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Evaluation of the Effect of
Intensive Resistance Exercises
on Anaerobic and Balance
Performance in Young Football
Players

Doctoral Thesis – set of publications – for obtaining
the scientific degree “Doctor of Science (*PhD*)”

Sector Group – Medical and Health Sciences

Sector – Health and Sports Sciences

Sub-Sector – Sports Pedagogy

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Riga, 2026



The research is carried out within the framework of the European Union Recovery and Resilience Mechanism Plan and the state budget funded project “RSU internal and RSU with LASE external consolidation” No. 5.2.1.1.i.0/2/24/I/CFLA/005, implemented under Doctoral Grant.

Abstract

Football is a dynamic team sport that requires intermittent effort levels from low to high intensities, indicated by a substantial volume of motor actions and unpredictable movement patterns. In football, physical performance is reflected in the quality of play and skill, while functional movement influences technique and prevents sports injuries.

The purpose of this work was to evaluate the effects of an eight-week combined RE program integrating self-loading, balance, and plyometric on anaerobic and balance performance in well-trained young male football players aged 14-16 years competing at regional and national levels. The study was conducted in the Riga region, Latvia, from 2022 to 2024.

In the first and second studies, we conducted a pilot to analyse 1) anaerobic and balance performance based on playing position, and 2) detection of asymmetry between the dominant (D) and non-dominant (ND) leg. 43 players (age = 15.81 ± 1.33 years, height (H) = 179.50 ± 6.14 cm, and body mass (BM) = 69.73 ± 9.35 kg) participated. They had more than five years of football experience, 7–8 hours of regular training per week, and competed regularly. The players were classified into 4 groups: Goalkeeper (GK) (N: 5, H: 185.42 ± 2.20 cm, BM: 76.20 ± 9.85 kg), Defenders (DEF) (N: 12, H: 182.48 ± 2.20 cm, BM: 73.70 ± 4.73 kg), Midfielders (MD) (N: 20, H: 174.89 ± 5.03 cm, BM: 63.77 ± 6.92 kg), and Forwards (F) (N: 6, H: 184.0 ± 3.69 cm, BM: 75.28 ± 12.25 kg).

1) a significant difference in peak power output (PPO) was observed across playing positions ($p = 0.018$, $\eta^2 = 0.226$), where F significantly greater in power output compared to MD ($p = 0.03$). Vertical jump characteristics, including jump height, flight time, and peak force, showed no significant differences across playing positions ($p = 0.11$ – 0.31). Average medial-lateral speed (AMLS) showed significant differences between ND ($p = 0.025$, $\eta^2 = 0.211$) and D leg ($p = 0.033$, $\eta^2 = 0.198$) based on the players' positions. AMLS showed statistically significant better results (slower movement speed) in GK compared to F in their ND ($p = 0.022$) and D leg ($p = 0.040$). However, other parameters of static and dynamic balance showed no statistical significance in the D/ND leg for 30s one-leg stance across groups.

2) no significant differences were found between the D and ND leg in all parameters of static balance, $p = 0.33$ – 0.72 . Similarly, dynamic balance results revealed no significant differences between the D and ND legs for the parameters: total stability index (TSI) ($p = 0.736$) and total trunk deviation (TTD) ($p = 0.789$). In addition, no correlation was found between static and dynamic balance tests, although minor links existed between TTD and EA ($r = 0.332$; $p = 0.03$), TTD and MLD ($r = 0.335$; $p = 0.02$), and TTD and TD ($r = 0.423$; $p = 0.01$).

In the third and fourth studies, we evaluated the effect of various RE on 3) anaerobic and 4) balance performance, ankle mobility, and explosive strength. 30 young players were randomly allocated to an intervention (IG) and a control (CG) group. The IG (N: 15, age: 15.8 ± 1.7 years, BM: 67.8 ± 11.9 kg, H: 177.2 ± 5.9 cm), and CG (N: 15, age: 15.7 ± 0.6 years, BM: 69.6 ± 4.8 kg, H: 180.3 ± 5.6 cm).

3) both groups demonstrated significant improvements in PPO during the Wingate Anaerobic test (WAnT) and six-second peak power output test (6 PPO), with percentage change ranging from 12–31 % ($p = 0.000$ – 0.02 ; $d = 0.97$ – 1.5). Absolute mean power (MP) significantly increased IG (21.8 %, $p = 0.001$) and CG (11.8 %, $p = 0.01$). However, no statistically significant improvement was observed in the fatigue index (FI) of participants from both groups.

4) IG significantly improved static and dynamic balance by -12 to -30 % ($p = 0.001$ – 0.04 , $d = 0.57$ – 1.14), active ankle ROM in PF and DF by 12–32 % ($p = 0.001$ – 0.02 , $d = 1.05$ – 1.19), isometric shin muscle force, torque and relative in PF and DF by 10–24 % ($p = 0.001$ – 0.03 , $d = 0.48$ – 1.31), and jump performance by 6–14 % ($p = 0.004$ – 0.01 , $d = 0.82$ – 1.27). No significant changes were observed in the CG, except for peak and relative torque DF by 10–19 % ($p = 0.01$ – 0.02 , $d = 0.55$ – 0.91), peak force DF in the dominant leg by 11 % ($p = 0.04$, $d = 0.71$) and jump height by 5 % ($p = 0.008$, $d = 0.82$). The statistically significant interactions between groups in all balance variables, ankle ROM, and ankle force of PF in the dominant leg, peak force and torque of DF in the dominant leg were calculated using ANCOVA analysis.

Based on research findings, variation in peak power output was revealed among player positions but not for jump and balance performance. Regularly monitoring physical fitness and functional movement is essential to ensure young players reach their peak performance and prevent injuries. The implementation of resistance exercises with progression, regularity, overload, and supervision is appropriate for young players to enhance their anaerobic and balance performance. Therefore, RE should be included in regular training for young footballers to improve physical fitness and functional mobility.

Keywords: resistance exercise, plyometric, self-loading training, balance training, peak power output, static and dynamic balance, ankle range of movement, shin muscle peak isometric force and torque, explosive strength.

Anotācija

Intensīvu pretestības vingrinājumu ietekmes uz jauno futbolistu anaerobajām darbspējām un līdzsvaru novērtējums

Futbols ir dinamisks komandu sporta veids, kur spēles laikā ir mainīga fiziskās slodzes intensitāte: no zemas līdz augstai. To raksturo liela kustību daudzveidība un neprognozējami kustību modeļi. Futbolā fiziskā sagatavotība atspoguļojas spēles un prasmju kvalitātē, savukārt, laba koordinācija un pareiza sporta kustību tehnika palīdz novērst sporta traumas.

Šī pētījuma mērķis bija novērtēt intensīvu pretestības vingrinājumu (PV) ietekmi uz anaerobo jaudu un līdzsvara spējām jauniešiem futbolistiem. Pētījums tika veikts no 2022. līdz 2024. gadam Rīgas reģionā, Latvijā.

Pirmajā un otrajā pētījuma posmā tika veikts pilotpētījums ar mērķi analizēt: 1) anaerobo darbspēju un līdzsvara atšķirības atkarībā no spēlētāja pozīcijas; 2) dominējošās (D) un nedominējošās (ND) kājas asimetrijas noteikšanu. Pētījumā piedalījās 43 spēlētāji (vidējais vecums bija $15,81 \pm 1,33$ gadi, auguma garums (A) – $179,50 \pm 6,14$ cm, ķermeņa masa (KM) = $69,73 \pm 9,35$ kg), viņiem bija vairāk nekā piecu gadu futbola treniņu pieredze, spēlētāji trenējās 7–8 stundas nedēļā un regulāri piedalījās sacensībās. Spēlētāji tika sadalīti četrās grupās: vārtsargi (GK) (N: 5, A: $185,42 \pm 2,20$ cm, KM: $76,20 \pm 9,85$ kg), aizsargi (DEF) (N: 12, A: $182,48 \pm 2,20$ cm, KM: $73,70 \pm 4,73$ kg), pussargi (MD) (N: 20, A: $174,89 \pm 5,03$ cm, KM: $63,77 \pm 6,92$ kg) un uzbrucēji (F) (N: 6, A: $184,00 \pm 3,69$ cm, KM: $75,28 \pm 12,25$ kg).

1) maksimālajā anaerobajā jaudā (PPO) tika konstatētas statistiski ticamas atšķirības starp spēlētāju pozīcijām ($p = 0,018$, $\eta^2 = 0,226$), kur uzbrucējiem (F) bija būtiski lielāka maksimālā jauda salīdzinājumā ar pussargiem (MD) ($p = 0,03$). Vertikālā lēciena raksturlielumi (maksimālais lēciena augstums, lidojuma fāzes laiks un maksimālais spēks) būtiski neatšķīrās starp spēlētāju pozīcijām ($p = 0,11$ – $0,31$). Statiskā līdzsvara raksturlielums stāvēt uz vienas kājas: vidējais ķermeņa spiediena centra novirzes ātrums mediolaterālā virzienā (AMLS) statistiski ticami atšķīrās stāvēt uz nedominējošās (ND) kāju ($p = 0,025$, $\eta^2 = 0,211$) un dominējošās (D) kājas ($p = 0,033$, $\eta^2 = 0,198$) dažādu pozīciju futbolistiem. AMLS rādītāji bija ticami labāki (lēnāks AMLS) vārtsargiem (GK) nekā uzbrucējiem (F) gan ND kājā ($p = 0,022$), gan D kājā ($p = 0,040$). Tomēr citi statiskā un dinamiskā līdzsvara raksturlielumi statistiski ticami neatšķīrās starp D un ND kāju 30 sekunžu testā stāvēt uz vienas kājas starp spēlētāju pozīcijām.

2) starp dominējošās (D) un nedominējošās (ND) kājas statiskā līdzsvara raksturlielumiem netika konstatētas statistiski ticamas atšķirības ($p = 0,33$ – $0,72$). Līdzīgi arī

dinamiskā līdzsvara rezultāti neuzrādīja ticamas atšķirības starp D un ND kāju šādos parametros: kopējais stabilitātes indekss (TSI) ($p = 0,736$) un kopējais ķermeņa augšdaļas novirzes leņķis (TTD) ($p = 0,789$). Papildus tam, netika noteikta statistiski ticama korelācija starp statiskā un dinamiskā līdzsvara testu rezultātiem, lai gan tika novērotas ticamas vidēji ciešas sakarības starp dinamiskā līdzsvara TTD un statiskā līdzsvara kopējo svārstību laukumu (EA) ($r = 0,332$, $p = 0,03$), TTD un statiskā līdzsvara vidējo ķermeņa spiediena centra novirzes ātrumu mediolaterālā virzienā AMLD ($r = 0,335$; $p = 0,02$), kā arī TTD un statiskā līdzsvara ķermeņa novirzes leņķi TD ($r = 0,423$, $p = 0,01$).

Trešajā un ceturtajā pētījumā tika novērtēta dažādu pretestības un līdzsvara vingrinājumu (PV) ietekme uz: 3) anaerobo jaudu un 4) statisko un dinamisko līdzsvaru, apakšstilba muskuļu maksimālo izometrisko spēku, pēdas locītavas kustību amplitūdu un eksplozīvo spēku vertikālajā lēcienā.

30 jaunie futbolisti tika sadalīti divās grupās pēc nejaušības principa, intervences grupā (IG) un kontroles grupā (CG). IG sastāvēja no 15 dalībniekiem (vecums: $15,8 \pm 1,7$ gadi, ķermeņa masa (KM): $67,8 \pm 11,9$ kg, auguma garums (A): $177,2 \pm 5,9$ cm), savukārt, CG veidoja 15 dalībnieki (vecums: $15,7 \pm 0,6$ gadi, KM: $69,6 \pm 4,8$ kg, A: $180,3 \pm 5,6$ cm).

3) abās dalībnieku grupās tika novērots statistiski ticams anaerobās jaudas (PPO) palielinājums Vingeita 30 sekunžu anaerobās slodzes testā (WAnT) un sešu sekunžu maksimālās anaerobās jaudas testā (6 PPO) uz veloergometra, ar procentuālo uzlabojumu robežās no 12 % līdz 31 % ($p = 0,000-0,02$, $d = 0,97-1,5$). Absolūtā vidējā jauda (MP) būtiski palielinājās gan intervences grupā (IG) (pieaugums par 21,8 %, $p = 0,001$), gan kontroles grupā (CG) (pieaugums par 11,8 %, $p = 0,01$). Tomēr noguruma indeksa (FI) rādītājos abās grupās netika konstatētas statistiski ticamas izmaiņas.

4) intervences grupā (IG) tika novērots statiskā un dinamiskā līdzsvarā statistiski ticams uzlabojums par -12 līdz -30 % ($p = 0,001-0,04$, $d = 0,57-1,14$), palielinājums aktīvajā pēdas kustības amplitūdā plantārās fleksijas (PF) un dorsālās fleksijas (DF) virzienā par 12-32 % ($p = 0,001-0,02$, $d = 1,05-1,19$), maksimālajā izometriskajā apakšstilba muskuļu spēkā, absolūtajā un relatīvajā griezes momentā par 6-14 % ($p = 0,004-0,01$, $d = 0,82-1,27$). Kontroles grupā (CG) netika konstatētas ticamas izmaiņas, izņemot maksimālo un relatīvo DF griezes momenta pieaugumu par 10-19 % ($p = 0,01-0,02$, $d = 0,55-0,91$), DF maksimālā spēka palielinājumu dominējošajā kājā par 11 % ($p = 0,04$, $d = 0,71$) un vertikālā lēciena augstuma palielinājumu par 5 % ($p = 0,008$, $d = 0,82$). Statistiski ticamas atšķirības starp grupām tika noteiktas visos līdzsvara raksturlielos, pēdas locītavas kustību amplitūdā, PF muskuļu spēkā dominējošajā kājā, kā arī DF muskuļu maksimālajā spēkā un griezes momentā dominējošajā kājā, kas tika noteikts, izmantojot ANCOVA analīzi.

Pamatojoties uz pētījuma rezultātiem, tika konstatētas ticamas atšķirības maksimālajā anaerobajā jaudā starp spēlētāju pozīcijām, taču netika novērotas ticamas atšķirības vertikālo lēcienu un līdzsvara raksturlielos. Regulāra fiziskās sagatavotības, koordinācijas un kustību tehnikas uzraudzība ir svarīga, lai nodrošinātu jauno futbolistu snieguma uzlabojumu un samazinātu traumu risku. Pretestības vingrinājumu iekļaušana ar atbilstošu slodzes intensitātes un apjoma progresiju, regularitāti un uzraudzību ir pareiza pieeja, lai uzlabotu anaerobo jaudu un līdzsvara spējas jaunajiem futbolistiem. Pretestības un līdzsvara vingrinājumi ir jāiekļauj ikdienas treniņu programmās, lai veicinātu fizisko sagatavotību un uzlabotu koordinācijas spējas un sporta kustību tehniku.

Atslēgvārdi: pretestības vingrinājumi, pliometrija, pretestības treniņi ar savu ķermeņa masu, līdzsvara vingrinājumi, maksimālā anaerobā jauda, statiskais un dinamiskais līdzsvars, pēdas locītavas kustību amplitūda, apakšstilba muskuļu maksimālais izometriskais spēks un griezes moments, eksplozīvais spēks.

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Abbreviations used in the Thesis

6 PPO	Six-second peak power output
AAPS	Average anterior-posterior sway speed
AMLS	Average medial-lateral sway speed
APD	Anterior-posterior deviation
CG	Control groups
CMJ	Countermovement jump
CP	Cadence peak
COD	Change of direction
CoP	Centre of pressure
DEF	Defenders
D	Dominant leg
DF	Dorsiflexion
EA	Ellipse area
F	Forwards
FI	Fatigue index
GK	Goalkeeper
HJ	Height jump
HR	Heart rate
IG	Intervention groups
MD	Midfielders
MF	Maximum force
MLD	Medial-lateral deviation
MP	Mean power
MVIC	Maximal voluntary isometric contraction
ND	Non-dominant leg
NSCA	National Strength and Conditioning Association
P	Perimeter
PF	Plantar flexion
PPO	Peak power output
RE	Resistance exercise
ROM	Range of Motion
RPE	Rate of perceived exertion
RPM	Revolutions per minute
RTSC	Resistance training skill competency
SSC	Stretch-shortening cycle

SJ	Squat jump
TD	Trunk deviation
TF	Time flight
TP	Time to peak
TSI	Total stability index
TTD	Total trunk deviation
WAnT	Wingate anaerobic test

Introduction

Football is a team sport that involves numerous actions over a 90-minute period, during which players undergo 1000 to 1400 unpredictable locomotor activity changes every 3 to 6 seconds (Castellano et al., 2011). Physical performance is one aspect of predicting team success, as a study by Redkva et al. (2018) proved that less fit players tend to perform fewer high-intensity actions throughout a match. During football matches, low-intensity movements comprised 70–84.1 %, moderate 8.3 %, and high-intensity 7.6 % of the total game (Bangsbo et al., 2006; Hoff, 2005; Hulton et al., 2008; Njororai, 2012). However, based on blood lactate (LA), heart rate (HR), and Rate of Perceived Exertion (RPE) responses, young elite football players experienced greater physiological stress during the first half of matches than in the second half (Aslan et al., 2012), but similar physiological stress during match play according to playing position (Aslan et al., 2012).

In addition to the high aerobic demands of football, analyses reveal that players sprint between 1 % and 11 % of the total game time. Each sprint lasts 2 to 4 seconds, with repetitions occurring every 60 to 90 seconds, resulting in approximately 60 to 90 sprints per match (Shalfawi, 2015). These sprints indicate a high energy demand on the anaerobic system and require repeated high-velocity sprints throughout the game. Anaerobic process becomes important when players perform intense actions (e. g., sprinting and shooting), transition between activities (e. g., backward running followed by a header), and during shifts to higher intensities (e. g., jogging to high-speed running) (Hostrup & Bangsbo, 2022; Nilsson & Cardinale, 2015). Brief intense actions occur over 250 times during a game that relies on the anaerobic energy system (Bangsbo et al., 2006). These actions are crucial to a game's final performance and results. Nikolaidis et al. (2018) in their study reported that the main effect of age on anaerobic test results (WAnT, 20-m sprint, SJ, and CMJ) was observed among male football players, with older age groups showing better performance. However, peak power ($p = 0.32$), mean power ($p = 0.54$), 20m ($p = 0.07$), SJ ($p = 0.65$), and CMJ ($p = 0.34$) were not significantly different in playing position.

In line with the previously mentioned, one fundamental neuromuscular attachment skill that may also contribute to successful football performance is balance (Paillard et al., 2006; Ricotti et al., 2013). The balance performance is related to the improvement of sport-specific skills, movement technique in football and injury prevention. The study by Mitrousis et al. (2023) revealed that improvements in static and dynamic balance after specific balance training enhance shooting accuracy with the dominant leg in young football players. Moreover, regular football training combined with balance training improved dynamic balance performance and reduced lower limb injuries by over 25 % (Gebel et al., 2018). Balance performance relies on

the central processing of ankle proprioceptive sense acuity. It contributes to reducing the incidence of falls and sports injuries (Han et al., 2015). Balance supported by ankle mobility and explosive strength of the lower extremity muscles is the most important contributor to various movements, particularly change of direction (COD) (Guzman et al., 2022). Ankle dorsiflexion plays a role in absorbing and transferring force, while balance ability may enable faster COD performance at various angles from 45° to 180° (Rouissi et al., 2018). Moreover, precise ankle rotation was linked to balance proficiency (stability of the supporting limb) and accuracy of ankle movements during shooting or passing (Cameron & Adams, 2003; Cè et al., 2018).

Paediatric fitness programmes should include various neuromuscular exercises to enhance motor skills and fitness, which are critical for football practice (Hammami et al., 2023). Resistance exercise (RE) is considered a key approach for improving football performance because of the link between strength levels and high-intensity actions (Nuñez et al., 2019; Swinton et al., 2014). RE is one of the prominent training methods to include in the regular training sessions of various sports due to its safety, effectiveness, and injury-prevention (Faigenbaum & Myer, 2010; Lloyd et al., 2014). RE refers to a conditioning method that gradually incorporates a variety of resistive loads, different movement velocities, and various training modalities aimed at improving health, fitness, and sports (Faigenbaum et al., 2009). RE methods include body weight, free weights, weight machines, elastic bands, medicine balls, and manual resistance. However, the term RE should be distinguished from the sport of weightlifting, which involves performing the snatch and clean and jerk (Faigenbaum et al., 2019). The fundamental principles of RE for youth are known as PROCESS (Progression, Regularity, Overload, Creativity, Enjoyment, Socialization, and Supervision) (Faigenbaum et al., 2016).

Integrative neuromuscular training is a multimodal form of exercise that implements resistance exercises, dynamic stability, core exercises, and plyometric and agility training performed in short intervals with intermittent rest (Myer et al., 2011). In the clinical report, which was reaffirmed in November 2024 by the American Academy of Pediatrics (Stricker et al., 2020), the authors suggested that RE can begin with 1–2 sets of 8–12 repetitions at a low intensity (i. e., 60 % 1 RM) as proper technique is developed. Afterward, the RE program can be progressed from 2–4 sets of 6–12 repetitions with a low to moderate intensity (≤ 80 % 1RM). Young athletes can be introduced to periodic phases of lower repetition ranges (< 6) at higher training intensity (> 80 % 1RM) provided that resistance training skill competency (RTSC) is high (Lesinski et al., 2016).

