two-Leg Jump (S2LJ) in U-13 male soccer players.

2. Material and Methods

A randomized controlled intervention study with a pre–post repeated-measures design was conducted to examine the effects of a structured neuromuscular training program on lower-limb explosive performance in youth soccer players. The independent variables were Time (pre-test and post-test) as a within-subjects factor and Type of Intervention (intervention vs. control) as a between-subjects factor. Dependent variables included jump height, maximal total force (Fmax total), and maximal total power (Pmax total) measured during a Single Two-Leg Jump (S2LJ) using a force platform.

2.1 Participants

A total of 57 male youth soccer players (mean age = 12.5 ± 0.6 years) participated in the study. Players were recruited from four U-13 soccer teams competing in organized youth leagues in Tirana, Albania. Participants were randomly assigned to either an intervention group (n = 28) or a control group (n = 29). Inclusion criteria were: (a) male sex, (b) chronological age between 12 and 13 years, (c) regular participation in organized soccer training (minimum three sessions per week), and (d) absence of musculoskeletal injury or medical conditions affecting physical performance during the study period.

All participants and their legal guardians were informed about the study procedures, benefits, and potential risks. Written informed consent was obtained from parents or guardians, and verbal assent was obtained from the players. The study was conducted in accordance with the Declaration of Helsinki and approved by the relevant institutional ethics committee.

2.2 Intervention Program

The intervention group completed a 12-week structured neuromuscular training program, integrated into regular soccer training sessions. The program was performed three times per week, with each session lasting approximately 15 minutes. Training content focused on: running and sprinting technique, coordination and rhythm exercises, reaction time drills, jumping and landing tasks, and multidirectional sprinting and change-of-direction movements. Exercises were progressively adapted across the intervention period to maintain appropriate training stimulus while ensuring age-appropriate load and technical quality. All sessions were supervised by qualified coaches and sport science professionals to ensure correct execution and safety. The control group continued their routine soccer training, which consisted primarily of technical, tactical, and game-based activities, without additional structured neuromuscular or explosive training components.

2.3 Testing Procedures

Testing was conducted one week before (pre-test) and one week after (post-test) the 12-week intervention period. All assessments were performed under standardized conditions in the same indoor facility. Participants were instructed to avoid strenuous physical activity for at least 48 hours before testing. Prior to testing, participants completed a standardized warm-up consisting of light running, dynamic stretching, and submaximal jumping exercises.

2.4 Force Platform Assessment

Lower-limb explosive performance was assessed using the Leonardo force platform (Novotec Medical GmbH, Germany). Participants performed the Single Two-Leg Jump (S2LJ) test, which involved a maximal vertical jump executed with both feet simultaneously. Hands were placed on the hips to minimize upper-body contribution.

Each participant performed three maximal trials, with adequate rest between attempts. The best trial was selected for analysis. The following variables were recorded and analyzed:

- Jump height (m),
- Maximal total force (Fmax total, kN),
- Maximal total power (Pmax total, kN).

Force-platform data were sampled and processed using the manufacturer's proprietary software according to standardized procedures.

2.5 Statistical Analysis

Descriptive statistics (mean ± standard deviation) were calculated for all variables. Statistical analyses were performed using IBM SPSS Statistics (Version 22). Normality and homogeneity of variance were assessed using descriptive diagnostics and Levene's test. A two-way repeated-measures ANOVA was conducted for each dependent variable, with Time (pre, post) as the within-subjects factor and Type of Intervention (intervention, control) as the between-subjects factor. Multivariate tests (Pillai's Trace, Wilks' Lambda) were examined alongside univariate results. Effect sizes were reported using partial eta squared (η^2p) and interpreted as small (≈ .01), medium (≈ .06), or large (≥ .14). Statistical significance was set at $p < .05$.

3. Results

Table 1 presents the descriptive statistics for Single Two-Leg Jump (S2LJ) height measured with the Leonardo platform for the control and intervention groups at pre- and post-test. At pre-test, the control group showed a higher mean jumping height (M = 0.3761 m, SD = 0.0583, n = 28) than the intervention group (M = 0.3242 m, SD = 0.0394, n = 29), with a total sample mean of 0.3528 m (SD = 0.0565, N = 57). At post-test, mean jumping height increased in both groups. The control group reached a mean of 0.3975 m (SD = 0.0631, n = 28), while the intervention group showed a mean of 0.3815 m (SD = 0.0406, n = 29). The total post-test mean for the sample was 0.3903 m (SD = 0.0541, N = 57).