The integrative neuromuscular training, including balance, strength, plyometric, and COD exercises, has been implemented to improve physical fitness in youth male soccer players (Hammami et al., 2023). Moreover, RE programs incorporating various training strategies and modalities have been shown to enhance overall physical fitness among young football players (Chaouachi et al., 2017; Hammami et al., 2016, 2023; Muehlbauer et al., 2019). However, RE protocols such as training duration, intensity, frequency, and exercise selection remain inconsistent in the existing literature. Another limitation of the current literature is the lack of investigation into the combined effects of multiple RE modalities on anaerobic and balance performance within a single structured training session. In addition, the potential contribution of underlying physiological and neuromuscular factors, such as ankle flexibility and shin muscle strength, to improvements in postural stability has received limited attention in youth football players. Therefore, further research is required to clarify the effectiveness of integrated RE programs that combine different neuromuscular training modalities in improving anaerobic and balance performance in young football players.

Aim of the Thesis

To evaluate the effects of an eight-week combined RE programs integrating self-loading, balance and plyometric on anaerobic and balance performance in well-trained young male football players aged 14–16 years competing at regional and national levels.

Objective of the Thesis

To achieve the aim of doctoral thesis, the following objectives are established:

- 1 To conduct a literature review related to the effects of RE on anaerobic and balance performance in young male football players. This review aims to map the existing scientific evidence on different RE modalities and their effectiveness in improving anaerobic and balance, including training protocols such as duration, intensity, frequency, set, and repetitions.
- 2 To analyse anaerobic and balance characteristics according to playing position in well-trained young male players aged 14–16 years (Tanner stage 3–4), with approximately 8 years of training experience, and competing at regional and national levels. Anaerobic measures include the six-second peak power output (6PPO) and the Wingate Anaerobic test (WAnT) with variables peak power output (PPO), mean power (MP), fatigue index (FI), and countermovement jump (CMJ) test (HJ, TF, and MF). Balance measures include static and dynamic balance tests. This analysis is conducted prior to designing the RE programs to determine whether training intervention for young players should be tailored according to the physical demands

of different playing positions: Goalkeepers (GK), Defenders (DEF), Midfielders (MD) and Forwards (F).

- 3 To identify asymmetry between D and ND legs during a 30-second one leg stance in static and dynamic balance assessments. Static balance variables include EA, P, APD, MLD, AAPS, and AMLS. Dynamic balance variables include TTD and TSI. The findings will be used to inform the appropriate design of dose-response of RE programs based on individual characteristics of the participants.
- 4 To evaluate the effects of an eight-week combined self-loading, balance, and plyometric exercises on: (a) anaerobic performance indicators, (b) balance-related variables, (c) ankle range of motion (plantar and dorsiflexion), and (d) peak isometric lower-leg muscle strength in well-trained male young football players.

Hypothesis of the Thesis

An eight-week combined RE programs integrating self-loading, balance and plyometric training will significantly improve anaerobic and balance performance in youth male football players aged 14–16 years.

Novelty of the Thesis

Although numerous resistance exercise (RE) programs have been widely studied in youth footballers, limited research has examined how specific RE protocols and modalities affect anaerobic performance and balance-related variables, including ankle flexibility and peak isometric shin muscle strength in young population. Considering the high anaerobic demands of football matches (Nobari et al., 2023) and the high percentage of lower-extremity injuries in youth players (71–80 %) (Read et al., 2016), with a 20 % proportion of ankle instability (Francia et al., 2022; Park et al., 2024), targeted development of anaerobic capacity, balance, and ankle mobility is essential during this age period stage. This thesis addresses this gap by investigating the effects of RE programs based on the PROCESS training principles on anaerobic performance and balance in youth football players aged 14–16 years, thereby contributing to improved training strategies for enhancing physical fitness and functional movement in young athletes.

1 Literature review

1.1 Characteristic physical demands of young football players during a football match

Football is a dynamic team sport where players connect within a complex system defined by technical and tactical elements, supported by physical and physiological attributes (Baptista, 2020; Mota et al., 2021; Pillitteri et al., 2023). Football involves varying effort levels from low to high, reflected by a large number of motor actions and unpredictable movement patterns (Bangsbo, 1994; Bradley et al., 2009; Pillitteri et al., 2023; Tereso et al., 2021). During football matches, low-intensity movements comprised 70–84.1 %, moderate of 8.3 %, and medium-intensity activities made up 7.6 % of the total game (Bangsbo et al., 2006; Hoff, 2005; Hulton et al., 2008; Njororai, 2012). The predominant actions in a football match consist of low-intensity activities, including walking and running (Stølen et al., 2005), while high-intensity actions are represented by sprinting, jumping, and changing direction (Di Salvo et al., 2009; Fang et al., 2021). During a match or training, global positioning systems (GPS) and video analysis identify players involved in standing (0–0.6 km/h-1), walking (0.7–7.1 km/h-1), jogging (7.2–14.3 km/h-1), running (14.4–19.7 km/h-1), high-speed running (19.8–25.1 km/h-1), and sprinting (> 25.1 km/h-1) (Bush et al., 2015; Nilsson & Cardinale, 2015).

The physical aspect of football is expressed in the contest for ball possession, running off the ball, dribbling, tackling, counter-attacking, overlapping, and jumping to head the ball and long tactical kicks (Helgerud et al., 2011; Hostrup & Bangsbo, 2022; Reilly et al., 2000; Stølen et al., 2005). Players experienced a change in physical activity every 4 to 6 seconds, depending on the positions of different players on the pitch (Chmura et al., 2018; Krusturp et al., 2005). Regarding the level of physical performance (amateur versus top level) and the maturity status (adolescent versus adult), there is a positive correlation between physical performance and distance covered, competitive ranking, quality of play, ability to sustain high-intensity activity, number of touch of the ball in the match, maintaining physical condition at a peak level during a match-play, and ability to speed up recovery process (Aquino et al., 2020; Atan et al., 2023; Bradley et al., 2013). According to the quality of competition (e. g., amateur, semi-professional, and professional), the physical demands imposed on football players intensify along with the level of competition (Bekris et al., 2021; França et al., 2022; Miguel et al., 2022; Tereso et al., 2021).

The adolescent period is the phase between childhood and adulthood in males aged 14 to 18 years, corresponding to Tanner stages 3 and 4 of sexual maturation (Beunen et al., 1992; Marshall & Tanner, 1970). In youth sports, athletes must develop a range of physical

abilities to achieve elite status (Eime et al., 2013; Janssen, 2007; Zwolski et al., 2017). Moreover, the successful physical football performance requires information processing to compete in dynamic environments and manage complex mobility (Eime et al., 2013; Malina, 2011; Malina et al., 2015), emphasizing the importance of cognitive skills in young football players. Previous studies revealed a positive correlation between motor skills, academic achievement, and the physical success of youth football players (Eime et al., 2013; Hermassi et al., 2022; Silva et al., 2022).

Muscle power and strength development immediately increase during maturity progress until age 20 years old (McMorris et al., 2000), particularly during early maturing male phase (Brown et al., 2017; Sweeney et al., 2023). Thus, the growth and maturation stages are crucial in evaluating the physical and technical abilities of youth football players (Hermassi et al., 2024; O'Brien-Smith et al., 2020). Given the rapid development of neuromuscular and sensorimotor control in youth (Dost et al., 2016; Malina et al., 2024), it is advisable to initiate training in football at an early age. Therefore, understanding the physical demands of a football match is crucial for coaches and sports trainers to formulate training programmes that effectively develop physical performance and reduce injuries in young players.

1.2 Effectiveness of youth resistance exercise (RE) on anaerobic and balance performance in young football players

Implementing resistance exercise (RE) has considerable interest as a strategic approach to improve the physical performance of young athletes (Suchomel et al., 2018). The National Strength and Conditioning Association (NSCA) defines RE as a specialised form of conditioning distinguished by the progressive incorporation of resistive loads, different movement velocities, and a diverse range of training modalities meticulously designed to improve health, fitness, and sports performance (Faigenbaum et al., 2009; Faigenbaum, 2000; Zwolski et al., 2017). Furthermore, scientific studies have consistently shown that RE positively impacts muscle strength, power and motor skill performance, as well as being safe and effective for young athletes (Behm et al., 2008; Collins et al., 2019; Faigenbaum & Myer, 2010; Harries et al., 2012; Slimani et al., 2018). In line with findings, evidence in the literature suggests that training-induced gains in muscular strength in children are primarily caused by neural adaptation (e. g., improved intra- and intermuscular coordination) rather than muscular factors (e. g., muscle hypertrophy) due to a lack of circulating anabolic hormones (e. g., testosterone) (Granacher et al., 2011; Ruas et al., 2024).

The study reviews and position papers published by advisory bodies have delved into different RE models, including appropriate exercise selection, sequencing, resistance levels, set numbers, and rest intervals between sets, to determine the impact of resistance exercise on

young athletes (Lesinski et al., 2016; Suarez et al., 2019). The volume and intensity are key characteristics of resistance exercise that are routinely manipulated within a training session or general phase of training (Lesinski et al., 2016; Lloyd et al., 2014; McQuilliam et al., 2020). The relationship between volume and intensity is inverse, where the greater the load (intensity), the lower number of repetitions that can be completed (volume) (Haff & Triplett, 2008). Both variables must be considered synergistically, as excessive exposure to high volume and intensity of sport-specific training may result in injury (Jayanthi et al., 2015; Post et al., 2017). Faigenbaum et al. (1999) (2009), Lloyd et al. (2014), Behringer et al. (2011) suggested that the minimal threshold to elicit enhancement in motor skill performance in children and adolescents lies at around 50 % of the one repetition maximum (1RM). According to their findings, RE at low-to-moderate load intensity and high movement velocity appears to be an adequate and effective stimulus to enhance performance in youth athletes. Furthermore, smaller doses of RE (e. g., 2–3 sets per exercise) may be sufficient to improve muscular strength in less-trained individuals, while larger doses of RE (e. g. 4–6 sets per exercise) may be required to achieve the same level of improvement in well-trained athletes (Suchomel et al., 2018).

A comprehensive search of the Scopus, Sport Discus, and Web of Science databases was performed to identify studies evaluating RE programmes on anaerobic and balance characteristics in adolescent football players. Fourteen studies that met the criteria and were published within the last five years up to 31 December 2023 were examined for inclusion. The search syntax included combined sets of terms related to RE (i. e., plyometric, weightlifting, and eccentric training) for the specific population (i. e., youth footballers or soccer). The total sample size across all the studies considered in this analysis was 568 young male adolescent football players (age = 15.27 ± 0.4 years). The maturity status of the participants (pre-peak height velocity (PHV) -0.25 ± 0.3 years from PHV, approaching peak height velocity -1.95 ± 0.3 years from PHV, and late post-peak height velocity (2.5 ± 0.6 years from PHV, while the puberty stage of the players (puberty stages 3–4) according to the Tanner method (Beunen et al., 1992).

The study presented different resistance exercise models for multiple activities. The variety of jumps in varied heights (20–80 cm) (Jlid et al., 2019), running with resistance (Chaalali et al., 2022), various balance exercises (Muehlbauer et al., 2019), weight lifting (Zghal et al., 2019), small-sided games (Arslan et al., 2021), core strength training (Gasim et al., 2022), and change of direction drills (Aloui et al., 2021). All studies indicate that integration of RE into regular training improves anaerobic and balance performance among adolescent footballers. The studies conducted the programmes for 2 to 15 weeks, with an average duration of 7.71 ± 2.68 weeks, 2 or 3 times weekly (2.64 ± 0.97) on alternate days.

The volume of training consists of 2–3 sets of 6–12 repetitions of each activity, at moderate to high intensity. The type of plyometric training was applied with 54–144 ground contacts per session. Integrating RE into regular football training significantly improved anaerobic characteristics (i. e., jump, sprint, change of direction) and balance performance in young footballers.

1.3 Optimization of balance characteristics supported by ankle mobility and implementation of different resistance exercises in young male football players

Balance refers to the human ability to maintain the centre of pressure (CoP) vertically aligned on the base of support (Pollock et al., 2000; Shumway-Cook A, 2017; Winter, 1995). Balance depends on rapid and continuous feedback from the somatosensory, visual, and vestibular systems to produce smooth and coordinated neuromuscular actions (Hrysomallis, 2011; Shumway-Cook A, 2017). The CoP characteristics comprised the amplitudes and the mean velocity of CoP movements in anteroposterior (AP) and mediolateral (ML) directions, and their standard deviations (SD) (Chen et al., 2020; Freitas et al., 2005; Moghadam et al., 2011). Balance is a complex process that requires the synchronised functioning of several sensory, motor, and biomechanical mechanisms (Palmieri et al., 2002). Balance quality is influenced by morphology, muscle strength, power, proprioception, and hemisphere laterality (Bishop et al., 2018; Brachman et al., 2017). Other factors, such as anthropometry, age, sex, and physical activity level, influence balance performance (Alonso et al., 2012; Eriksrud et al., 2019). Balance is typically categorised into two types: static and dynamic. Both types of balance are essential for daily and sports movements. Static balance is defined as the capacity to maintain the centre of mass above the base of support with minimal movement (Hrysomallis, 2011) in unperturbed environments (Macpherson et al., 2012). In contrast, dynamic balance refers to maintaining or adjusting equilibrium during movement or successfully maintaining body balance in changing postural conditions (Davlin, 2004; Paillard, 2019b).

The ability to maintain balance is significantly related sports performance. Research data indicated that the most successful athletes, in terms of competitive level, showed superior postural stability in both ecological and non-ecological circumstances (Paillard, 2019a; Zemková, 2014). Better neuromuscular control of postural and core stability contributes to more efficient functional movements specific to sports performance (Bressel et al., 2007; Paillard, 2017; Zemková & Zapletalová, 2022). On the other hand, a review of the literature found that balance deficits are associated with an increased risk of falls and injuries, including ankle sprains, muscle tears, tendon and ligament injuries among athletes in various sports (Brachman et al., 2017). Balance is the fundamental skill of neuromuscular attachment that contributes to

successful football performance (Meiners & Loudon, 2020; Ricotti, 2011). In particular techniques in football, the dominant leg is used for most techniques, such as shooting, passing, juggling, dribbling, and receiving the ball (Barone et al., 2011; Chew-Bullock et al., 2012), while the non-dominant leg is used to support the body weight (Barone et al., 2011; Zouhal et al., 2018). Furthermore, considerable differences in balance ability observed among players at various technical levels suggest that balance performance varies depending on the level of competition (Butler et al., 2012; Paillard et al., 2006) and the playing position (Jadczak et al., 2019; Mahmoudi et al., 2023).

Balance capacity is supported by the central processing of ankle proprioceptive senses to enhance sport performance and injury prevention (Han et al., 2015). A prior study revealed that ankle strength and range of motion (ROM) are associated with balance control ability (Kim & Kim, 2018; Trajković et al., 2021). Kim & Kim (2018) reported that ankle ROM had the greatest influence on centre of pressure (COP) amplitude and sway velocity in anterior-posterior (AP) and medial-lateral (ML) directions during single leg-quiet stance in young, and trained athletes. Moreover, the increased strength of the shin muscle enhanced static and dynamic balance. The activities, such as running and jumping, ankle plantar flexor (PF), support the body weight and propel the body backward in the late stance of running activity (Kawakami et al., 2008; Sakanaka et al., 2018). Ankle dorsiflexion (DF) ROM improves take-off and landing stability (Dowling et al., 2018; Patti et al., 2024; Taylor et al., 2021; Yun et al., 2016). A study by Akbari et al. (2023) found that reduced ROM ankle DF correlates with an increased number of landing errors during soccer-specific tasks.

Each sports discipline induces specific postural and training adaptations related to the muscles involved in the sport-specific movements. Pontaga (2024) concluded that the training program, which includes the development of sports-specific skills and integrates balance and plyometric exercises, influences balance performance more than the sex of athletes. Consistent with this, a literature review by Ramachandran (2021) revealed that plyometric jump training is an effective method for improving various measures of balance performance (dynamic and static), regardless of participants' gender and age. Furthermore, a current study shows that balance and proprioceptive training can improve balance and technical skills among young football players (Gidu et al., 2022; Mitrousis et al., 2023). Nevertheless, the positive effect of an RE program on postural stability supported by ankle mobility in adolescent athletes remains unexplored. This is a crucial age period for the development of specific skills, and performance at this age can be linked to success in adulthood. Therefore, one of the objectives of this dissertation is to investigate the effects of combined balance and plyometric training on

balance improvement and its determining factors, such as ankle range of motion and shin muscle strength, in young football players.

1.4 Optimisation of anaerobic characteristics and implementation of different resistance exercises in young male football players

Anaerobic, in physiological terms, refers to the capacity of all living organisms' organs and systems, particularly the central nervous system, to perform at high intensity for a short period (Chamari & Padulo, 2015; Green, 1994), but it is also connected to technique and the degree of economy in movement (Sporiš et al., 2014). Anaerobic is defined as the maximal amount of adenosine triphosphate (ATP) resynthesized through anaerobic metabolism (by the whole organism) during a specific mode of maximal short-duration exercise (Green & Dawson, 1993; McArdle et al., 2006). The anaerobic system (non-mitochondrial) responds immediately to exercise energy demands and may help maintain high muscle force and power production (Baker et al., 2010). Furthermore, anaerobic energy production through glycolysis leads to lactic acid production and the accompanying H^+ accumulation in muscle fibres, causing a decrease in calcium (Ca^{2+}) concentration in sarcoplasm, which leads to a reduction of the rate of ATP resynthesis in anaerobic glycolysis reaction (Hostrup & Bangsbo, 2017; Nogueira et al., 2013). As a result, the anaerobic system has limitations, and thus, prolonged intensive exercise either stops or reduces power output.

A distinction must be made between anaerobic power and capacity. Anaerobic power represents the highest rate of anaerobic energy release. In contrast, anaerobic capacity refers to the maximal anaerobic energy production an individual can achieve during intensive, prolonged exercise performed to exhaustion (Hostrup & Bangsbo, 2017). Anaerobic power and capacity can be identified during the all-out 30s test on a cycle ergometer, commonly known as the Wingate anaerobic test (WAnT). This test provides three main variables: peak power output (PPO), mean power (MP), and fatigue index (FI). PPO is known as 'anaerobic power' and is determined by the peak mechanical power recorded during the test, which usually occurs in the first 5 to 10 seconds (Nikolaïdis, 2014; Nikolaidis & Knechtle, 2021). This score demonstrates the power generation capacity of the ATP- Creatine phosphate (PCr) system. MP is considered the 'anaerobic capacity' and represents the average mechanical power maintained during the 30 seconds (Bar-Or, 1987; Castañeda-Babarro, 2021). This score demonstrates the ability to produce energy through the ATP-PCr system and glycolytic metabolism. Fatigue index (FI) represents the loss of power experienced from the moment maximum power is reached at the end of the test (Beneke et al., 2002) and is related to the total capacity to produce ATP-PCr and glycolytic metabolism.

The contribution of anaerobic performance becomes crucial when football players perform intense actions (e. g., sprint and shooting), in transition between activities (e. g., backwards running followed by a header), and during shifts to higher intensities (e. g., jogging to high-speed running) (Buchheit et al., 2015; Hostrup & Bangsbo, 2022; Sporiš et al., 2014). As mentioned in the literature, competitive match-play requirements include an all-out sprint every 90 seconds on average and high-intensity efforts every 30 seconds for each player. Although sprinting and high-intensity actions occur only in 8–12 % of covered running distance, these actions are considered match outcomes (Krustrup & Bangsbo, 2001; Rampinini et al., 2007; Reilly et al., 2000). Approximately 150–250 short bursts of intense action such as repetitive sprints, demonstrate that anaerobic play a significant role, particularly in crucial moments of the match (AlTaweel et al., 2022; Bangsbo et al., 2007). The current study by França et al. (2024) concluded that lower-body power is a significant positive predictor of jump, sprint, and agility in young football players. Furthermore, anaerobic performance in young players strongly correlates with anthropometric characteristics, maturity state, and training load (Nobari et al., 2020, 2023). Young players can achieve greater anaerobic power and capacity during the training season if their coaches provide the appropriate workload of exercises, considering their peak growth velocity (growth spurt), and maturity offset.

A review of the scientific literature conducted by the author (ARS and IP) in 2024 found that combining plyometric with sprint training (Aloui et al., 2021), change direction (Michailidis et al., 2023), or combining RE with a small side game (Arslan et al., 2021), and plyometric (Zghal et al., 2019). These are excellent strategies to improve anaerobic power in young football players. This evidence showed that RE combination is more effective than solely plyometric exercises for improving anaerobic parameters, such as strength, sprinting, and jumping performance. In this context, various modalities of resistance exercise (RE) interventions enhance different neuromuscular attributes (e. g., force and power development rate, stretch-shortening cycle function). Further research is needed to evaluate the effects of resistance exercise on morphological, metabolic, and functional changes in young footballers to improve anaerobic performance, which is the objective of the present study.

2 Material and methods

2.1 Study design and population criteria

The study was conducted in the Riga region, Latvia, from 2022 to 2024. The research protocol was prepared in accordance with all National regulations and institutional policies and followed the Declaration of Helsinki. It was approved by the Ethics Committee of the Latvian Academy of Sport Education (meeting Protocol No. 6, Decision No. 1/51813, 24 February 2023). The study protocol was implemented and reported in accordance with the Standard Protocol Items: Recommendations for Intervention Trials (SPRIT) statement. Parental and participant consents were obtained after a thorough explanation of the study's purpose, procedures, risks, and benefits. The participants read and signed a consent form approved by Latvian Academy of Sports Education Ethics Committee.

Forty-three young male football players (age = 15.81 ± 1.33 years) participated in the first and second studies. However, the third and fourth studies were based on 30 players who were eligible for further analysis. Participants were randomly assigned to an intervention (IG) and control (CG) groups (Figure 2.1). We used Microsoft Excel (Microsoft Corporation, Redmond, WA, USA) to randomly assign 30 players to each group using the formula = SORTBY(SQUENCE(30), RANDARRAY(30, 1, 1, 30, TRUE)). No statistically significant differences were detected between IG and CG at the mean age, training experience, volume, and anthropometric data.

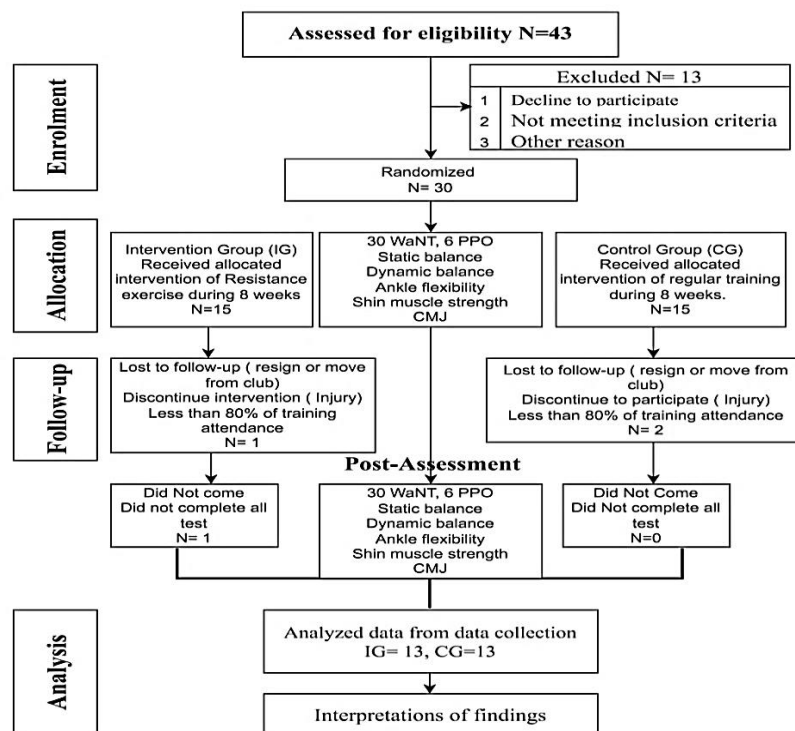


Figure 2.1 **CONSORT diagrams of the full recruitment and randomization process**

They played soccer regularly, about four to five training sessions per week (each lasting around 90 minutes), on natural and synthetic grass. They have about eight years of experience as players and have competed in regional and national competitions. The participants' maturation was estimated using the Tanner method (Beunen et al., 1992), as assessed by the same sport physician. Participants classified as Tanner stages 3 and 4 to exclude the influence of a growth spurt on the footballers' performance. Players were excluded if they had any of the following conditions: painful legs during the test, vestibular disorders, treatment for inner ear disease, or a concussion within three months before the start of this study, as determined by direct inquiry.

2.2 Intervention of combined resistance exercise that included regular training

The CG participants conducted a regular football training program during the 8-week intervention. They had five 90-minute-long training sessions per week. The regular training sessions of both the CG and IG included 40 minutes of plyometric exercises twice per week during the preparation period and once per week during the competition season. The RE interventions were structured so that players in one group were not under the impression that they did not receive a specific intervention.

The subjective intensity of internal training load, which included the volume and intensity of each session, as well as the weekly training load, was evaluated after the training session using the perceived exertion rating scale (RPE) based on the methods proposed by Impellizzeri et al. (2004) and previously used in soccer with the CR 10 scale. Approximately 30 minutes after each training session, players were asked to rate the global intensity of the exercise performed during the previous session based on the category ratio: 10 RPE scale.

The resistance exercise program consisted of balance and plyometric training, as well as self-loading training. The third study on anaerobic performance implemented RE that combined plyometric and self-loading. Similarly, in the fourth study on balance, ankle mobility and explosive strength, resistance exercises were implemented as a balance and plyometric training (Figure 2.2). Subjects were carefully instructed before intervention, received a practical demonstration, and performed a familiarization exercise. In an anaerobic study, IG performed plyometric (hurdle jumps, lateral hurdle jumps, bouncy strides, and single-leg hop jumps) followed by a 20-meter sprint and self-loading training (isometric squat and deep squat, lunge, side lateral lunge, single-leg squat left/right, weight displacement, maximal speed with partner resistance).

On the other hand, the experimental study on balance, ankle mobility, and explosive strength on intervention groups (IG), performed a RE modality that combines balance and

plyometric training. The balance training consisted of four types of exercises: 1) maintaining a static position with semi-squatted legs: both or single leg and holding a medicine ball in the hands, 2) squat and throwing the medical ball vertically upwards, then standing up and catching the ball, 3) standing and keeping a balance position on the balance wobble board with a resistance band positioned around the thighs above the knee, 4) standing and keeping a balance position on the roller balance board with a resistance band positioned around the shins below the knee. The dose-response for balance training followed the protocol outlined by Gebel et al (Gebel, Prieske, et al., 2020). Each exercise lasted 20–40 seconds, with 3 repetitions per set. A 30-second break was given between sets, and the rest periods between different exercises were 120 seconds.

Figure	Type balance training	Figure	Type plyometric training
	Maintaining a static position with semi-squatted legs: both or a single leg, and holding a medicine ball in the hands		Counter-movement jump on both legs over the hurdle
	Performing a squat and throwing the medical ball vertically upwards, then standing up and catching the ball.		Hops on the right and left leg above the hurdle
	Standing and keeping a balance position on the balance wobble board with a resistance band positioned around the thighs above the knee		Single leg jumps forward and backwards, side to side in front of the cone.
	Standing and keeping a balance position on the roller balance board with a resistance band positioned around the shins below the knee.		Skipping the jump rope on both legs and a single leg

Figure 2.2 **Balance and plyometric training**

The plyometric training consisted of four types of exercises: 1) countermovement jump on both legs over the hurdle, 2) hops on the right and left legs above the hurdle, 3) single-leg jumps forward and backward, side to side in front of a cone, 4) skipping the jump rope on both legs and a single leg. Based on the recommendations of Bedoya et al. (2015), plyometric exercises were performed in 2–4 sets of 6–15 repetitions per set. The rest intervals between

each set and different exercises were 60–120 seconds. The initial number of ground contacts per session was set at 50–60, with progression leading to a maximum of 80–120 contacts per session.

During the intervention, balance training was performed before plyometric exercises to achieve optimal functional movement and muscular fitness outcomes (Behm et al., 2008; Granacher & Behm, 2023). The intensity of training increased biweekly by adjusting repetitions, duration, and difficulty (Annex 1). Throughout the training session, coaches provided instructions on proper technique and movement. The coach verbally encouraged the players to exert maximal effort during the training.

2.3 Assessment

2.3.1 Assessment design

The evaluation was performed in the afternoon (from 4 to 6 pm) using the equipment available in the RSU Latvian Academy of Sport Education (LASE) sport science laboratory. All testing was scheduled in the afternoon to control diurnal variations. All football players participated in a familiarization session before the formal testing, during which they were informed of all procedures. The participants practiced 2–3 trials of each test to avoid any learning effects during the experimental session. The ambient temperature range in the room was 18–20°C, and the humidity was 35–50 %. The players were consistently asked to wear indoor sportswear during the tests in the laboratory.

Baseline measurements were performed 4 days after the end of the familiarization session. The evaluation included anthropometric and physical fitness performance (Six-second peak power test (6PPO), Wingate anaerobic endurance test (WAnT), countermovement vertical jump test (CMJ), static and dynamic balance, and ankle mobility. The dominant leg was determined by asking participants which leg they would use to kick a soccer ball as far as possible with maximal force (Baldon et al., 2012; Kollock et al., 2015).

All devices and platforms used in this research have demonstrated validity and reliability in measuring peak power output on the bicycle ergometer (Herbert et al., 2015; Wehbe et al., 2015), short-term strength endurance on the bicycle ergometer (Nikolaidis & Knechtle, 2021; Nikolaidis et al., 2016), vertical jump for muscle strength and power investigation (Bellicha et al., 2022; Glatthorn et al., 2011), static and dynamic balance (Srishti et al., 2023), ankle range of motion (Lind et al., 2022), shin muscles' peak isometric strength (Kolber & Cleland, 2005).

2.3.2 Anthropometric assessments

Anthropometric data were collected by the same experienced evaluator, who assessed height and body mass. Anthropometric measurements of young football players wearing briefs were taken using a SECA 220 for height (accuracy of up to 1 mm) and SECA 874 scales for weight (accuracy of up to 0.05 kg) (SECA, Hamburg, Germany). Body mass index (BMI) was calculated by dividing weight in kilograms (kg) by the square of height in meters (m²).

2.3.3 Six-second peak power output test (6PPO)

The six-second peak power output test was performed on a cycle ergometer (Wattbike Pro, Nottingham, UK). The saddle heights were individually adjusted to each subject, and the toe clips supported the feet. During two minutes of warm-up, players performed a steady-state ‘easy spin’ at a self-selected cadence with the air and magnetic resistance fixed at the lowest settings (level 1 and 1), respectively (Wehbe et al., 2015). Air and magnetic resistances are used and increased during the test. The Wattbike was ‘zeroed’ before testing to ensure reliability, as recommended by the manufacturer. The investigator selects the resistance levels based on the subject’s body mass. The test was initiated following a 5-second countdown, followed by a firm verbal command “GO”. The completion of the test was indicated with another verbal command, ‘STOP’. The investigator stabilised the Wattbike throughout the test to prevent the ergometer shift (Herbert et al., 2015; Hopker et al., 2010). Immediately following one minute of active recovery, ‘easy spin’ was conducted at self-selected cadence with both resistance settings returning to level 1. The highest power value recorded during the six-second test was analysed from two trials in our investigation.

2.3.4 Wingate anaerobic test (WAnT)

The WAnT was conducted according to widely accepted recommendations for standardization (Inbar et al., 1996) (Bar-Or, 1987). The test was initiated with a standardised 5-minute cycling warm-up at a resistance of 50W. The test included two 3-second sprints at the end of the 3rd and 5th minutes as preparation for the sprint. The resistance settings (the air and magnetic) on the Wattbike monitor were based on each football player’s body mass. After a 10-minute rest, the subjects were instructed to pedal as fast as possible (Beneke et al., 2002). Strong verbal encouragement was given to help the player keep a high pedalling rate during the 30 seconds. After the test was completed, the subjects were supervised during a 30-minute rest in a sitting position.

The Wattbike Pro cycle ergometer’s performance computer calculated power via a load cell next to the chain. As force is exerted through the cranks, the load cell calculates the power by the sum of all forces applied during one complete pedal revolution. After completing

the test, the power output in Watts (W) shown on the Wattbike monitor is calculated using the following equation: $P (W) = [F(N) * l(m)] / T(s)$, where F the force applied in N multiplied by the distance covered in meters (m) and divided by the time in seconds (s). The peak power (W), mean power (W), relative peak and mean power (W/kg) (absolute divided by the body mass), and fatigue index (%) were analysed.

2.3.5 Countermovement jump test (CMJ)

The participant stood on a vertical jump force platform, with their hands placed at their waist, jumping vertically upward as high as possible after a quick squat. Participants had to remain upright before performing the vertical jump, starting with a countermovement until the legs were bent to an angle of 90° (Petrigna et al., 2019) and both hands were positioned on the hips. Subjects began a countermovement jump in one motion after a verbal command. The best jump test result (the highest jump) was used for analysis after three jump trials. The Optojump (Microgate, Srl., Bolzano, Italy) measured jump height and time flight. The force plate BTSP-6000 (BTS Bioengineering, Garbagnate Milanese, Italy) measured the maximum ground reaction force production.

2.3.6 Static balance test

Static and dynamic balance were evaluated using the ProKin 252 stabilometric platform (TecnoBody, Dalmine, Italy). The trunk sensor was attached to the chest in the middle of the sternal bone. Balance characteristics were measured in a one-leg stance. The longitudinal axis of the leg was determined by establishing a tangent line connecting the midpoint of the middle toe to the central point of the heel. Participants placed their hands on their hips, and the unweighted leg was maintained at 45° of knee flexion during the test. Contact was not allowed between the raised and stance limbs (Mauch et al., 2011).

Players were instructed to maintain a one-leg stance for 30 seconds with their eyes open and focus on a stationary target. After 30 seconds of standing on each leg, the device displayed the characteristics: ellipse area (EA) of the body's centre of pressure (CoP) movements, perimeter (P) of the centre of pressure movements area, distances of sway in the anterior-posterior (APD), medial-lateral direction (MLD), trunk deviation (TD) angle, average anterior-posterior (AAPS) and medial-lateral (AMLS) speed of the CoP. The total length of the circumference of the disorganised lines of the sway of CoP was used to determine the perimeter of the area of body sway (P). Shorter perimeter length (P) indicates better postural balance (Donath et al., 2012). Furthermore, the EA of the body's centre of pressure sway was an established elliptical form that covered at least 90 % or 95 % of the chaotic sway lines. Balance performance is better with a smaller ellipse area (EA) (Asseman et al., 2004).

2.3.7 Dynamic balance test

The players were instructed to maintain balance in a one-leg stance, looking straight ahead at the screen with their eyes open for 30 seconds. The movable balance platform of the system works with air piston servo motors and performs measurements in every direction with an operating angle of 15°. The device presented data on dynamic balance characteristics, including a total stability index (TSI) and total trunk deviation (TTD) angle. TSI was classified as normative for trained subjects with a value of 0–0.83, normal between 0.84 and 2.32, and poor dynamic balance if it exceeded 2.33. A higher score of the total stability index and the trunk deviation angle meant a worse sense of trunk position. The normal TSI value for the studied age group (18 to 35-year-olds) is 0.82–2.26 (Cachupe et al., 2001). Balance instability was considered in participants with a TSI value higher than 2.3 (Finn et al., 1999).

Based on previous protocols (Meiners & Loudon; 2020, Pizzigalli et al., 2013), two trials were performed, one on each lower extremity, with eyes open for a test duration of 30 seconds and a 30-minute break between balance tests. If subjects did not complete the 30-second test without error, one additional trial was given to the participant to complete the test.

2.3.8 Ankle range of movement plantar and dorsal flexion test

Participants were seated with a knee flexed to 90° for plantar flexion (PF) and dorsiflexion (DF) range of motion (ROM) measurements at the talocrural joint. The ROM was measured using a Jamar Plus digital goniometer (Performance Health, United Kingdom), following the protocols “A Guide to Goniometry by Norkin and White” (2017). Landmark: A dot 2 cm below the tip of the lateral malleolus was marked, and another dot 10 cm above the tip of the lateral malleolus on the posterior of the fibula. The pivot point of the goniometer was placed on the lateral malleolus. The fixed arm was kept parallel to the lateral midline of the fibula, while the movable arm was parallel to the lateral midline of the fifth metatarsal bone (Tavares et al., 2017). The average score from three trials was calculated.

2.3.9 Shin muscles’ peak isometric strength test

Strength of the ankle plantar (soleus, gastrocnemius, plantaris, tibialis posterior, peroneus longus and brevis) and dorsiflexor muscle (extensor hallucis longus, extensor digitorum longus, tibialis anterior) were measured. Participants were positioned supine with their feet in a neutral position. A handheld dynamometer (MicroFET2 ; Hogan Health Industries Inc., Draper, UT, United States) was used to examine the maximal voluntary isometric contraction (MVIC) of the shin muscle. The device was positioned against the dorsal surface of the foot, just proximal to the metatarsal heads, to measure the peak force of the ankle

dorsiflexor muscle. To measure the peak isometric force of the plantar flexor muscle, the device was placed on the plantar surface of the foot, just proximal to the first metatarsal heads (Spink et al., 2010). The participant pushed the dynamometer against the physiotherapist's hand as hard as possible for 3 seconds with each foot, taking a minute interval between trials (Gapeyeva, 2015). The peak muscle-generated force depends on the maximal voluntary effort exerted by the participant. Three trials assessed the maximum force, and participants were encouraged to push the dynamometer as strongly as possible. Peak force (N) was obtained from the highest score from three trials of maximal voluntary contractions (MVC). Peak torque (N*m) was calculated from peak force multiplied by the arm length (m) (linear distance from the posterior lateral malleolus to the metatarsal heads). The torques were divided by body mass (Nm/kg) to obtain relative peak torques (Gapeyeva, 2015).

2.3.10 Statistical processing of results

Statistical analysis was performed using SPSS version 26.0 (IBM Corp., USA). All variables were expressed as the mean and standard deviation. The Shapiro-Wilk normality test was used to assess the data distribution. A purposive sampling strategy was used, and participants were selected based on their age (14–16 years), sex (male), experiences as football players, and other relevant factors related to the study's focus, as explained in the inclusion and exclusion criteria section.

In study 1, the Kruskal-Wallis H test was used to compare peak power output, explosive lower-limb muscle strength, and balance characteristics according to their playing positions. For a significant difference, Post hoc Dunn's test was conducted to find which group was favoured. Eta-squared (η^2) was used to calculate the effect sizes: 0.01 small, 0.06 medium, and 0.14 large (Richardson, 2011).

In study 2, the Mann-Whitney test was conducted to compare the significance of differences between Dominant (D) and Nondominant (ND) legs in static and dynamic and dynamic balance tests. On the other hand, Spearman's rank correlation was used to assess the relationship between static and dynamic balance characteristics.

The sample sizes for studies 3 and 4 were estimated by G*Power 1.9.4 analysis. Based on an effect size (f) > 0.80 from a previous study (Hammami et al., 2023) with 80 % statistical power ($\beta = 0.8$) and $\alpha = 0.05$, the analysis indicated a minimum requirement of 12 participants per group. To account for a potential dropout rate of 20 %, 30 well-trained adolescent male players were recruited for this study. Within-group changes (pre- (t_0) to post- (t_1) test were calculated using the paired t-test. Effect size calculated by Cohen's d (trivial = < 0.2, small = < 0.5, moderate = < 0.8, large = > 0.8 (Cohen, 2013). Percentage changes were

calculated as: $[(\text{pre} - \text{post}) / \text{pre}] \times 100$. The significance of differences in the characteristics between the groups was analysed using ANCOVA (2×2), with effect size reported as partial eta-squared (η^2) with small = 0.01, medium = 0.06, large = 0.15.

3 Results

3.1 Analysis of anaerobic and balance performance in young football players by playing position <http://dx.doi.org/10.16926/sit.2025.01.05> (Study 1)

In the first data collection (2023/2024 season), we conducted a pilot study to assess peak power output, explosive lower-limb strength, and balance performance in young football players across playing positions. Forty-three young male footballers (age = 15.81 ± 1.33 years) from football clubs in Riga participated. They had more than five years of football experience, 7–8 hours of regular training per week, and competed regularly. They players was classified into four groups: Goalkeeper (GK) (N:5, H: 185.42 ± 2.20 cm, BM: 76.20 ± 9.85 kg), Defenders (DEF) (N:12, H: 182.48 ± 2.20 cm, BM: 73.70 ± 4.73 kg), Midfielders (MD) (N: 20, H: 174.89 ± 5.03 cm, BM: 63.77 ± 6.92 kg), Forwards (F) (N:6 H: 184.00 ± 3.69 cm, BM: 75.28 ± 12.25 kg).

3.1.1 Peak power output and jump performance by playing position

As shown in Table 3.1, significant differences in anaerobic peak power output were observed across playing position ($p = 0.018$, $\eta^2 = 0.226$), indicating a moderate effect size. However, neither cadence peak nor time to peak parameters differed significantly among groups. The post-hoc Dunn analysis revealed that forwards (F) have significantly greater power output production than midfielders (MD) (885.83 ± 77.18 W vs. 690.54 ± 198.97 W, $p = 0.003$). In contrast, vertical jump characteristics (jump height, flight time, and peak force) did not differ significantly across playing position ($p = 0.11$ – 0.31).