Table 1: Descriptive statistics for Single Two-Leg Jump (S2LJ) height

Type_Intervention		Mean	Std. Deviation	N
LeonardoS2LJ_Jumping_Height_pre	Control	0.3761	0.05831	28
	Intervention	0.3242	0.03942	29
	Total	**0.3528**	**0.05651**	**57**
LeonardoS2LJ_Jumping_Height_post	Control	0.3975	0.06314	28
	Intervention	0.3815	0.04059	29
	Total	**0.3903**	**0.05412**	**57**

The within-subjects analysis showed a statistically significant main effect of Time, $F(1, 38) = 227.74$, $p < .001$, partial $\eta^2 = .857$. The result was identical across all sphericity corrections (sphericity assumed, Greenhouse–Geisser, Huynh–Feldt, and lower-bound). A statistically significant Time × Type of Intervention interaction was also observed, $F(1, 38) = 47.75$, $p < .001$, partial $\eta^2 = .557$. This effect remained consistent across all sphericity adjustment methods.

Table 2: Within-subjects analysis for Single Two-Leg Jump (S2LJ) height

Measure:	MEASURE_1			
Source		**F**	**Sig.**	**Partial Eta Squared**
Time	Sphericity Assumed	227.737	0.000	0.857
	Greenhouse-Geisser	227.737	0.000	0.857
	Huynh-Feldt	227.737	0.000	0.857
	Lower-bound	227.737	0.000	0.857
Time * Type_Intervention	Sphericity Assumed	47.752	0.000	0.557
	Greenhouse-Geisser	47.752	0.000	0.557
	Huynh-Feldt	47.752	0.000	0.557
	Lower-bound	47.752	0.000	0.557
Error(Time)	Sphericity Assumed	0.002		
	Greenhouse-Geisser	0.002		
	Huynh-Feldt	0.002		
	Lower-bound	0.002		

The within-subjects contrasts analysis indicated a statistically significant linear effect of Time, $F(1, 38) = 227.74$, $p < .001$, partial $\eta^2 = .857$. A statistically significant linear Time × Type of Intervention interaction was also observed, $F(1, 38) = 47.75$, $p < .001$, partial $\eta^2 = .557$.

Table 3: The within-subjects contrasts analysis

Measure:	MEASURE_1			
Source		**F**	**Sig.**	**Partial Eta Squared**
Time	Linear	227.737	0.000	0.857
Time * Type_Intervention	Linear	47.752	0.000	0.557
Error(Time)	Linear			

Table 4 presents the descriptive statistics for maximal total force (Fmax total, kN) obtained during the Single Two-Leg Jump (S2LJ) test measured with the Leonardo platform for the control and intervention groups at pre- and post-test. At pre-test, mean maximal force values were similar between groups, with the control group recording a mean of 1.2391 kN (SD = 0.2226, n = 28) and the intervention group a mean of 1.2656 kN (SD = 0.1859, n = 29). The total sample mean at baseline was 1.2510 kN (SD = 0.2047, N = 57). At post-test, increases in maximal force were observed in both groups. The control group reached a mean Fmax of 1.2941 kN (SD = 0.2455, n = 28), while the intervention group demonstrated a higher mean value of 1.3944 kN (SD = 0.1936, n = 29). The overall post-test mean for the sample was 1.3393 kN (SD = 0.2266, N = 57).