Table 3.1

Six-second peak power and counter-movement jump based on playing position

PPO 6s variables	Position	Mean	Std. Dev	95 % CI		p-value	Eta-square (η^2)
				Lower	Upper		
PPO (W)	GK	855	46.24	797.57	912.42	0.003*	0.226
	DEF	816.75	109.65	747.08	886.41		
	MD	690.54	198.97	597.42	783.66		
	F	885.83	77.18	804.82	966.83		
CP (Rpm)	GK	151.6	14.94	133.04	170.15	0.904	0.009
	DEF	150.91	10.16	144.45	157.37		
	MD	152.55	14.54	145.74	159.35		
	F	154.83	14.51	139.6	170.06		
TP (s)	GK	1.59	0.99	0.35	2.83	0.782	0.053
	DEF	1.34	0.65	0.93	1.76		
	MD	1.33	0.6	1.05	1.61		
	F	1.78	1	0.72	2.84		

Table 3.1 continued

CMJ variables	Position	Mean	Std. Dev	95 % CI		p-value	Eta- square (η^2)
				Lower	Upper		
JH (cm)	GK	42.84	2.56	39.66	46.02	0.316	0.055
	DEF	40.27	5.19	36.97	43.56		
	MD	39.37	5.98	36.57	42.17		
	F	38.63	2.81	35.68	41.58		
TF (s)	GK	0.59	0.02	0.57	0.61	0.272	0.070
	DEF	0.57	0.04	0.55	0.6		
	MD	0.57	0.04	0.55	0.59		
	F	0.56	0.02	0.53	0.58		
PF (N)	GK	1850.14	222.01	1574.48	2125.8	0.111	0.175
	DEF	1824.36	270.82	1652.29	1996.43		
	MD	1571.48	270.38	1444.93	1698.02		
	F	1819.3	439.45	1358.12	2280.48		

PPO (Peak power output), CP (cadence peak), TP (Time to peak), W(watt), Rpm (Revolutions per minute), JH (Jump height), TF (Time flight), PF (Peak force), cm (centimetres), s (Seconds), N (Newton). Notes: * – Significant difference among players position ($p < 0.05$)

3.1.2 Static and Dynamic Balance by playing position

The characteristics of static balance, such as ellipse area (EA), perimeter (P), and average anterior-posterior movement speed (AAPS) of the centre of pressure, exhibited no significant differences among players positions ($p = 0.17$ – 0.45). Conversely, average medial-lateral movement speed (AMLS) showed a significant difference between the non-dominant ($p = 0.025$, $\eta^2 = 0.211$) and the dominant ($p = 0.033$, $\eta^2 = 0.198$) legs based on the players' positions (Table 3.2). Additionally, AMLS post-hoc analysis (Dunn's test) identified disparities between goalkeepers and forwards in their non-dominant (27.29 ± 5.34 vs. 47.21 ± 17.02 ($p = 0.022$) and dominant leg (31.37 ± 5.94 vs. 52.29 ± 20.5) ($p = 0.040$). Regarding dynamic balance, no statistically significant difference was observed between the dominant/non-dominant legs during the 30-second one-leg stance test across players' positions, $p = 0.16$ – 0.61 .

Table 3.2

Static and dynamic balance performance according to playing position

Static balance variables	Position	Mean	Std. dev	95 % CI		p-value	Eta- (η^2)
				Lower	Upper		
EA (mm²) ND	GK	860.4	214.96	593.49	1127.3	0.324	0.109
	DEF	743.22	320.5	539.58	946.85		
	MD	847.02	401.06	659.32	1034.72		
	F	1172.82	593.81	549.65	1795.99		
EA (mm²) D	GK	985.62	331.99	573.4	1397.84	0.456	0.042
	DEF	823.11	221.02	682.68	963.53		
	MD	896.3	432.26	694	1098.6		
	F	1034.64	254.33	767.73	1301.54		

Table 3.2 continued

Static balance variables	Position	Mean	Std. dev	95 % CI		p-value	Eta- (η^2)
				Lower	Upper		
P (mm) ND	GK	1215.62	190.36	979.26	1451.99	0.171	0.171
	DEF	1476.71	369.31	1242.06	1711.35		
	MD	1596.23	520.65	1352.56	1839.91		
	F	2036.29	793.06	1204.02	2868.56		
P (mm) D	GK	1369.26	235.62	1076.7	1661.82	0.423	0.089
	DEF	1639.68	509.22	1316.14	1963.22		
	MD	1584.23	454.16	1371.68	1796.78		
	F	1923.35	666.94	1223.44	2623.26		
AAPS (mm/s) ND	GK	24.18	3.24	20.16	28.2	0.406	0.09
	DEF	29.33	8.06	24.21	34.45		
	MD	31.89	11.9	26.33	37.46		
	F	36.87	17.25	18.76	54.98		
AAPS (mm/s) D	GK	26.24	5.34	19.61	32.87	0.307	0.102
	DEF	32.34	9.25	26.46	38.22		
	MD	29.46	9.46	25.03	33.88		
	F	37.32	13.7	22.94	51.69		
AMLS (mm/s) ND	GK	27.29	5.34	20.66	33.92	0.025*	0.211
	DEF	32.94	9.05	27.19	38.69		
	MD	35.43	10.65	30.44	40.41		
	F	47.21	17.02	29.34	65.08		
AMLS (mm/s) D	GK	31.37	5.94	23.99	38.75	0.033*	0.198
	DEF	36.77	13.11	28.44	45.1		
	MD	36.77	9.97	32.11	41.44		
	F	52.29	20.5	30.78	73.81		
TSI (°) ND	GK	2.57	0.87	1.5	3.65	0.571	0.047
	DEF	2.18	0.73	1.72	2.64		
	MD	2.33	0.83	1.94	2.72		
	F	2.67	0.66	1.98	3.36		
TSI (°) D	GK	2.7	1.25	1.14	4.25	0.619	0.027
	DEF	2.37	1.01	1.73	3.01		
	MD	2.23	0.91	1.81	2.66		
	F	2.4	0.43	1.95	2.85		
TTD (°) ND	GK	2.01	0.8	1.02	3.01	0.168	0.12
	DEF	3.43	2.61	1.77	5.09		
	MD	2.31	1.35	1.68	2.94		
	F	3.86	2.47	1.27	6.45		
TTD (°) D	GK	3.29	2.53	0.15	6.43	0.483	0.06
	DEF	3.03	2.43	1.49	4.57		
	MD	2.28	1.85	1.41	3.14		
	F	3.62	2.04	1.48	5.76		

EA (Ellipse area), P (Perimeter), AAPS (Average Anterior – Posterior speed), AMLS (Average Medial – Lateral speed), TSI (Total Stability Index), TTD (Trunk Total Deviation), (°) (Degree). ND (non-dominant leg), D (dominant leg). * – Significant difference among players position ($p < 0.05$).

3.2 Identification of asymmetries between the dominant (D) and nondominant (ND) leg and the relationship between static and dynamic balance parameters. <https://doi.org/10.5114/hm/186752> (Study 2)

The results shown in Table 3.3 were obtained from the best value of each parameter of static and dynamic balance in a 30-second one-leg stance with eyes open. No significant differences were found between the dominant (D) and nondominant (ND) legs in all variables of static balance $p = 0.33\text{--}0.72$. Similarly, dynamic balance results revealed no significant differences between D and ND legs for parameters: TSI ($Z = -0.337$, $p = 0.736$), and TTD ($Z = -0.268$, $p = 0.789$).

Table 3.3

Static and Dynamic balance between the dominant and non-dominant leg

Variables	Non-dominant	Dominant	Z	p-value	Partial Eta-Squared
Static Balance					
EA (mm²)	858.09 ± 383.88	905.56 ± 347.33	-0.816	0.414	0.004
P (mm)	1580.02 ± 534.23	1622.02 ± 490.72	-0.428	0.669	0.002
APD (mm)	8.46 ± 2.83	8.58 ± 2.50	-0.350	0.726	0.001
MLD (mm)	5.39 ± 1.15	5.64 ± 1.02	-0.890	0.437	0.013
TD (°)	1.93 ± 0.90	1.72 ± 0.73	-0.808	0.419	0.017
AAPS (mm/s)	30.97 ± 11.36	30.98 ± 9.89	-0.229	0.819	–
AMLS (mm/s)	35.43 ± 11.81	38.31 ± 13.36	-0.967	0.333	0.013
TSI (°)	2.35 ± 0.78	2.35 ± 0.90	-0.337	0.736	–
TTD (°)	2.72 ± 1.97	2.87 ± 2.09	-0.268	0.789	0.001

Abbreviation: EA (Ellipse area), P (Perimeter), APD (Anterior-Posterior deviation), MLD (Medial-Lateral Deviation), TD (Trunk Deviation), AAPS (Average Anterior – Posterior speed), AMLS (Average Medial-Lateral speed), TSI (Total Stability Index), TTD (Trunk Total Deviation), (°) (Degree). ND (non-dominant leg), D (dominant leg).

Data Table 3.4 was obtained from each parameter's average score of the D and ND legs during 30 seconds with eyes open. In general, no statistically meaningful relationship was detected between static and dynamic balance for the parameters: TSI and EA ($r = 0.13$, $p = 0.38$), TSI and PA ($r = -0.06$, $p = 0.69$), TSI and APD ($r = 0.14$, $p = 0.34$), TSI and MLD ($r = 0.10$, $p = 0.51$), TSI and TD ($r = 0.16$, $p = 0.30$), TSI and AAPS ($r = -0.00$, $p = 0.96$), TSI and AMLS ($r = -0.03$, $p = 0.83$), TTD and PA ($r = 0.04$, $p = 0.77$), TTD and APD ($r = 0.26$, $p = 0.08$), TTD and AAPS ($r = 0.09$, $p = 0.55$), TTD and AMLS ($r = 0.04$, $p = 0.78$). Statistically significant relationships were demonstrated among TTD and EA ($r = 0.33$, $p = 0.03$), TTD and MLD ($r = 0.33$, $p = 0.02$), and TTD and TD ($r = 0.42$, $p = 0.05$, with small to moderate effects).

Table 3.4

Correlation between dynamic and static balance parameters

Variables	EA (mm ²)	P (mm)	APD (mm)	MLD (mm)	TD (°)	AAPS (mm/s)	AMLS (mm/s)
TSI (°)	0.136	-0.062	0.147	0.101	0.161	-0.006	-0.032
	0.386	0.693	0.345	0.518	0.301	0.969	0.837
TTD (°)	.332	0.045	0.267	.335	.423	0.092	0.043
	0.03	0.773	0.083	0.028	0.005	0.557	0.784

Abbreviation: EA (Ellipse area), P (Perimeter), APD (Anterior-Posterior deviation), MLD (Medial-Lateral Deviation), TD (Trunk Deviation) AAPS (Average Anterior – Posterior speed), AMLS (Average Medial – Lateral speed), TSI (Total Stability Index), TTD (Trunk Total Deviation), (°) (Degree). ND (non-dominant leg), D (dominant leg).

3.3 Effects of 8-week combined resistance training and regular training on anaerobic performance (Study 3)

The data were collected during the 2023/2024 season. Importantly, the improvement in anaerobic performance resulted from incorporated resistance training (plyometric and self-loading) and regular training. The resistance exercises consisted of plyometric (hurdle jumps, lateral hurdle jumps, bouncy strides, and single-leg hop jumps) followed by a 20-meter sprint and self-loading training (isometric squat and deep squat, lunge, side lateral lunge, single-leg squat left/right, weight displacement, and maximal speed with partner resistance). Therefore, we acknowledge this improvement not solely in the experimental (intervention) group but also in the control group as part of the training routine. We observed that during regular training sessions, the coach of the control group implemented sprint training (e. g., interval sprint training, sprint with resistance) and small side games, which resulted in significant improvement in anaerobic performance.

IG and CG demonstrated significant improvements in peak power output during the Wingate Anaerobic test (WAnt) and six-second peak power output test (PPO 6s), with percentage change ranging from 12–31 % ($p = 0.000–0.02$; $d = 0.97–1.5$) (Table 4.5, Figure 3.1A). Absolute mean power significantly increased IG (453.46 ± 53.46 vs. 552.61 ± 94.49) and CG (541.92 ± 59.65 vs. 605.84 ± 75.69). While only IG showed a significant improvement in relative power output, neither group exhibited statistically significant changes in relative mean power. No significant improvement was detected in fatigue index (percentage of power lost from the beginning to the end of the test) and in the rate of power development (time to peak) in both groups. The analysis of covariance (ANCOVA) revealed no significant group-by-time interaction effects for all parameters of anaerobic performance ($p = 0.12–0.90$) (Figure 3.1 B).

Table 3.5

Anaerobic performance before (pre-) and after (post-test)

Variables	Intervention Groups				Control Groups				ANCOVA				
	$\bar{x}1$	$\bar{x}2$	%	p	d	$\bar{x}1$	$\bar{x}2$	%	p	d	F	P	η_p^2
PPO 30 WanT (W)	665 ± 103.47	854.38 ± 140.84	28.48	0.00*	1.53	785.46 ± 91.22	884.07 ± 97.30	12.55	0.025*	1.04	0.157	0.696	0.007
Relative PPO (w/kg)	10.10 ± 1.07	11.79 ± 1.12	16.73	0.006*	1.54	11.16 ± 0.97	12.04 ± 1.49	7.89	0.112	0.69	0.736	0.400	0.031
Mean Power (W)	453.46 ± 53.46	552.61 ± 94.49	21.87	0.001*	1.29	541.92 ± 59.65	605.84 ± 75.69	11.80	0.018*	0.93	0.020	0.889	0.001
Relative MP (w/kg)	6.94 ± 0.83	7.62 ± 0.88	9.80	0.105	0.79	7.70 ± 0.58	8.24 ± 1.13	7.01	0.137	0.60	2.614	0.120	0.102
Fatigue Index (%)	45.76 ± 7.92	49.30 ± 7.81	7.74	0.227	0.45	47.46 ± 3.79	49.38 ± 5.59	4.05	0.249	0.40	0.014	0.906	0.001
6 PPO (W)	723.07 ± 124.50	959.53 ± 172.73	32.70	0.001*	1.57	833.15 ± 78.86	977.38 ± 111.78	17.31	0.002*	0.970	0.025	0.877	0.001
Time to peak (s)	1.32 ± 0.63	1.29 ± 1.04	-2.27	0.900	0.03	1.53 ± 0.79	1.67 ± 0.99	9.15	0.741	0.15	0.942	0.342	0.041

Abbreviation: PPO = peak power output, MP = mean power, WAnT = Wingate anaerobic test, 6PPO = six-second peak power output test, $\bar{x}1$ = mean pre-test, $\bar{x}2$ = mean post-test, Δ % = percentage change from pre to post-test, η_p^2 = partial eta square. * Significant difference: $p < 0.05$ between pre- and post-test within groups.

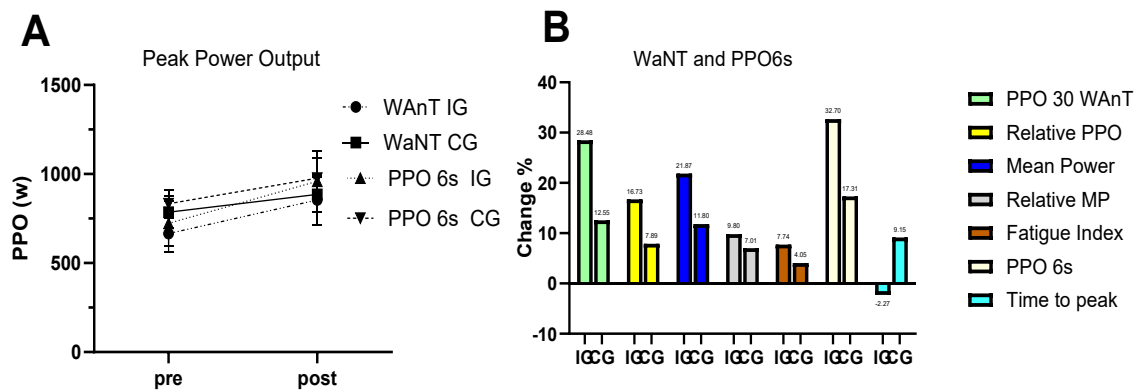


Figure 3.1 Change peak power output during Wingate anaerobic and Six-second test in intervention (IG) and control groups (CG) (A), relative percentage change among variables of Anaerobic test (B)

3.4 Effects of combined resistance training (balance and plyometric) on balance performance and its determining factors in young football players. <https://doi.org/10.5334/paah.472> (Study 4)

Thirty male young players were randomly allocated to an intervention (IG) and a control (CG) group. The IG (N: 15, age: 15.8 ± 1.7 years, body mass of 67.8 ± 11.9 kg, height of 177.2 ± 5.9 cm, BMI of 21.9 ± 2.8 kg/m²), and CG (N: 15, age: 15.7 ± 0.6 years, body mass of 69.6 ± 4.8 kg, height of 180.3 ± 5.6 cm, BMI of 21.8 ± 1.4 kg/m²). No differences between groups in the baseline of anthropometric characteristics ($p > 0.05$). The final sample size for analysis was reduced to 26 players: a) two players missed the post-intervention test; b) two participants did not fully complete this study due to injury. Obtaining an adherence rate of 86.67 %, the data were eligible for further analysis.

3.4.1 Effects of integrative balance and plyometric training on static and dynamic balance

A significant group (IG and CG) x time (pre-and post) interaction was observed for static balance, with EA dominant (D) leg ($F = 6.62$; $p = 0.017$; $\eta^2 = 0.224$) and non-dominant (ND) leg ($F = 4.6620$; $p = 0.042$; $\eta^2 = 0.167$) (Table 3.6) (Annex 2). The absolute mean value of EA decreased significantly to 96–101 mm² in IG (Figure 3.2A). Furthermore, significant interactions were found perimeter (P) of D leg ($F = 18.303$; $p = 0.001$; $\eta^2 = 0.443$), and ND leg ($F = 14.780$; $p = 0.001$; $\eta^2 = 0.391$), average anterior–posterior speed (AAPS) of D leg ($F = 10.816$; $p = 0.001$; $\eta^2 = 0.320$) and ND leg ($F = 10.794$; $p = 0.003$; $\eta^2 = 0.436$), and average medial-lateral speed (AMLS) of D leg ($F = 10.599$; $p = 0.003$; $\eta^2 = 0.315$) and ND leg ($F = 13.521$; $p = 0.001$; $\eta^2 = 0.370$). Within-group analysis revealed significant pre-to-post changes for all static balance characteristics in the IG ($p = 0.001$ – 0.045), with relative percentage change ranging from -10 % to -14 % (Figure 3.3A). Conversely, no significant change was observed in the CG after eight weeks of training routines.

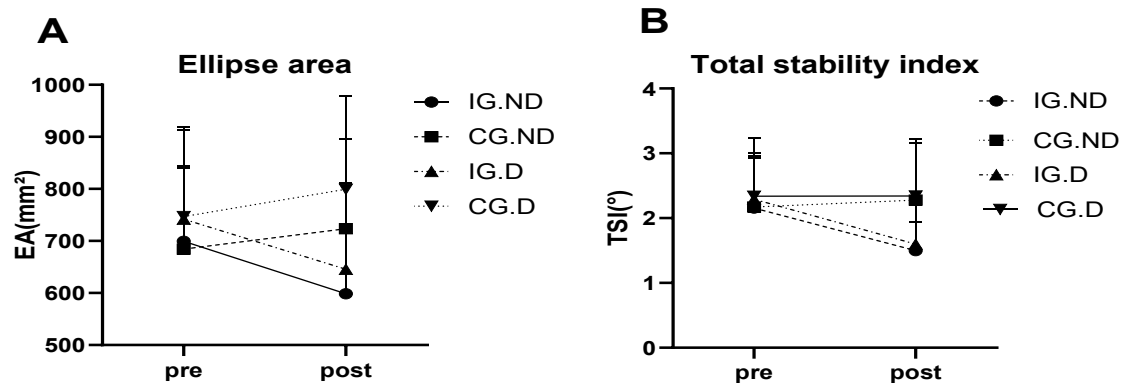


Figure 3.2 Changes of values of the ellipse area in static balance (A), and total stability index in dynamic balance (B) before and after the intervention

Significant between-groups differences were shown in total stability index (TSI) for D leg ($F = 5.793$; $p = 0.025$; $\eta^2 = 0.201$) and ND leg ($F = 7.675$; $p = 0.025$; $\eta^2 = 0.250$) (Figure 3.2B). Moreover, IG demonstrated improvement in total trunk deviation (TTD) for D leg ($2.36 \pm 0.67^\circ$ vs. $1.91 \pm 0.59^\circ$) and ND leg ($2.36 \pm 0.67^\circ$ vs. $1.74 \pm 0.72^\circ$), with significant interaction in D / ND leg ($F = 4.506, 4.444$; $p = 0.045, 0.046$; $\eta^2 = 0.164, 0.162$, respectively). Within-group analysis showed that IG significantly improved TSI and TTD for D leg ($\Delta =$ from -25% to -30% ; $p = 0.013$; $d = 1.89$), and ND leg ($\Delta =$ from -26 to -30% ; $p = 0.007$; $d = 1.89$). In contrast, the CG showed no significant improvements in both parameters (Figure 3.3 B)

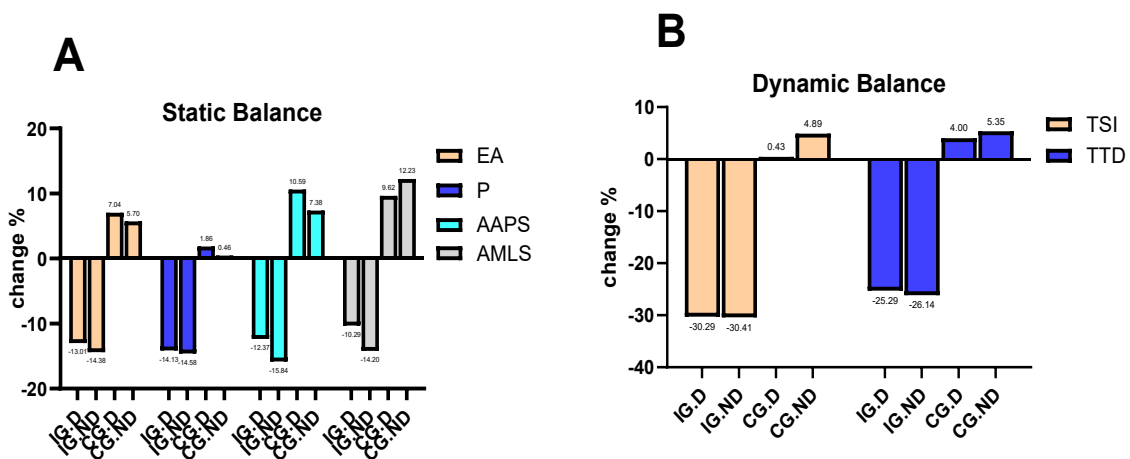


Figure 3.3 Relative percentage changes among the variables of static balance (A), dynamic balance (B) before and after the intervention

3.4.2 Effects of integrative balance and plyometric training on the active ankle plantar and dorsiflexion range of motion

Analysis of covariance (ANCOVA) revealed a significant group (IG and CG) x time (pre- and post) interaction for plantar flexion (PF) D leg ($F = 4.751$; $p = 0.040$; $\eta^2 = 0.171$), and ND leg ($F = 5.432$; $p = 0.029$; $\eta^2 = 0.191$). Similarly, a significant interaction was

observed for dorsiflexion (DF) in D leg ($F = 5.284$; $p = 0.031$; $\eta^2 = 0.187$) and ND leg ($F = 7.645$; $p = 0.011$; $\eta^2 = 0.249$) (Table 3.7) (Annex 2).