Table 4: Descriptive statistics for maximal total force (Fmax total, kN)

Type_Intervention		Mean	Std. Deviation	N
LeonardoS2LJ_Fmaxtotal_kN_pre	Control	1.2391	0.22256	28
	Intervention	1.2656	0.18589	29
	Total	**1.2510**	**0.20472**	**57**
LeonardoS2LJ_Fmaxtotal_kN_post	Control	1.2941	0.24547	28
	Intervention	1.3944	0.19358	29
	Total	**1.3393**	**0.22657**	**57**

The within-subjects analysis revealed a statistically significant main effect of Time on maximal total force during the Single Two-Leg Jump, $F(1, 38) = 55.92$, $p < .001$, partial $\eta^2 = .595$. This effect was identical across all sphericity corrections (sphericity assumed, Greenhouse–Geisser, Huynh–Feldt, and lower-bound). A statistically significant Time × Type of Intervention interaction was also observed, $F(1, 38) = 9.01$, $p = .005$, partial $\eta^2 = .192$, with consistent results across all sphericity adjustment methods.

Table 5: Within-subjects analysis for maximal total force (Fmax total, kN)

Measure:	MEASURE_1				
Source		**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Time	Sphericity Assumed	0.167	55.916	0.000	0.595
	Greenhouse-Geisser	0.167	55.916	0.000	0.595
	Huynh-Feldt	0.167	55.916	0.000	0.595
	Lower-bound	0.167	55.916	0.000	0.595
Time * Type_Intervention	Sphericity Assumed	0.027	9.012	0.005	0.192
	Greenhouse-Geisser	0.027	9.012	0.005	0.192
	Huynh-Feldt	0.027	9.012	0.005	0.192
	Lower-bound	0.027	9.012	0.005	0.192
Error(Time)	Sphericity Assumed	0.003			
	Greenhouse-Geisser	0.003			
	Huynh-Feldt	0.003			
	Lower-bound	0.003			

The within-subjects contrasts analysis revealed a statistically significant linear effect of Time on maximal total force, $F(1, 38) = 55.92$, $p < .001$, partial $\eta^2 = .595$. In addition, a statistically significant linear Time × Type of Intervention interaction was observed, $F(1, 38) = 9.01$, $p = .005$, partial $\eta^2 = .192$.

Table 6: The within-subjects contrasts

Measure:	MEASURE_1				
Source		**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Time	Linear	0.167	55.916	0.000	0.595
Time * Type_Intervention	Linear	0.027	9.012	0.005	0.192
Error(Time)	Linear	0.003			

Table 7 presents the descriptive statistics for maximal total power (Pmax total) obtained during the Single Two-Leg Jump (S2LJ) test measured with the Leonardo platform for the control and intervention groups at pre- and post-test. At pre-test, the control group demonstrated a mean maximal power of 2.2727 kN (SD = 0.6258, n = 28), while the intervention group showed a mean of 2.1233 kN (SD = 0.1776, n = 29). The total sample mean at baseline was 2.2055 kN (SD = 0.4799, N = 57). At post-test, increases in maximal power were observed in both groups. The control group reached a mean Pmax of 2.3659 kN (SD = 0.6794, n = 28), and the intervention group demonstrated a mean value of 2.3322 kN (SD = 0.2927, n = 29). The overall post-test mean for the total sample was 2.3508 kN (SD = 0.5350, N = 57).

Table 7: Descriptive statistics for maximal total power (Pmax total)

Type_Intervention		Mean	Std. Deviation	N
LeonardoS2LJ_Pmaxtotal_kN_pre	Control	2.2727	0.62579	28
	Intervention	2.1233	0.17760	29
	Total	**2.2055**	**0.47988**	**57**
LeonardoS2LJ_Pmaxtotal_kN_post	Control	2.3659	0.67944	28
	Intervention	2.3322	0.29269	29
	Total	**2.3508**	**0.53498**	**57**

A statistically significant Time × Type of Intervention interaction was also observed, $F(1, 38) = 5.09$, $p = .030$, partial $\eta^2 = .118$, with consistent results across all sphericity adjustment methods.