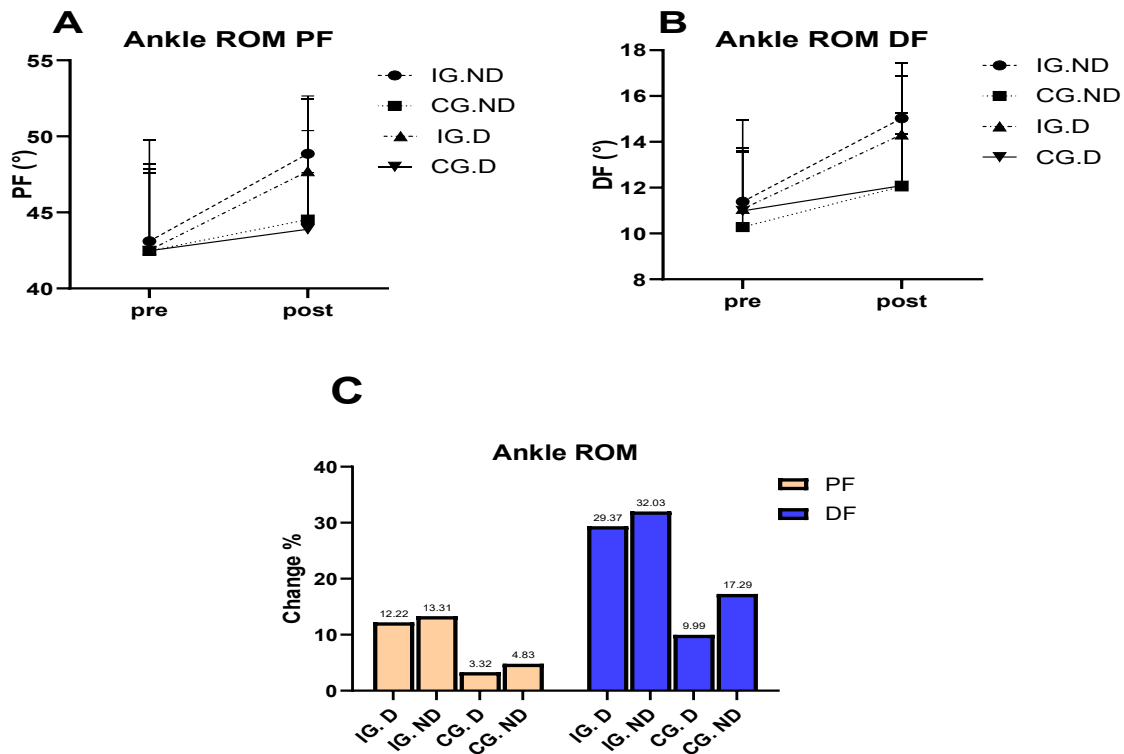


Figure 3.4 Change ROM value of plantar flexion (A), Dorsiflexion (B), and relative percentage change range of motion PF and DF (C) before and after the intervention

Within-group analysis showed significant increase from pre-to-post intervention in the IG for PF D leg ($\Delta = 13$ %, $p = 0.027$; $d = 1.06$) and ND leg ($\Delta = 12$ %; $p = 0.002$; $d = 1.05$). The absolute mean value of DF enhanced significantly in the IG for D leg ($11^\circ \pm 3^\circ$ vs. $14^\circ \pm 3^\circ$) and ND leg ($11^\circ \pm 4^\circ$ vs. $15^\circ \pm 2^\circ$) (Figure 3.4A). Significant improvement in DF for D leg ($\Delta = 32$ %; $p = 0.001$; $d = 1.19$) and ND leg ($\Delta = 29$ %; $p = 0.000$; $d = 1.27$). The absolute mean value of DF enhanced significantly in the IG for D leg ($11^\circ \pm 3^\circ$ vs. $14^\circ \pm 3^\circ$) and ND leg ($11^\circ \pm 4^\circ$ vs. $15^\circ \pm 2^\circ$) (Figure 4.4B). In contrast, the CG showed no significant changes in the PF or DF for either the D or ND leg ($p = 0.06$ – 0.47). The percentage relative change in PF and DF for both groups is shown in Figure 3.4C.

3.4.3 Effects of balance and plyometric training on peak isometric shin muscle strength

Pre-and post-test comparisons revealed significant improvement in the IG for peak force of plantar flexor (PF) muscles in the dominant (D) leg (136 ± 34 N vs. 151 ± 29 N; $p = 0.01$), and non-dominant (ND) leg (134 ± 35 N vs. 148 ± 22 N; $p = 0.03$) (Table 4.8) (Annex 2). Additionally, the IG showed a significant increase in peak torque for plantar flexion (PF) (4–7 N.m), dorsiflexion (DF) in both groups (3–4 N.m) (Figure 3.5 A and B). The CG also

demonstrated improvements in peak force and torque of the DF muscles in the D leg, and relative torque in both legs ($p = 0.01$ – 0.04).

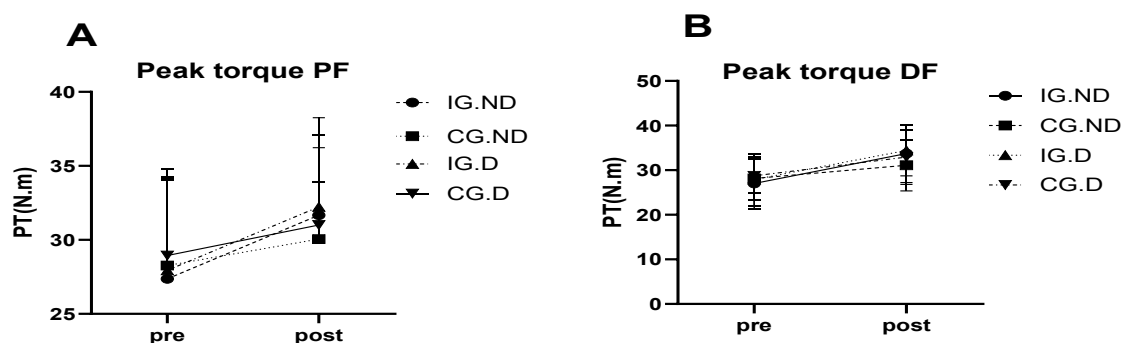


Figure 3.5 Change value of peak torque plantar flexion (A), and peak torque dorsiflexion (B)

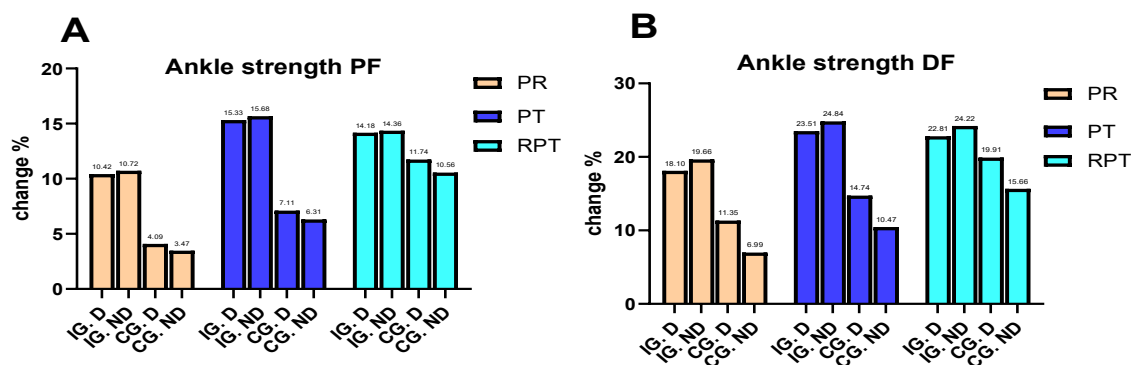


Figure 3.6 Relative percentage change of the shin muscle peak isometric force of plantar flexor muscles (A), and dorsiflexor muscles (B) before and after the intervention

Pairwise comparisons indicated a significant group $\times$ time interaction for peak force of PF muscles in the D leg ($F = 5.246$; $p = 0.031$; $\eta^2 = 0.186$), DF muscles in the ND leg ($F = 5.144$; $p = 0.033$; $\eta^2 = 0.183$) and peak torque of DF muscles in the ND leg ($F = 5.075$; $p = 0.034$; $\eta^2 = 0.181$). The changes in percentages in all parameters of the shin muscle peak isometric of IG and CG are shown in Figure 3.6 A and B.

3.4.4 Effects of balance and plyometric training on counter movement jump characteristics

The countermovement jump (CMJ) revealed significant improvement in height jump (HJ) for the intervention group (IG) ($\Delta = 10$ %; $p = 0.000$; $d = 1.27$) and control group (CG) ($\Delta = 6$ %; $p = 0.008$; $d = 0.82$) (Figure 3.7A). The absolute mean values for jump height increased in the IG (39 ± 2 cm vs. 43 ± 4 cm) and CG (39 ± 3 cm vs. 42 ± 3 cm). Moreover, within-group analysis showed significant improvement in flight time (-6 %; $p = 0.017$; $d = 0.82$) and maximum force ($\Delta = 14$ %; $p = 0.004$; $d = 1.07$) for the IG, but no significant improvement for CG. Analysis of covariance (ANCOVA) revealed no significant group and

time interaction for CMJ characteristics ($p > 0.05$). The changes in the characteristics of jumps in the percentage of jump performance of IG and CG were presented in Figure 3.7B.

Table 3.9

Countermovement jump characteristics before and after intervention

Variables	Intervention group					Control Group					ANCOVA		
	$\bar{x}1$	$\bar{x}2$	%	p	d	$\bar{x}1$	$\bar{x}2$	%	p	d	F	P	η_p^2
Height [cm]	39.15 ± 1.75	43.19 ± 4.12	10.34	0.000*	1.27	39.35 ± 2.59	41.56 ± 2.77	5.63	0.008*	0.82	2.389	0.136	0.094
Time Flights [s]	0.55 ± 0.04	0.59 ± 0.05	6.74	0.017*	0.82	0.57 ± 0.02	0.58 ± 0.03	2.23	0.324	0.48	0.543	0.468	0.023
Maximum force [N]	1643.62 ± 189.60	1876.79 ± 242.60	14.19	0.004*	1.07	1717.62 ± 154.61	1816.89 ± 185.11	5.78	0.195	0.580	0.774	0.388	0.033

Abbreviation: $\bar{x}1$ = mean pre-test, $\bar{x}2$ = mean post-test, $\Delta\%$ = percentage change from pre to post-test, Dominant, non-dominant, η_p^2 = Partial eta square. * – Significant difference: $p < 0.05$ between pre- and post-test within groups; § significant difference: $p < 0.05$ between intervention and control groups.

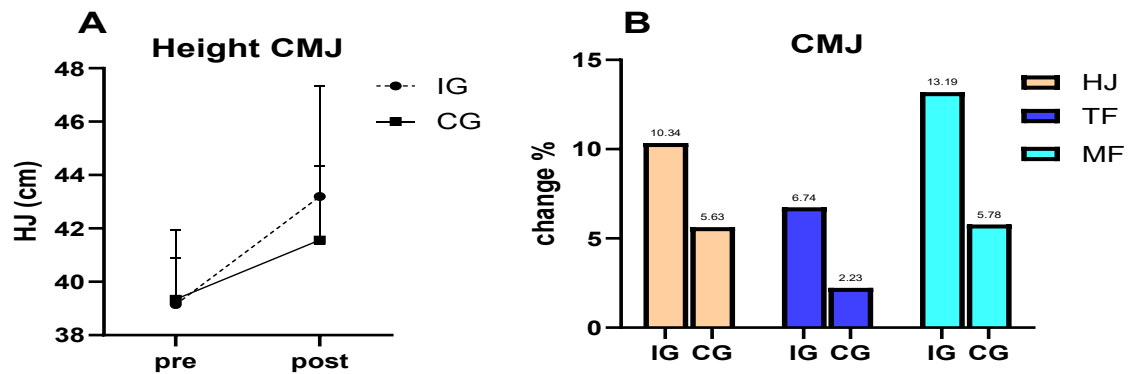


Figure 3.7 Change value of height jump characteristics (A), and relative percentage change of all characteristic countermovement jump (B) before and after the intervention

The data presented in the results section were derived from the author's previously published articles. It may be causing similarities.

4 Discussions

4.1 Leg muscle peak power output and explosive strength in young football players by playing position

The peak power output (PPO), based on the maximum and rate of force production, was influenced by the growth and maturation of adolescents (Armstrong et al., 2001; Bar-Or & Rowland, 2004; Nobari et al., 2023). Our findings revealed that the Forward positions are significantly different from the midfielders ($p = 0.003$), with the leg muscle peak power output of forwards being greater than that of midfielders (195 watts higher). There was no significant interaction of PPO among goalkeepers, defenders, and forwards. Several prior studies reported different peak power outputs based on playing position (defender, forward, or goalkeeper is the highest), but all studies agree that the midfielder has the lowest PPO (AlTaweel et al., 2022; Joo & Seo, 2016; Nikolaidis, 2014). One factor determining the influence of power production is body composition, including height, weight, and body mass index. In our study, the midfielder (height = 174cm, weight = 63 kg, BMI = 20 kg/m²) had the lowest anthropometric values among the groups. A study by Nikolaidis et al. (2018) proved that the peak power, mean power, squat and countermovement jump ($p = 0.001$ – 0.023 ; $\eta^2 = 0.34$ – 0.37) in adults were significantly greater than in youth players, highlighting the influence of age on anaerobic performance.

Vertical jump tests are commonly used to evaluate explosive lower-body strength by measuring jump height and mechanical power (Hübner et al., 2013). Although similar to the cycle ergometer test for determining peak power (Doré et al., 2008), their mechanisms differ and cannot be interchanged (Gross & Lüthy, 2020). The current study found no significant differences in vertical jump characteristics (height, flight time, and maximum force) among player positions ($p = 0.11$ – 0.31). These results consistently agreed with previous studies performed on elite Slovak football players (Pivovarniček et al., 2015), National Collegiate Athletic Association (NCCA) (Harry et al., 2018), and youth footballers (Silva et al., 2022), exhibited no significant difference in jump performance across playing positions. In line with a previous study by McLellan et al. (2011), we observed a positive effect of maximum force production on jump height, with the development of peak reaction force being a significant predictor of the vertical jump height.

4.2 Static and dynamic balance by playing position

The variation of static and dynamic balance performance was demonstrated among professional football players based on their playing position (Jadczak et al., 2019; Mahmoudi et al., 2023). Previous studies agree that midfielders have the best postural stability due to their ability to cover the greatest distance (approximately 19 km per game) (Baptista et al., 2018)

and touch the ball the most frequently when performing activities such as shooting, passing, and dribbling. In contrast to our study, no significant differences in static or dynamic balance were found according to the playing positions of young football players. We found a minor difference in medial-lateral sway speed among groups ($p = 0.02$), with goalkeepers displaying a lower speed (24–27 mm/s) compared to the others. This finding is consistent with that of Jadcak et al. (2019), who reported that the static balance of professional football players with their eyes open was not influenced by playing position. Furthermore, prior studies have not found differences in football players' dynamic balance performance with eyes open and closed across playing position (Ateş, 2019; Böge & Çalışkan, 2023). As an explanation for our finding that the playing position does not solely influence balance ability, but rather experiences as football players (Teixeira et al., 2011), and the other factors, such as leg muscle strength, power, joint mobility, and sensorimotor function, are more important balance performance predictors, these characteristics continue to improve until the end of puberty.

4.3 Identification of asymmetries between dominant (D) and nondominant (ND) leg, and the relationship between static and dynamic balance

Balance performance is influenced by environmental and experimental conditions, as well as intrinsic factors such as body somatotype, muscle strength, awareness of body position, and brain hemisphere function (Cioncoloni et al., 2016; Paillard & Noé, 2020). The dominant leg (leg preference) is primarily used to perform movement or motor tasks that require force development and precision (e. g., stepping up, hooping, executing a ball, and picking up), while the nondominant (stance) leg supports the body (Huurnink et al., 2014). However, the effect of the dominant leg on single-leg postural stability depends on the specific context. Based on our findings in young football players: (1) There is no significant difference between the D and ND leg in static and dynamic balance. (2) No statistical relationship exists between static and dynamic balance parameters.

The football players consistently use one leg for mobilization and the contralateral leg for stabilization tasks (Carey et al., 2001), where players typically use their dominant leg to shoot, pass, and dribble the ball, while the non-dominant leg is used to stabilise body position. The present study revealed no difference between both legs in static balance variables: ellipse area (EA), perimeter (P), average anterior-posterior (AAPS), and medial-lateral (AMLS) sway speed $p = 0.33$ – 0.72 , and dynamic balance characteristics: total stability index (TSI), total trunk deviation (TTD) angle $p = 0.73$ – 0.78 . Our results are in good agreement with the data observed by Pau et al. (2015), a negligible difference between D and ND legs in static balance ($F(4,95) = 0.63$, $p = 0.641$) and dynamic balance characteristics ($F(6,93) = 0.80$, $p = 0.571$) among Italian professional and youth league football players. Similarly to the healthy

population of young adults, there is no difference in unilateral postural stability between D and ND lower limbs (the body centre of pressure (COP) sway area $p = 0.50$, sway path length $p = 0.89$) (Hoffman et al., 1998), and COP speed $p = 0.10$ in healthy athletes (Huurnink et al., 2014). In summary, the current study suggests that leg preference has no effect on postural stability in young football players. This finding confirms that effective interaction between lateralised neural structures is responsible for controlling stability and reducing performance asymmetry between legs.

The static and dynamic balances are related to the control of the body centre of pressure displacement, but the two balance expressions are not interchangeable. We observed in our study that there was no correlation between static and dynamic balance parameters, except for TTD and EA ($r = 0.332$; $p = 0.03$), TTD and MLD ($r = 0.335$; $p = 0.02$), and TTD and TD ($r = 0.423$; $p = 0.01$). Similar results are obtained by Pau et al. (2015), revealed no correlations were found between static and dynamic balance characteristics except for vertical time to stabilization and centre of pressure displacements in the anterior-posterior direction ($r = 0.29$, $p = 0.003$). Maintaining dynamic balance is more challenging in conditions with a reduced base of support and the greater mass of the moving limb (Teixeira et al., 2013). These authors suggested that players' extensive training requiring dynamic unipedal balance in different football-related skills leads to a general improvement in balance control, including static balance (Teixeira et al., 2013). In our preliminary study, we found that the result of dynamic balance performance was categorised as poor if the total stability index value was 2.35 or higher. Therefore, our next study will investigate the effect of a combined balance and plyometric training program on improving balance performance and its influencing factors in young football players.

4.4 Effects of 8-week combined resistance training and regular training on anaerobic performance

This study investigated the effect of an 8-week combined resistance exercise program (plyometric and self-loading) in young football players [the result of the study was presented at the Tartu conference, Estonia, 2024]. Intervention group (IG) demonstrated significant improvements in peak power output (PPO) during the 30-second Wingate Anaerobic test ($p = 0.000$, $d = 1.53$) and six-second peak power output test ($p = 0.001$, $d = 1.57$). Moreover, other anaerobic performance variables, including relative PPO and mean power (MP), also improved significantly ($p = 0.006$, and $p = 0.001$, respectively). Consistent with IG, CG, which engaged solely in standard training, exhibited enhancements in PPO for 30s WAnT ($p = 0.025$) and 6s PPO ($p = 0.002$). CG participants performed plyometric exercises as part of their routine training sessions twice per week, each lasting 45 minutes, during the winter season (November

to March) and once per week during the competition period (from April to October). However, this study did not monitor the intensity of plyometric exercises performed by the footballers from the CG. This finding indicated that regular football training, combined with intensive resistance training twice a week, led to a greater enhancement of anaerobic performance. Two types of RE programmes (plyometric and self-loading) induce nerve adjustments on neuromuscular activation levels, motor intermuscular and intramuscular coordination, and the elastic benefits of the stretch-shortening cycle (SSC) (Davies et al., 2015).