Table 8: Within-subjects analysis for maximal total force (Pmax total, kN)

Measure:	MEASURE_1				
Source		**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Time	Sphericity Assumed	0.452	34.672	0.000	0.477
	Greenhouse-Geisser	0.452	34.672	0.000	0.477
	Huynh-Feldt	0.452	34.672	0.000	0.477
	Lower-bound	0.452	34.672	0.000	0.477
Time * Type_Intervention	Sphericity Assumed	0.066	5.087	0.030	0.118
	Greenhouse-Geisser	0.066	5.087	0.030	0.118
	Huynh-Feldt	0.066	5.087	0.030	0.118
	Lower-bound	0.066	5.087	0.030	0.118
Error(Time)	Sphericity Assumed	0.013			
	Greenhouse-Geisser	0.013			
	Huynh-Feldt	0.013			
	Lower-bound	0.013			

The within-subjects contrasts analysis revealed a statistically significant linear effect of Time on maximal total power, $F(1, 38) = 34.67$, $p < .001$, partial $\eta^2 = .477$. In addition, a statistically significant linear Time × Type of Intervention interaction was observed, $F(1, 38) = 5.09$, $p = .030$, partial $\eta^2 = .118$.

Table 9: Within-subjects contrasts analysis

Measure:	MEASURE_1				
Source		**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Time	Linear	0.452	34.672	0.000	0.477
Time * Type_Intervention	Linear	0.066	5.087	0.030	0.118
Error(Time)	Linear	0.013			

4. Discussion

The findings of the present study demonstrate that a 12-week structured neuromuscular intervention produced significantly greater time-related improvements in jump height, maximal force, and maximal power compared with routine soccer training alone. The observed main effects of time across all variables are consistent with previous longitudinal research showing that youth soccer players naturally improve explosive performance due to growth, maturation, and regular sport participation [14,9]. Early adolescence is characterized by rapid neural adaptations, including enhanced motor unit recruitment and intermuscular coordination, which strongly influence explosive performance even in the absence of heavy resistance training [3,6].

The significant Time × Type of Intervention interactions observed across all performance variables indicate that the structured neuromuscular program altered the trajectory of neuromuscular development beyond routine training effects. Jump height demonstrated the largest interaction effect, followed by maximal force, with a smaller but still significant interaction observed for maximal power. This pattern is biomechanically meaningful, as jump height integrates force, velocity, coordination, and technique, making it highly sensitive to neuromuscular training interventions [4,5].

Improvements in maximal force are consistent with previous studies showing that neuromuscular and plyometric training enhances force production in youth athletes primarily through neural mechanisms rather than muscle hypertrophy [10,11]. In contrast, maximal power adaptations were more moderate, which aligns with evidence suggesting that power development in pre- and early-pubertal athletes may lag behind force or jump height improvements due to the complex interaction between force and velocity and the need for longer training exposure [7,15].

The lack of significant between-subjects effects for maximal force and power further highlights that longitudinal interaction effects are often more informative than cross-sectional comparisons in youth intervention studies [16,17]. The use of the Leonardo force platform enabled a multidimensional assessment of explosive performance, supporting the robustness and sensitivity of the findings [12,13].

5. Recommendations

From an applied standpoint, the integrated findings demonstrate that a low-volume, time-efficient neuromuscular intervention (15 minutes, three times per week) can meaningfully enhance multiple components of explosive performance in youth soccer players. Improvements in jump height, force, and power are directly relevant to soccer-specific actions such as heading duels, sprint acceleration, and rapid changes of direction [2]. Importantly, the intervention aligns with long-term athlete development models, which emphasize coordination, movement quality, and neuromuscular efficiency during early adolescence rather than early specialization in maximal strength training [8; 7].

6. Conclusion

This study provides integrated evidence that a 12-week structured neuromuscular training intervention significantly enhances lower-limb explosive performance in U-13 male soccer players, as reflected by improvements in jump height, maximal force, and maximal power measured via the Leonardo S2LJ test. While all players improved over time, the intervention group demonstrated consistently greater time-related gains, confirmed by significant Time × Type of Intervention interactions across all performance variables. Jump height showed the most pronounced response to the intervention, followed by maximal force and maximal power, highlighting the differential sensitivity of explosive performance components to neuromuscular training during early adolescence. These findings underscore the importance of using a multidimensional assessment approach when evaluating training effects in youth athletes. In conclusion, integrating short, targeted neuromuscular training sessions within routine soccer practice is an effective strategy for promoting explosive performance development during a critical stage of athletic growth. The results support the inclusion of coordinated jumping, force-oriented, and movement-based exercises within youth soccer development programs to optimize neuromuscular adaptations and long-term performance potential.

Conflict of Interest Statement
The authors declare no conflicts of interest.

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