In line with the current study, Assunção et al., (2018) reported that 10 weeks of low-volume plyometric training (2x/week) combined with traditional training significantly improved mean power (MP) (394.85 ± 76.62 W/kg to 452.88 ± 81.09 W/kg), and PPO (520.43 ± 85.31 W/kg to 577.06 ± 100.78 W/kg). This finding proves that plyometric training induces muscular efficiency (Spurrs et al., 2003) and lower-body maximal muscle strength (de Villarreal et al., 2010). Another explanation for the effect of resistance training on anaerobic performance is the improvement in running economy and cadence, as studied by Balsalobre-Fernández et al. (2016) and Booth & Orr (2016), which correlated to maximal power production. Moreover, plyometric combined with various form of resistance training is more beneficial (20 %) for improving maximal strength than stand-alone (Sáez de Villarreal et al., 2013). Previous studies have shown that a combination of plyometric with a change of direction (Aloui et al., 2021; Michailidis et al., 2023), sprint interval training (Aloui et al., 2021; Ferley et al., 2020) improves various anaerobic assessments in young football players.

There is no significant changes in the fatigue index (FI) for both groups (IG = 0.227 and CG = 0.249), indicating that while peak power output improved, the ability to sustain high-intensity effort throughout the 30-second WAnT remained unchanged. FI can be linked to football demands that involve repetitions and/or maintenance of high levels of muscle work, such as high-intensity running, jumping performance, and change of direction (Mohr & Krstrup, 2016). Therefore, future studies should consider incorporating resistance training focused on strength endurance, extending intervention durations, and including variations of plyometric exercise to enhance anaerobic power and capacity. Furthermore, to assess improvements in fatigue resistance resulting from the training intervention, lactate concentration should be included in the evaluation, which is a limitation of the current study.

4.5 Effects of combined resistance training (balance and plyometric) on balance performance and its determining factors in young football players

We conducted an eight-week combined balance and plyometric training program, which led to improvements in static and dynamic balance ($p = 0.001$ – 0.045 , $d = 0.5$ – 1.14) in young players. Static balance demonstrated reduced centre of pressure (COP) displacement (EA)

($\pm 14\%$), perimeter length (P) ($\pm 14\%$), and decreased sway speed anterior-posterior (AP) and medial-lateral (ML) directions ($\pm 15\%$). On the other hand, dynamic balance improved: the total stability index (TSI) and sway trunk deviation (TTD) angle $p = 0.002\text{--}0.013$ ($0.62^\circ\text{--}0.70^\circ$ lower than baseline). Dafkou et al. (2021) reported a 33 % reduction in the centre of pressure sway after eight weeks of eccentric, balance, and core exercises incorporated into football routines. In line with this, improvements in AP and ML COP sway speed (with eyes open/closed) have been observed following proprioceptive training in taekwondo poomsae athletes (Yoo et al., 2018), and among individuals with functional ankle instability (Surakhamhaeng et al., 2020).

Current studies provide sports equipment (e. g. wobble board, roller balance board, medicine ball, resistance band), variation surfaces (e. g. stable/unstable), level difficulty (Gebel, Prieske, et al., 2020; Schedler et al., 2020) effect to sensory components for the displacement of the centre of pressure, including a proprioceptive sense (i. e. somatosensory, visual, and vestibular systems). Progression of difficulty levels during balance training (Gebel, Lehmann, et al., 2020; Schedler et al., 2020), as implemented in our intervention (e. g. bipedal/unipedal stance, unstable/stable platform, and sway stability on roller board, with/without arm support), enhanced neuromuscular activation, which is necessary for balance performance. Additionally, the included plyometric exercises may enhance balance performance, similar to the role of balance training (Ramachandran et al., 2021), but with different training characteristics. Plyometric training induced improvement in motor control and rate of force development, thereby decreasing centre of pressure (COP) displacement and enhanced stability during specific movement.

In the present study, following an eight-week balance and plyometric training, the active range of motion for plantar flexion increased by 5° (13 %), and dorsiflexion by 4° (32 %) in the IG ($p = 0.001\text{--}0.02$). Similar to a study conducted by Alahmari et al. (2021), a 6-week program of strength and balance exercises improved talocrural joint mobility by 3.7° (44.3 %) in PF and 3.5° (45.2 %) in DF among individuals with functional ankle instability (FAI). Current studies indicate that balance and plyometric training affect ankle proprioception by enhancing sensory feedback related to muscle length changes, joint position sense, and movement speed (Alahmari et al., 2021). This training regimen also induces muscle relaxation and promotes greater stretch magnitudes during balance interventions, increasing dorsiflexion ROM, and improved functional movement and stability (Lazarou et al., 2018).

Maximal voluntary isometric strength of the shin muscle increased in plantar flexor muscle absolute peak force ± 14 N (10 %), relative peak force ± 5 N/kg (15 %), and relative peak torque ± 0.6 N.m/kg (14 %), with moderate effect size ($p = 0.001\text{--}0.038$, $d = 0.45\text{--}0.74$).

Moreover, IG also improved in dorsiflexion strength because the absolute peak force of the DF muscle increased by ± 25 N (19 %), relative peak force $\pm$ N/kg (24 %), and relative peak torque increased by 0.10 N.m/kg (22 %), with a large effect size. One of the most highlighted improvements in shin muscle isometric strength may be explained by combining stable and unstable platforms for balance training to enhance muscle strength and coordination, particularly for joint stability (Anderson & Behm, 2005). Balance training on stable and unstable surfaces, particularly with the addition of band resistance, improved ankle strength and reduced valgus deformity of the ankles (Kim et al., 2017). On the other hand, plyometric exercises with various jump conditions (CMJ, Hop, leap, skip) also improve force production and muscular coordination, which in turn affect ankle joint position sense (Huang et al., 2021). The current study agrees that combining plyometric and balance exercises is more effective in mitigating ankle joint position sense errors and enhancing neuromuscular control, compared to plyometric training alone (Huang et al., 2021), even for athletes with functional ankle instability (Park et al., 2024).

The improvement in jump performance in our study might be attributed to plyometric training, which enhanced motor recruitment and the stretch-shortening cycle (SSC) (Davies et al., 2015; Sammoud et al., 2024). Incorporating balance and plyometric training over six weeks improved jump height in youth football players ($p = 0.002$, $d = 2.21$) (Muehlbauer et al., 2019). As in the previous studies, variation of plyometric (e. g., CMJ, hurdle jump, ankle jump, lateral hops) and balance (e. g. standing or squatting on single/ bilateral on a Swiss ball) exercises led to improvements in jump performance in young footballers within the eight-week intervention (Chaouachi et al., 2017; Hammami et al., 2016; Makhoul et al., 2018). Plyometric training on a stable surface improved neuromuscular adaptation (Granacher & Behm, 2023), including enhanced motor unit recruitment, optimised synergistic muscle activation, and reduced antagonistic muscle activity (Markovic & Mikulic, 2010).

4.6 Strengths and limitations of the study

The present study expands the existing knowledge and aims to fill the gap regarding the impact of resistance exercise on anaerobic and balance performance and its influencing factors in the lower leg. With respect to balance ability, balance and coordination skills are not fully mature in children (Behm et al., 2010). Therefore, balance training may serve as an important preliminary phase to enhance movement stability, muscular strength, and power when combined with plyometric exercises. A key strength of this study lies in its contribution to improving balance performance, supported by the positive effects of ankle range of motion and peak isometric shin muscle strength. The present study also dealt with the influence of

integrating self-loading and plyometric training on anaerobic performance. Furthermore, the interventions lead to improvements in peak and mean power output, as well as jump performance. The findings of the present research suggest that balance training can be performed for 30–40 seconds per exercise, 2–3 repetitions per balance exercise, on both unstable and stable platforms, using resistance bands and a medicine ball in static and dynamic conditions. Plyometric exercises may be performed in 2–3 sets of 6–10 repetitions, using bipedal and unipedal stances, with approximately 60–140 ground contacts per session, twice per week on alternate days, with intensity and difficulty progressively increased every two weeks.

Nevertheless, there are several limitations of the study that need to be mentioned as follows:

- 1 **Study 1. Balance and anaerobic performance according to playing position.** This study involves only young male players aged 14-16 years and categorized them into 4 playing positions: GK, DEF, MD and F.
- 2 **Study 2. Identification of interlimb asymmetries in young football players.** Only static and dynamic balance assessments are used to determine interlimb asymmetry during one-leg stance . To enhance understanding of asymmetry in balance performance, additional assessments such as ankle range of motion, peak isometric ankle strength, and lower-body explosive strength (e. g., jump tests) should be considered.
- 3 **Study 3. Effects of 8-week regular training on anaerobic performance.** A blood lactate concentration was not measured during the 30-second Wingate Anaerobic test. By analysing blood lactate concentration and ventilatory threshold, researchers can investigate varied factors in blood levels and breathing to pinpoint the critical exercise intensity at which a player can sustain maximum effort for an extended period.
- 4 **Study 4. Combined balance and plyometric training improves balance, ankle mobility, and jump performance.** The study was conducted an intensive 8-week mesocycle intervention, which did not assess the long-term effects of balance and plyometric training. Furthermore, electromyography (EMG) to assess muscle activation and electroencephalography (EEG) to evaluate postural sway and cortical activity were not utilized.

Future studies should consider including participants with varying characteristics (age, training experience, competition level), a larger sample size, and longer period of intervention to investigate long-term training effect. Methodological assessment, such as

electromyography (EMG) to analyse muscle activation pattern, and isokinetic ankle strength should be incorporated. Additional physiological measures, such as blood lactate concentration, and football-specific field tests, such as the Running-Based Anaerobic Sprint Test (RAST), should be included to assess anaerobic performance.

Conclusions

- 1 The literature review identified fourteen studies examining the effects of resistance exercise on anaerobic and balance performance in young football players. The evidence indicates that combined RE programs, particularly integrating plyometric with regular football training significantly improve anaerobic performance and balance-related variables. High-quality studies suggested that optimal adaptations occur following approximately eight weeks of training, performed 2–3 times per week on non-consecutive days, at moderate-to-high intensity, with a volume of 2–3 sets of 6–12 repetitions per exercise. Overall, these findings confirm that integrating RE into regular football training enhances key performance components, including sprinting, jumping, and change-of-direction ability, while also improving balance, as evidenced by reductions in centre-of-pressure displacement and postural sway.
- 2 Anaerobic and balance performance according to playing position.
 - a. PPO significantly differed significantly among playing positions, with forwards position demonstrating significantly higher PPO compared to midfielders.
 - b. No significant differences were observed among four playing position groups in CMJ variables including peak force production, height jump, and flight time.
 - c. Although GK position demonstrates slower average medial-lateral speed (AMLS) than F position, overall, all groups have similar static and dynamic balance characteristics.
 - d. To improve anaerobic and balance performance in young players, these findings suggest that RE programs including duration, intensity, volume, set and repetition can be designed in a generalized manner for all players, regardless of playing position.
- 3 Identification of asymmetries between the dominant (D) and nondominant (ND) legs in young football players and the relationship between static and dynamic balance.
 - a. Young players in this study showed symmetrical between both legs, with no significant differences between D and ND legs in static and dynamic balance.
 - b. However, the pre-assessment revealed that participants experienced limited dynamic balance proficiency (TSI=2.35). Therefore, the design of RE intervention should be included balance, core stability, or proprioceptive training to improve overall balance quality.
 - c. As static and dynamic balance was uncorrelated, both components should be evaluated separately to provide comprehensive information about balance proficiency in young population.

- 4 Effects of 8-week combined RE programs integrating self-loading, balance and plyometric on anaerobic and balance performance.
- a. The combined RE program (self-loading and plyometric training) alongside regular football training significantly enhanced anaerobic performance in young football players, as evidenced by improvements in peak power output (PPO) and mean power (MP).
 - b. However, no significant changes were observed in fatigue index (FI), indicating that while peak power output improved, the ability to sustain high-intensity effort throughout the 30-second WAnT remained unchanged.
 - c. The combined balance and plyometric training program significantly improved static and dynamic balance in young football players, as evidenced by reductions in centre of pressure (COP) displacement, sway speed, and improved trunk stability.
 - d. Improvements in ankle range of motion and peak isometric strength of plantar and dorsiflexion muscles further support the effectiveness of RE in enhancing neuromuscular function and proprioceptive feedback.
 - e. The integration of plyometric training improved vertical jump performance through increased motor unit recruitment and stretch-shortening cycle efficiency.

Practical recommendation

This study provides scientific validation for the implementation of intensive RE within a structured training program, emphasizing an appropriate dose-response relationship for young football players. Coaches are recommended to implement RE programs including balance, self-loading, and plyometric training based on an integrative neuromuscular training approach with multifarious movement to improve balance and anaerobic performance in young athletes aged 14–16 years. To sustain performance improvements, coaches are encouraged to apply similar this RE protocols during the preseason, followed by appropriate adjustments in training frequency, volume, intensity, and duration throughout the competitive season.

Prior to implementing balance and plyometric training protocols, practitioners are advised to conduct preliminary assessments to evaluate symmetry between dominant and non-dominant limbs and to determine an appropriate RE dose-response relationship. In addition, strength and conditioning practitioners should emphasize integrative neuromuscular training approaches rather than isolated training programs based on playing position.

Proposals

This study proposes an integrated resistance exercise (RE) approach that combines self-loading, plyometric, and balance training to enhance anaerobic performance and neuromuscular function in young football players. The proposed RE program consists of an 8-week intervention, with sessions performed twice weekly on non-consecutive days. Each session included 2–4 sets of 6–15 repetitions at moderate to high intensity and lasted approximately 30–40 minutes. Progressive overload was applied by systematically increasing intensity, volume, level of difficulty, and duration every two weeks.

The integration of self-loading resistance with balance and plyometric training demonstrated improvements in balance, ankle range of motion, shin muscle isometric strength, and jump performance in young football players. Furthermore, the combined self-loading and plyometric improved peak power output and mean power but did not significantly affect fatigue index. Future research should examine additional training components, such as repeated sprint or additional strength endurance training, to further enhance fatigue resistance.

If balance and plyometric exercises are conducted in a single training session, balance exercises should be performed before plyometric to optimize functional movement and enhance proprioceptive afferent responses, thereby promoting faster and greater neuromuscular activation during plyometric exercises.

Publications and reports on topics of the Doctoral Thesis

Publications:

1. Sinulingga, A. R., Pontaga, I., & Slaidiņš, K. (2024). An assessment of static and dynamic balance effectiveness in one-leg stance of young footballers. *Human Movement*, 25(2), 97–104. <https://doi.org/10.5114/hm/186752>
2. Sinulingga, A. R., & Pontaga, I. (2024). A Review of the Effect of Resistance Exercise on Development of Anaerobic and Balance Performance in Adolescent Footballers. *International Journal of Kinesiology and Sports Science*, 12(4), 8–20. <https://doi.org/10.7575/aiac.ijkss.v.12n.4p.8>
3. Sinulingga, A.R., Pontaga, I., & Slaidiņš, K. (2025). Analysis of peak power output, lower limb explosive strength, and balance performance of young football players according to their playing position: A pilot study. *Sport i Turystyka. Środkowoeuropejskie Czasopismo Naukowe*, 8(1), 97–114. <http://dx.doi.org/10.16926/sit.2025.01.05>
4. Sinulingga, A. R., Slaidiņš, K., Salajeva, A., Liepa, A., & Pontaga, I. (2025). Effect of Integrative Balance and Plyometric Training on Balance, Ankle Mobility, and Jump Performance in Youth Football Players: A Randomized Controlled Trial. *Physical Activity and Health*, 9(1), pp. 146–160. <https://doi.org/10.5334/paah.472>

Reports and theses at international congresses and conferences:

1. Correlation between Sprint Cycle Ergometer and Vertical Jump Test Results to Determine Anaerobic Performance in Young Football Players. 22nd Annual Scientific Conference of Montenegrin Sports Academy “Sport, Physical Activity and Health: Contemporary Perspectives.” **Dubrovnik, Croatia, 3–6 April 2025.** <https://www.mjssm.me/?sekcija = article&artid = 505>
2. Assessment of Correlation between Dynamic Balance, Flexibility of Ankle Joints, and Shin Muscles Peak Isometric Strength in Adolescent Football Players. International Research Conference on Medical and Health Care Sciences, RSU research. **Riga, Latvia, 26–28 March 2025.** https://rw2025.rsu.lv/sites/default/files/documents_en/RW2025_Abtract-Book-KUP.pdf
3. Effect of Resistance Training on Anaerobic Performance and Dynamic Balance of Young Football Players: The 17th Conference of Baltic Society and Sport Science, **Tartu, Estonia, 24–26 April 2024.** <https://sporditeadused.ut.ee/et/sisu/17th-conference-baltic-society-sport-sciences>
4. Anaerobic Performance and Balance in Young Football Players: A Pilot Study, The 16th Conference of Baltic Society and Sport Science: “Current Trend in Sport Sciences and Physical Education”, **Poland, May 25–26, 2023.** https://science.rsu.lv/ws/portalfiles/portal/95693708/Book_of_abstract_BSSS_2023.pdf
5. Anaerobic Performance and Balance in Young Football Players: A review. The 15th International Scientific Conference of doctoral and master’s students of the Latvian Academy of Sports Pedagogy in sports science, **Riga, Latvia, 2023.** https://lspa.lv/images/Augstu_sasniegumu_sports_2023.pdf

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2. Alahmari, K. A., Kakaraparthi, V. N., Reddy, R. S., Silvian, P., Tedla, J. S., Rengaramanujam, K., & Ahmad, I. (2021). Combined Effects of Strengthening and Proprioceptive Training on Stability, Balance, and Proprioception Among Subjects with Chronic Ankle Instability in Different Age Groups: Evaluation of Clinical Outcome Measures. *Indian Journal of Orthopaedics*, 55(1), 199–208. <https://doi.org/10.1007/s43465-020-00192-6>
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Acknowledgments

I am incredibly grateful to my scientific supervisor, **Dr. med. Prof. Inese Pontaga**, for her invaluable guidance, time, and extensive support throughout the research and writing process, as well as for her contribution to developing all scientific concepts.

I would like to thank all the players who participated in this study, especially **Kristaps Slaidiņš**, who has motivated players to participate in this work.

Thanks to **Anna Zuša, Miks Laksbergs, Anastasija Salajeva, and Agris Liepa** for helping me with data collection.

I am grateful to **Assoc. Prof. Iveta Boge**, who was the first to guide and support me when I came to Latvia.

I am grateful to my amazing family for their love and support, and to my wife, Sofiany, and my future child, for your patience. Thank God, I am about to become a father.

The Thesis was supported by the project RSU Internal and RSU with LSPA external consolidation No. 5.2.1.1.i.0/2/24/I/CFLA/005. In addition, I was supported by Study in Latvia.
Liels paldies, Latvija!

Annexes

Description: balance and plyometric training

Materials for balance training	Week 1, 2	Week 3, 4	Week 5, 6	Week 7, 8	Training descriptions
Static and dynamic balance					
Medicine ball 1.5 Kg + hoops (static balance performance, core stabilization + leg muscle strength endurance)	2 × 40s	3 × 40s	2 × 30s	3 × 30s	Semi-squat position on one or both legs while holding a medicine ball. Place both legs together or stand on a single leg. Stand in a semi-squat position (knee flexion angle to 45°). The head, neck, and back should be in line. The head should be straight, and the gaze should be forward. Hold a medicine ball with both hands in front of the body for some time, and the eyes should be open.
Medicine ball 1.5 Kg (dynamic balance, core stabilization)	2 × 40s	3 × 40s	2 × 30s	3 × 30s	Squat while throwing the medicine ball vertically upwards, then stand up and catch the ball. Stand with feet positioned at shoulder-width to produce maximum power. The position of the head, neck, and back should be in one line. Bend the hip and knee joints to 90° (squat position) and return to a stabilized position while throwing the medicine ball vertically. Use the core, shoulders, and arms to throw the ball, engaging your core muscles.
Balance wobble board + resistance band (dynamic balance)	2 × 30s	3 × 30s	2 × 40s	3 × 40s	Standing and keeping a balanced position on the balance wobble board with a resistance band positioned around the thighs above the knee. Put on a resistance band around the thighs above the knees and stand on both feet on the balance wobble board. Bend the hip and knee joints to 40°. Keep the back straight. Distribute the weight on the body's center of pressure.
Balance board + roller + resistance band (dynamic balance)	2 × 30s	3 × 30s	2 × 40s	3 × 40s	Standing and keeping a balanced position on the roller balance board with a resistance band positioned around the shins below the knee. Put on a resistance band around the shins below the knees and stand on both feet on the balance wobble board. Bend the hip and knee joints to 45° (squat position). Keep the back straight. Sway your body sideways for some time. Shift your weight from side to side to move the board in those directions.
Materials for plyometric training	Week 1, 2	Week 3, 4	Week 5, 6	Week 7, 8	Training descriptions
Plyometric training					
Hurdle jump++ resistance band. (leg muscle explosive power)	2 × 8	2 × 10	3 × 8	3 × 10	Counter-movement jump on both legs over the hurdle. Start with hip-width feet apart and knees slightly bent. Jump forward and backwards over the hurdles. In the landing phase, bend ankles, knees, and hips to absorb impact energy.
Hurdle (leg muscle explosive power)	2 × 8	2 × 10	3 × 8	3 × 10	Lateral hurdle hop. Perform the jump by pushing off the right foot to land on the left foot above the hurdle, and vice versa. In the landing phase, bend ankles, knees, and hips to absorb the impact energy.
Cone triangle hop (Displace the triangle cones by a distance of 1 m) (leg muscle explosive power)	2×6/leg	2×8/leg	3×4/leg	3×5/leg	Single leg jumps forward and backwards, and side to side in front of the cone. Jump forward by taking off on one leg and landing on the opposite leg in front of the cone. Bend your knee to 90° to touch the cone with the knee of the landed leg while the opposite leg hangs. Jump backwards to the starting point. Second step: hop to the right from one leg to the other, then hop to the left. Repeat the hops starting with the opposite leg.
Skipping Rope (leg muscle explosive power)	Na	Na	3 × 30s	2 × 40s	Skipping rope with single and both legs. Stand with both legs in the middle of the rope. Feet are shoulder-width apart. Jump with a consistent bound and steady rhythm. Use wrists to swing the rope over the head. Align the upper body, hips, knees, and feet. Keep the pelvis horizontal. Continue skipping rope on the right and left leg, respectively.

Table 4.6

Static and dynamic balance value before and after intervention

Variables	Intervention groups					Control groups					ANCOVA		
	$\bar{x}1$	$\bar{x}2$	%	p	d	$\bar{x}1$	$\bar{x}2$	%	p	d	F	p	η_p^2
Static Balance													
Ellipse area [mm ²] D													
ND													
Perimeter [mm] D													
ND													
Anterior- Posterior Speed [mm/s] D													
ND													
Medial- Lateral Speed [mm/s] D													
ND													
27.56 ± 6.57	28.85 ± 3.27	23.99 ± 3.62	24.70 ± 4.14	1213.68 ± 187.1	1259.77 ± 169.33	699.28 ± 145.3	741.94 ± 171.49						
23.65 ± 4.17	25.88 ± 4.23	20.19 ± 3.32	21.65 ± 3.7	1037.44 ± 166.85	1081.75 ± 138.9	598.70 ± 117.76	45.42 ± 166.95						
-14.20	-10.29	-15.84	-12.37	-14.52	-14.13	-14.38	-13.01						
0.038*	0.023*	0.001*	0.015*	0.001*	0.001*	0.045*	0.033*						
0.71	0.78	1.09	0.77	0.99	1.14	0.76	0.57						
27.82 ± 8.55	30.24 ± 5.69	25.37 ± 6.14	25.44 ± 4.8	1282.21 ± 201.04	1271.87 ± 162.87	684.39 ± 156.76	746.95 ± 172.73						
31.23 ± 6.05	33.15 ± 6.55	27.24 ± 5.13	28.14 ± 6	1288.13 ± 181.33	1295.56 ± 155.08	723.42 ± 172.75	799.56 ± 179.27						
12.23	9.62	7.38	10.59	0.46	1.86	5.70	7.04						
0.258	0.286	0.312	0.172	0.908	0.641	0.549	0.331						
0.45	0.47	0.33	0.49	0.03	0.14	0.23	0.29						
13.521	10.599	17.794	10.816	14.780	18.303	4.622	6.620						
0.001 [§]	0.003 [§]	0.001 [§]	0.003 [§]	0.001 [§]	0.001 [§]	0.042 [§]	0.017 [§]						
0.370	0.315	0.436	0.320	0.391	0.443	0.167	0.224						

Table 4.6 continued

Variables	Intervention groups					Control groups					ANCOVA		
	$\bar{x}1$	$\bar{x}2$	%	p	d	$\bar{x}1$	$\bar{x}2$	%	p	d	F	p	η_p^2
Dynamic Balance													
Total stability index [°] D	2.29 ± 0.63	1.59 ± 0.74	-30.29	0.002*	1.01	2.33 ± 0.9	2.34 ± 0.87	0.43	0.994	0.01	5.793	0.025§	0.201
ND	2.15 ± 0.79	1.50 ± 0.44	-30.41	0.013*	1.02	2.17 ± 0.82	2.27 ± 0.78	4.89	0.771	0.12	7.675	0.011§	0.250
Trunk Total Deviation [°] D	2.56 ± 0.67	1.91 ± 0.59	-25.59	0.013*	1.03	2.60 ± 0.99	2.70 ± 1.49	4.00	0.721	0.08	4.506	0.045§	0.164
ND	2.36 ± 0.67	1.74 ± 0.72	-26.14	0.007*	0.89	2.37 ± 0.97	2.50 ± 1.38	5.35	0.685	0.13	4.444	0.046§	0.162

Abbreviation: $\bar{x}1$ = mean pre-test, $\bar{x}2$ = mean post-test, % = percentage change from pre to post-test, d = Cohen, D = Dominant, ND = Non-dominant, η_p^2 = Partial eta square. * – Significant difference: $p < 0.05$ between pre- and post-test within groups; § significant difference: $p < 0.05$ between intervention and control groups.

Table 4.7

Plantar and dorsiflexion values before and after intervention

Variables	Intervention groups					Control Group					ANCOVA		
	$\bar{x}1$	$\bar{x}2$	%	p	d	$\bar{x}1$	$\bar{x}2$	%	p	d	F	p	η_p^2
PF [°] D	42.51 ± 5.09	47.71 ± 4.76	12.22	0.002*	1.05	42.49 ± 5.7	43.90 ± 3.72	3.32	0.474	0.29	5.432	0.029§	0.191
ND	43.11 ± 6.61	48.85 ± 3.81	13.31	0.027*	1.06	42.47 ± 5.38	44.53 ± 5.85	4.83	0.322	0.36	4.751	0.040§	0.171
DF [°] D	11.07 ± 2.51	14.32 ± 2.57	29.37	0.001*	1.27	10.99 ± 2.75	12.09 ± 2.25	9.99	0.134	0.43	7.645	0.011§	0.249

Table 4.7 continued

Variables	Intervention groups					Control Group					ANCOVA		
	$\bar{x}1$	$\bar{x}2$	%	p	d	$\bar{x}1$	$\bar{x}2$	%	p	d	F	p	η_p^2
ND	11.39 $\pm$ 3.55	15.03 $\pm$ 2.41	32.03	0.001*	1.19	10.28 $\pm$ 3.29	12.05 $\pm$ 2.57	17.29	0.067	0.59	5.284	0.031§	0.187

Abbreviation: PF = Plantar flexion, DF = Dorsiflexion $\bar{x}1$ = mean pre-test, $\bar{x}2$ = mean post-test, % = percentage change from pre to post-test, d = Cohen, D = Dominant, ND = Non-dominant, η_p^2 = Partial eta square. * – Significant difference: $p < 0.05$ between pre- and post-test within groups; § significant difference: $p < 0.05$ between intervention and control groups.

Table 4.8

Shin muscle peak isometric force and torque values before and after intervention

Variables	Intervention group					Control Group					ANCOVA		
	$\bar{x}1$	$\bar{x}2$	%	p	d	$\bar{x}1$	$\bar{x}2$	%	p	d	F	p	η_p^2
Plantar flexion													
Peak force [N] D													
		136.32 $\pm$ 33.79											
		150.52 $\pm$ 29.04											
		10.42											
		0.006*											
		0.45											
		136.71 $\pm$ 22.25											
		142.30 $\pm$ 23.35											
		4.09											
		0.253											
		0.24											
		5.246											
		0.031§											
		0.186											
ND													
		133.50 $\pm$ 35.04											
		147.81 $\pm$ 22.35											
		10.72											
		0.038*											
		0.48											
		133.70 $\pm$ 23											
		138.34 $\pm$ 14.66											
		3.47											
		0.433											
		0.24											
		3.096											
		0.092											
		0.119											
Peak torque [N·m] D													
		27.93 $\pm$ 6.3											
		32.23 $\pm$ 6.02											
		15.38											
		0.001*											
		0.69											
		28.94 $\pm$ 5.83											
		31.00 $\pm$ 6.04											
		7.11											
		0.101											
		0.34											
		2.156											
		0.156											
		0.086											
ND													
		27.37 $\pm$ 6.77											
		31.66 $\pm$ 4.56											
		15.68											
		0.005*											
		0.74											
		28.27 $\pm$ 5.74											
		30.05 $\pm$ 3.88											
		6.31											
		0.232											
		0.36											
		2.347											
		0.139											
		0.093											
		0.093											
Relative peak torque [N·m/kg] D													
		0.46 $\pm$ 0.11											
		0.52 $\pm$ 0.10											
		14.18											
		0.001*											
		0.62											
		0.46 $\pm$ 0.10											
		0.51 $\pm$ 0.13											
		11.74											
		0.164											
		0.46											
		0.160											
		0.693											
		0.007											
ND													
		0.45 $\pm$ 0.11											
		0.51 $\pm$ 0.09											
		14.36											
		0.013*											
		0.56											
		0.45 $\pm$ 0.1											
		0.49 $\pm$ 0.11											
		10.56											
		0.139											
		0.45											
		0.268											
		0.610											
		0.012											

Table 4.8 continued

Variables	Intervention group					Control Group					ANCOVA		
	$\bar{x}1$	$\bar{x}2$	%	p	d	$\bar{x}1$	$\bar{x}2$	%	p	d	F	p	η_p^2
Dorsiflexion													
Peak force [N] D													
	135.23 ± 27.71	160.66 ± 27.83	18.80	0.001*	0.91	136.19 ± 15.99	151.65 ± 26.29	11.35	0.049*	0.71	1.434	0.243	0.059
ND	131.32 ± 28.34	157.53 ± 32.41	19.96	0.001*	0.86	133.38 ± 21.06	142.70 ± 22.35	6.99	0.119	0.42	5.144	0.033§	0.183
Peak torque [N·m] D													
	27.87 ± 5.84	34.43 ± 5.70	23.51	0.001*	1.13	28.72 ± 3.80	32.95 ± 6.14	14.74	0.014*	0.82	1.435	0.243	0.059
ND	27.01 ± 5.78	33.72 ± 6.52	24.84	0.001*	1.08	28.14 ± 4.81	31.09 ± 5.77	10.47	0.025*	0.55	5.075	0.034§	0.181
Relative peak torque [N·m/kg] D													
	0.45 ± 0.08	0.55 ± 0.09	22.81	0.001*	1.21	0.45 ± 0.07	0.54 ± 0.12	19.19	0.012*	0.91	0.191	0.666	0.008
ND	0.43 ± 0.07	0.54 ± 0.09	24.22	0.001*	1.32	0.44 ± 0.07	0.51 ± 0.13	15.66	0.029*	0.67	1.028	0.321	0.043

Abbreviation: $\bar{x}1$ = mean pre-test, $\bar{x}2$ = mean post-test, % = percentage change from pre to post-test, d = Cohen, Dominant, non-dominant, η_p^2 = Partial eta square. * – Significant difference: $p < 0.05$ between pre- and post-test within groups; § significant difference: $p < 0.05$ between intervention and control groups.

**Ethics Committee Permission approved by
the Latvian Academy of Sports Education**

**Latvijas Sporta pedagogijas akadēmija
Ētikas komisijas
Atzinums**

2023.gada 24.februāris

Nr. 1/51813

Akadēmiskā doktora augstākās izglītības programmas „SPORTA ZINĀTNE” (kods 51813) studenta **Rinaldi SINULINGGA** pētījums **“EVALUATION OF THE EFFECT OF INTENSIVE RESISTANCE EXERCISES ON ANAEROBIC AND BALANCE PERFORMANCE IN YOUNG FOOTBALL PLAYERS”** tiks veikts saskaņā ar normatīvajiem aktiem par ētikas normu ievērošanu zinātniskajos pētījumos.

Pamats: Ētikas komisijas sēdes protokols Nr. 6, atzinuma Nr.1/51813, 2023.gada 24.februārī

Komisijas locekle



Monta Jakovļeva

Assertion agreement

Assertion Of Parents' Agreement

I,....., agree/disagree

/ Name, surname /

that my son/daughter.....

/ Name, surname /

participates in the research of Andrew Rinaldi Sinulingga

/ Name, surname /

**Evaluation of The Effect Of Intensive Resistance Exercises On Anaerobic And
Balance Performance In Young Football Players**

/title/

Signature:

Date

Assertion of a Research Participant's Agreement

Participants aged 14 or more years

I (participant name, surname)....., am
informed

/ Name, surname /

about Andrew Rinaldi Sinulingga

/ Name, surname /

research **"Evaluation of The Effect Of Intensive Resistance Exercises On Anaerobic
And Balance Performance In Young Football Players"**

/title/

aim and organization. With my signature I assert that voluntarily agree to
participate in this research.

*.....
(signature)*

Date:

Form data collection

Name			
Age (years)	16 ⁰		
Experience (years)	10		
Training (hours/week)	8		
Dominant leg	re below knee		
Anthropometrical			
Height (m)	185	Body mass index (kg/m ²)	18.6
Weight (Kg)	63.7		
Peak power 6s Bicycle Ergometer			
Peak power output(w)	944	cadence (rpm)	
Time to peak (s)	60.49		154
Dynamic Balance			
	Left leg	Right leg	
Total Stability Index	1,78	2,75	
Trunk total Stedev	1,68	2,04	
Static Balance			
	Left leg	Right leg	
Ellipse area (mm ²)	468,09	566,34	
Perimeter (mm)	19,84,28	1567,7	
Stedev. Front-Back	4,9	5,83	
Stedev. Medial-Lateral	5,09	5,5	
Trunk Stedev	1,31	1,23	
Average Front-Back speed (mm/s)	19,31	25,5	
Average Medial-Lateral speed (mm/s)	34,70	40,92	
Vertical Jump Hand on Hip		Vertical Jump free Arms	
Height jump (cm)	34,4 31,6 35,5	380 37,8 40,1	
Time flight (s)	0,552 0,508 0,538	0,557 0,555 0,572	
Peak force (N)	1323,4 1280,4 1274,1	1363,5 1339,9 1468,13	

Anaerobic endurance 30s Wingate test			
Average power 5s max (w)	630	Cadence (rpm)	137
Average power 5s min (w)	337	Distance (m)	425
Power/ mass (w/kg)	7,60	Speed average (km/h)	51,0
Peak power (w)	691	Fatigue factor (5)	416
Power average (w)	489	Cadence peak (rpm)	191
5s max (w/kg)	9,89	time to peak	00.67

Thank you for participating in this test

This test will help you to know about your fitness level to improve your performance

Before conducting this test, ensure yourself:

1. You feel good without any sick symptoms.
2. Sleep well before doing the test tomorrow.
3. Get enough rest before doing this test.
4. Wear dry-fit clothes/jerseys and running shoes during this test.
5. Bring your bottle drink to prevent thirstily during the test
6. 1 hour before the test, you are not feeling hungry or full.

19.12.2023

Football players name, surname

Age: 14

Dominant leg: Right

Pedas: primum?

Body height: 160,5

Body weight: 43,5

Ankle injuries in the past:

Date: 19.12.2023

Movement of the foot Characteristic	Plantar flexion (talocrural joint)		Dorsal flexion (talocrural joint)		Inversion (subtalar joint)		Eversion (subtalar joint)	
	L	R	L	R	L	R	L	R
Active range of movements (ROM), degrees	1. 40	45	1. 20	15	1. 10	10	1. 5	5
	2. 40	45	2. 20	15	2. 10	10	2. 5	5
	3. 40	45	3. 20	15	3. 10	10	3. 5	5
Passive range of movements (ROM), degrees	1. 45	52	1. 25	19	1. 25	20	1. 17	7
	2. 40	52	2. 25	19	2. 25	20	2. 17	7
	3. 45	52	3. 25	19	3. 25	20	3. 17	7
Level arm's length of the foot, m	Distance between malleolus medialis and the distal head of the 1st metatarsal bones head		1. 17	17	Distance between malleolus lateralis and the distal head of the 5th metatarsal bones head		1. 20	20
			2. 17	17			2. 20	20
			3. 17	17			3. 20	20
Isometric peak force, N	1. 125,0	125,9	1. 126,3	120,5	1. 40,0	45,3	1. 48,7	51,6
	2. 125,9	122,3	2. 128,1	138,3	2. 40,7	36,0	2. 49,1	52,6
	3. 119,0	123,0	3. 126,3	139,2	3. 40,9	35,3	3. 41,2	58,2
Isometric peak torque, N·m	1.		1.		1.		1.	
	2.		2.		2.		2.	
	3.		3.		3.		3.	



PAAH
PHYSICAL ACTIVITY
AND HEALTH

Effect of Integrative Balance and Plyometric Training on Balance, Ankle Mobility, and Jump Performance in Youth Football Players: A Randomized Controlled Trial

RESEARCH

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KRISTAPS SLAIÐIŅŠ

ANASTASIJA SALAJEVA

AGRIS LIEPA

INESE PONTAGA

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ubiquity press

ABSTRACT

Background: Football players can improve their technical skills and reduce the risk of injury by enhancing their balance, which is supported by ankle mobility and explosive strength of the lower extremities.

Aimed: To examine the effect of an eight-week integrative balance and plyometric training on static and dynamic balance, ankle active range of movements (ROM), shin muscle strength, and jumping performance in young football players.

Methods: Thirty 15.8 ± 1.7 years old male players were randomly assigned to an intervention group (IG, $n = 15$) and a control group (CG, $n = 15$). Assessment included: 1) static balance (ellipse area, perimeter, and average anterior-posterior/medial-lateral movement speed, 2) dynamic balance (total stability index, and total trunk deviation angle), 3) active ankle plantar flexion (PF) and dorsiflexion (DF) range of movement (ROM), 4) peak isometric force, absolute and relative torque of ankle plantar and dorsal flexion, 5) countermovement jump (jump height, flight time and maximum ground reaction force).

Results: IG significantly improved in static and dynamic balance by -12 to -30% ($p = 0.001-0.04$, $d = 0.57-1.14$), active ankle ROM in PF and DF by 12-32% ($p = 0.001-0.02$, $d = 1.05-1.19$), isometric shin muscle force, absolute and relative torques in PF and DF by 10-24% ($p = 0.001-0.03$, $d = 0.48-1.31$), and jump performance by 6-14% ($p = 0.004-0.01$, $d = 0.82-1.27$). No significant pre-to-post changes were observed in the CG, except for absolute and relative peak torque of DF by 10-19% ($p = 0.01-0.02$, $d = 0.55-0.91$), peak force DF in the dominant leg by 11% ($p = 0.04$, $d = 0.71$), and jump height by 5% ($p = 0.008$, $d = 0.82$). ANCOVA revealed significant interaction between groups in all balance variables, ankle ROM, and ankle force of PF in the dominant leg, the peak force and torque of DF in the dominant leg.

Conclusions: Eight weeks of integrative balance and plyometric exercise effectively improve balance performance, ankle mobility, peak and explosive leg muscle strength in young football players. This intervention should be considered for inclusion in regular training to improve functional mobility in young footballers.

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KEYWORDS:

Balance training; plyometric; ankle range of movement; shin muscle peak isometric torque; explosive strength; static and dynamic balance

TO CITE THIS ARTICLE:

Sinulingga, A. R., Slaidiņš, K., Salajeva, A., Liepa, A., & Pontaga, I. (2025). Effect of Integrative Balance and Plyometric Training on Balance, Ankle Mobility, and Jump Performance in Youth Football Players: A Randomized Controlled Trial. *Physical Activity and Health*, 9(1), pp. 146-160. DOI: <https://doi.org/10.5334/paah.472>

1. INTRODUCTION

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DOI: 10.5334/paah.472

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Balance performance refers to the human ability to maintain the body's centre of gravity over the base of support. Balance depends on rapid and continuous feedback from the somatosensory, visual, and vestibular systems to produce smooth and coordinated neuromuscular actions (Hrysomallis, 2011; Shumway & Woollacott, 2007). Due to the wide range of unpredictable actions in the football match, balance plays a crucial role for fundamental motor skills, such as jumping, shooting, accelerating, decelerating, sprinting, and changing directions at various angles (Evangelos et al., 2012). Moreover, the high number of dynamic unilateral technical skills in which players used their dominant (D) leg for shooting, passing, juggling, dribbling, and receiving the ball, but a non-dominant (ND) leg simultaneously provides stabilization of body position. Barone et al. (2011) and Chew-Bullock et al. (2012) suggested that players should improve their balance proficiency. The capacity for balance performance is significantly different between professional and youth players (Pau et al., 2015), and in different levels of competition (Butler et al., 2012; Paillard et al., 2006) and depends on playing positions (Jadczak et al., 2019).

Balance capacity is provided by the central processing of the proprioceptive senses coming from the ankle proprioceptors to enhance sport performance and to reduce the number of falls and injuries (Han et al., 2015). Studies performed by Kim & Kim (2018) and Trajkovic (2021) confirmed that ankle strength and range of motion (ROM) were related to balance control ability. Regarding football performance, precise ankle rotation was considered to be linked to balance proficiency (stability of the supporting limb) and accuracy of ankle movements in shooting or passing (Cameron & Adams, 2003; Cè et al., 2018). Moreover, balance supported by ankle mobility and explosive strength of the lower extremity most contributes to various movements and different situations that are necessary within a game, particularly change of direction (Guzman et al., 2022). Ankle dorsiflexion plays a role in absorbing and transferring force, while balance ability may enable faster COD performance at various angles from 45 to 180 (Rouissi et al., 2018). However, deficit ankle dorsiflexion ROM was associated with an increased number of landing errors during football-specific tasks (Akbari et al., 2023).

Based on the observations of Surakhamhaeng et al. (2020), balance training alone led solely to an enhancement in balance in the Y-dynamic balance test for the lower body. The plyometric exercises additionally improve not only jumping performance but also result in enhancement of balance characteristics: reduction of body centre of pressure movement amplitude and speed in anteroposterior and mediolateral directions measured using a 3D motion analysis system. Therefore, the combination of balance and plyometric exercises should be more effective in improving balance characteristics than solely balance training.

Pediatric fitness programs should include various neuromuscular exercises to enhance motor skills and fitness, which are critical for football practice (Hammami et al., 2023). Recent studies have focused on developing novel neuromuscular training for sprint, agility, jump characteristics, change of direction, balance control, and technical skill in young football players (Chaouachi et al., 2017; Hammami et al., 2016, 2023; Muehlbauer et al., 2019). For instance, implementation of eight weeks of neuromuscular training (e.g. balance, plyometric, strength, change of direction training) (Hammami et al., 2023) significantly improved dynamic balance ($p < 0.001$, $d = 1.90$), 1RM back squat ($p = 0.001$, $d = 1.70$), jump performance ($p < 0.001$ – 0.02 , $d = 0.80$ – 2.40), linear sprint ($p < 0.01$, $d = 1.6$) and change of direction ($p < 0.05$, $d = 0.70$) in youth male football players. Additionally, various training strategies to incorporate balance and plyometric exercises have been shown to enhance overall physical fitness among young football players (Chaouachi et al., 2017; Hammami et al., 2016, 2023; Muehlbauer et al., 2019).

Plyometric training effectively enhances the knee extensor muscle peak isometric strength and power (vertical jump height) (Váczai et al., 2013), which were related to peak force production and acceleration in dynamic squats and jumps (Ramirez-Campillo et al., 2013). Davies et al. (2015) in their review article highly recommended inclusion of the plyometric exercises in late stage of rehabilitation of athletes. Balance training refers to the neurophysiological adaptation of the central nervous system to improve the spinal and supraspinal structures' functions in providing motor control, which was concluded in the review article (Taube et al., 2008). Hrysomallis (2011) mentioned in his review that balance training was beneficial for motor performance, rehabilitation, and injury prevention. While the previously mentioned studies have demonstrated the effectiveness of plyometric and balance training on overall physical fitness in football players, we focused on investigating how this training modality enhances

balance performance and lower leg characteristics, including factors such as ankle flexibility, peak isometric strength of shin muscles, and explosive strength of the lower leg which is not investigated in wide scale. Evidence has revealed that injuries in male youth football players occur mainly in the lower extremities (71–80%) (Read et al., 2016), with a 20% proportion of ankle instability due to impaired neuromuscular control during dynamic movements (Francia et al., 2022; Park et al., 2024). Therefore, our study aimed to investigate the effects of integrative balance and plyometric training on static and dynamic balance performance, active ankle range of movements, shin muscle strength, and jumping performance in young footballers. We hypothesized that providing balance and plyometric training (including progression of difficulty, variation of resistive load movements, and duration) would lead to significant improvement in balance performance, ankle mobility, and explosive lower extremity strength.

2. METHODS

2.1. PARTICIPANTS

The sample size was estimated by G*Power 1.9.4 analysis. Based on an effect size (f) value of >0.80 derived from the dynamic balance results from a previous study (Hammami et al., 2023) which was with 80% statistical power ($\beta = 0.8$) and $\alpha = 0.05$, the analysis indicated a minimum requirement of 12 participants per group. To account for a potential dropout rate of 20%, 30 well-trained adolescent male players from a football club in Riga, Latvia, were recruited for this study (Figure 1).

Eligible participants met the following criteria: aged 14–16 years and classified at pubertal stages 3 and 4 according to the Tanner scale (Beunen et al., 1992). Players had regular training sessions four times per week (7.5 ± 2.1 hours per week). They have at least five years of training experience in football (8.1 ± 2.6 years) and participate in competitions on weekends. Exclusion criteria: pain in the lower limbs during study, ankle sprain within the previous six months, surgery within the last 12 months, visual and vestibular disorders, ongoing treatment for inner ear or sinus infection, or a concussion within three months before the study.

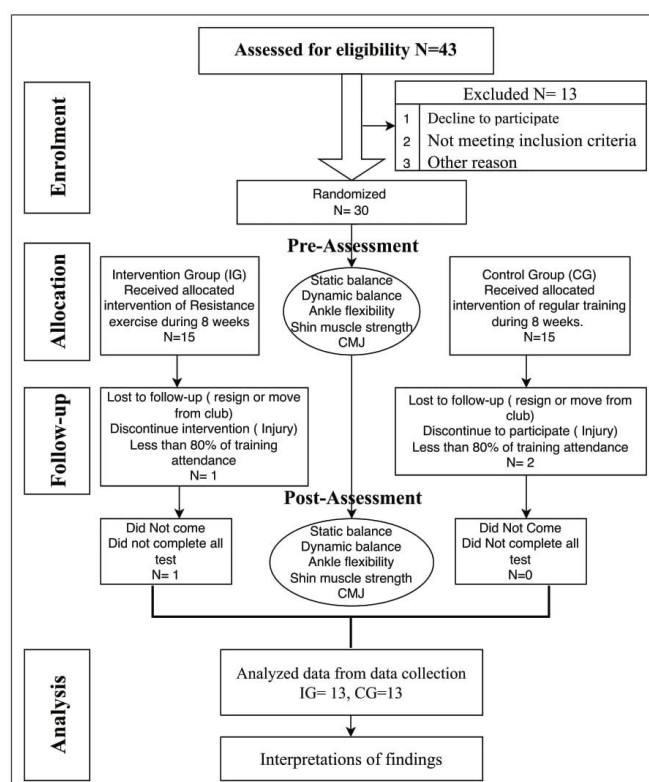


Figure 1 CONSORT diagram of participants, recruitment, allocation, follow-up, and analysis.

The cohort was stratified into a randomized control study with an intervention (IG) and a control (CG) group. The IG (N: 15, age: 15.8 ± 1.7 years, body mass of 67.8 ± 11.9 kg, height of 177.2 ± 5.9 cm, body mass index BMI of 21.9 ± 2.8 kg/m²), and CG (N: 15, age: 15.7 ± 0.6 years, body mass of 69.6 ± 4.8 kg, height of 180.3 ± 5.6 cm, BMI of 21.8 ± 1.4 kg/m²). No differences in anthropometric characteristics were observed at baseline between groups ($p > 0.05$). Before the study commencement, subjects and their parents provided informed consent. This study was conducted following the requirements of the Helsinki Declaration, and the protocol was approved by the Ethics Committee of the Latvian Academy of Sports Education (Meeting protocol No. 6, decision no. 1/51813, February 24, 2023).

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2.2. TRAINING PROGRAM

The training intervention was conducted twice weekly on alternate days during eight weeks (April–May 2024) at the beginning of the competitive season. Each session lasted 30–45 minutes and began with a standardized 15-minute warm-up, which included general and local exercises, as well as active stretching for the legs and trunk.

The balance training consisted of four types of exercises: 1) semi-squat position on one or both legs while holding a medicine ball, 2) squat while throwing the medicine ball vertically upwards, then stand up and catch the ball, 3) standing and keeping a balance position on the balance wobble board with a resistance band positioned around the thighs above the knee, 4) standing and keeping a balance position on the roller balance board with a resistance band positioned around the shins below the knee. The dose-response for balance training followed the protocol outlined by Gebel, Prieske et al. (2020). Each exercise lasted 20–40 seconds, and 3 sets were performed. A 30-second break between the sets, and the rest periods between different exercises were 120 seconds.

The plyometric training consisted of four types of exercises: 1) countermovement jump on both legs over the hurdle, 2) lateral hurdle hop, 3) single leg jumps forward and backward, side to side in front of cone, 4) Skipping rope with single and both legs. Plyometric exercises were performed with 2–4 sets of 6–15 repetitions per set, as it was recommended for youth football players (Bedoya et al., 2015). Rest intervals between sets of different exercises were established at 60–120 seconds. The initial number of ground contacts per session was set at 50–60, with progression leading to a maximum of 80–120 contacts per session.

During the intervention, balance training was performed before plyometric exercises to achieve optimal functional movement and muscular fitness outcomes (Behm et al., 2008; Granacher & Behm, 2023). Training intensity increased biweekly by adjusting the number of repetitions, duration, and difficulty of exercises (Table 1 and Figure 2). Throughout the training session,

Table 1 Description an eight week of integrative neuromuscular training program.

MATERIALS FOR BALANCE TRAINING	SET × REPETITION				TRAINING DESCRIPTIONS
	WEEK 1, 2	WEEK 3, 4	WEEK 5,6	WEEK 7, 8	
Static and dynamic balance					
Medicine ball 1.5 Kg + hoops (static balance performance, core stabilization + leg muscle strength endurance)	2 × 40s	3 × 40s	2 × 30s	3 × 30s	Semi-squat position on one or both legs while holding a medicine ball. Place both legs together or stand on a single leg. Stand in a semi-squat position (knee flexion angle to 45°). The head, neck, and back should be on a line. The head should be straight, and the gaze should be forward. Hold a medicine ball with both hands in front of the body for some time, the eyes should be open.
Medicine ball 1.5 Kg (dynamic balance, core stabilization)	2 × 40s	3 × 40s	2 × 30s	3 × 30s	Squat while throwing the medicine ball vertically upwards, then stand up and catch the ball. Stand with feet positioned at shoulder-width to produce maximum power. The position of the head, neck, and back should be in one line. Bend hip and knee joints to 90° (squat position) and return to a stabilized position while throwing the medicine ball vertically. Use the core, shoulders, and arms to throw the ball, engaging your core muscles.
Balance wobble board + resistance band (dynamic balance)	2 × 30s	3 × 30s	2 × 40s	3 × 40s	Standing and keeping a balanced position on the balance wobble board with a resistance band positioned around the thighs above the knee. Put on a resistance band around the thighs above the knees, and stand on both feet on the balance wobble board. Bend the hip and knee joints to 40°. Keep the back straight. Distribute the weight on the body center of pressure.
Balance board + roller+ resistance band (dynamic balance)	2 × 30s	3 × 30s	2 × 40s	3 × 40s	Standing and keeping a balanced position on the roller balance board with a resistance band positioned around the shins below the knee. Put on a resistance band around the shins below the knees, and stand on both feet on the balance wobble board. Bend hip and knee joints to 45° (squat position). Keep the back straight. Sway your body sideways for some time. Shift your weight from side to side to move the board in those directions.

(Contd.)

MATERIALS FOR PLYOMETRIC TRAINING	WEEK 1, 2	WEEK 3, 4	WEEK 5, 6	WEEK 7, 8	TRAINING DESCRIPTIONS
Plyometric training					
Hurdle jump++ resistance band. (leg muscle explosive power)	2 × 8	2 × 10	3 × 8	3 × 10	Counter-movement jump on both legs over the hurdle. Start with feet hip-width apart and knees slightly bent. Jump forward and backward over the hurdles. In the landing phase, bend ankles, knees, and hips to absorb impact energy.
Hurdle (leg muscle explosive power)	2 × 8	2 × 10	3 × 8	3 × 10	Lateral hurdle hop. Perform the hop by pushing off the right foot to land on the left foot over the hurdle, and vice versa. In the landing phase, bend ankles, knees, and hips to absorb the impact energy.
Cone triangle hop (Displace triangle cones with a distance of 1 m) (leg muscle explosive power)	2 × 6/ leg	2 × 8/ leg	3 × 4/ leg	3 × 5/ leg	Single leg jumps forward and backward, and side to side in front of the cone. Jump forward by taking off on one leg and land on the opposite leg in front of the cone. Bend your knee to 90° to touch the cone with the knee of the landed leg while the opposite leg hangs. Jump backward to the starting point. Second step: hop to the right from one leg to the other, then hop to the left. Repeat the hops starting with the opposite leg.
Skipping Rope (leg muscle explosive power)	Na	Na	3 × 30s	2 × 40s	Skipping rope with single and both legs. Stand with both legs in the middle of the rope. Feet are shoulder-width apart. Jump with a consistent bound and steady rhythm. Use wrists to swing the rope over the head. Align the upper body, hips, knees, and feet. Keep the pelvis horizontal. Continue skipping rope on the right and left leg, respectively.

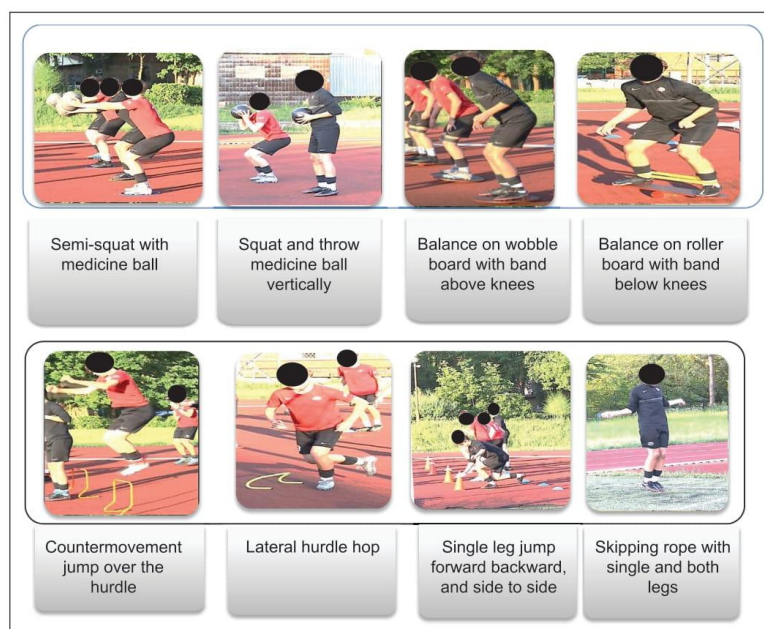


Figure 2 Illustration of balance and plyometric training.

coaches provided instructions on proper technique for balance and plyometric exercises. The coach verbally encouraged the players to exert maximal efforts during the training. Regarding the control group, they participated in their regular training sessions (e.g., 30–40 minutes of physical training and 60–90 minutes of technique and game play), which consisted of game-based training without any specific intervention.

2.3. STUDY MEASUREMENT

2.3.1. Procedure for data collection

The measurements were conducted in the afternoon (from 4 to 6 p.m.) at the Health Care Research Center of Riga Stradiņš University, Latvian Academy of Sports Education. The ambient temperature was maintained between 20 and 22°C, with relative air humidity levels of 35–45%. Players were instructed to wear indoor sportswear during testing. A familiarization

session was conducted for all testing protocols to prevent potential learning effects two weeks before the baseline assessments. The pre-test was administered before the beginning of the training program. Post-test measurement was conducted in the following week after finishing the training intervention. For objectivity, the assessment was performed by two blinded investigators who were unaware of which participant was from the intervention or control group. Leg dominance was determined by instructing players to kick the ball with maximal force (Baldon et al., 2012; Kollock et al., 2015). A 10–15 minute standardized warm-up exercise protocol was performed before testing. One day before testing, players were advised to rest and avoid training or match play.

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2.3.2. Anthropometric data collection

Height was measured using the SECA 2020 telescopic stadiometer (SECA, Hamburg, Germany), with an accuracy of ± 1 mm. Body weight was assessed using a SECA 874 digital scale (SECA, Hamburg, Germany), with a precision of measurement of ± 0.05 kg. Body mass index (BMI) was calculated with the standard formula: $BMI = \text{mass (kg)}/\text{height (m)}^2$ (Gallagher et al., 2000).

2.3.3. Static Balance Test

The static and dynamic balance performance was assessed using the ProKin 252 stabilometric platform (TecnoBody, Dalmine, Italy). The platform features a 55 cm diameter surface, a 20 Hz sampling rate, and a sensitivity of 0.1° . A trunk sensor was positioned on the chest at the midpoint of the sternum. Balance was measured within 30 seconds of one-legged stance, barefoot with eyes open. The foot's longitudinal axis was detected as the tangent line between the midpoint of the middle of the toe and the central point of the heel. Subjects were instructed to place their hands on their hips and focus their sight on a crosshair target (at a distance of 1 m at eye-level height). The supporting leg was maintained at a knee flexion angle of 30° , while the opposite leg was flexed at an angle of 45° (Mauch & Hakin, 2011). It was not allowed to touch the supporting leg with the opposite leg. After completing the 30s stance on each leg, the device recorded the following static balance parameters: ellipse area (EA) covered by the centre of pressure (CoP) movements, representing at least 90–95% of the sway lines. A smaller EA indicates better balance performance (Asseman et al., 2004). Perimeter length (P) is the total length of the circumference of the CoP sway lines. Average anterior-posterior speed (AAPS) and medial-lateral speed (AMLS) of CoP movements were determined in mm/s.

2.3.4. Dynamic Balance test

During the dynamic balance test, the movable balance platform of the system operates with air piston servo motors and can perform measurements in all directions within an operating angle of 15° . Total stability index (TSI) and total trunk deviation angle (TTD) were recorded as dynamic balance parameters. TSI refers to the distance between the body pressure centre and the centre of the movable platform. If the participant's centre of pressure (CoP) is closer to the centre of the movable platform, it indicates better dynamic balance performance. Similar to TSI, TTD refers to the sways of the trunk (anterior-posterior and medial-lateral) during a 30-second single-leg stance dynamic balance test. TSI values were classified: for athletes, TSI must be 0–0.83; for untrained participants, the norm was 0.84–2.32, and poor balance performance was detected if the TSI value exceeded 2.33. Higher scores of TSI and TTD indicated weaker dynamic balance performance. Following previous protocols (Meiners & Loudon, 2020; Sinulingga et al., 2024), participants were allowed one additional trial if they failed to complete the 30-second test without errors.

2.3.5. Ankle joint range of movement test

Active ankle range of movement (ROM) for plantar flexion (PF) and dorsiflexion (DF) was measured using a Jamar Plus digital goniometer (Performance Health, United Kingdom), following protocols outlined by Norkin and White (2016). Participants were seated with their knees flexed at a 90° angle. Two points were marked, 2 cm distal and 10 cm proximal to the lateral malleolus. The goniometer's pivot point was aligned with the lateral malleolus, while the fixed arm was positioned parallel to the lateral midline of the fibula. The movable arms were aligned with the lateral midline of the fifth metatarsal bone. ROM ($^\circ$) was measured across three trials per participant, with mean values used for analysis (Maior et al., 2020).

2.3.6. Ankle muscle strength test

The peak isometric forces of the plantar flexor (PF) and dorsiflexor (DF) muscles were measured by a handheld dynamometer (MicroFET2 wireless; Hoggan Health Industries, West Jordan, USA). The reliability of the hand-held dynamometry procedure was excellent for both intrarater ($ICC_{3,1} = 0.78-0.94$) and interrater ($ICC_{3,1} = 0.77-0.88$) (Spink et al., 2010). PF muscle force was measured with the dynamometer contacting the plantar surface of the foot (proximal to the first metatarsal bone head). DF muscle force measurements were taken from the dorsal surface of the foot (proximal to the metatarsal bones' heads) (Spink et al., 2010). Subjects were seated on a standard table, their hips flexed at the right angle (90°), and their knees extended. The investigator applied counterforce against the ankle DF and PF participants' muscle force using his dominant hand. Verbal encouragement was given during each contraction. The duration of each trial was 3 s, with a 1-minute rest interval between the trials. The maximum force (N) was selected for statistical analysis. Absolute peak torque (N·m) was calculated by multiplying the peak force by the length of lever arms (m) [the distance from the medial malleolus to the distal head of the first metatarsal bone]. Relative peak torque (Nm/kg) was calculated by dividing the absolute peak torque by the body mass of the participant: peak torque (PT)/body mass (BM).

2.3.7. Countermovement Jump test

Before starting the countermovement jump test (CMJ), participants were instructed to place their hands fixed on their hips (Aragon-Vargas, 2000). Participants had to remain upright before jumping, starting with a counter-movement until the hips and knees were bent to the right angle of 90° (Petrigna et al., 2019). Players started a counter-movement jump maximally in one motion immediately after a verbal command given by the investigator. Jump height and flight time were measured using an Optojump (Microgate, Srl., Bolzano, Italy). Maximum force production in the jump test was recorded using a force plate BTSP-6000 (BTS Bioengineering, Garbagnate Milanese, Italy).

2.4. STATISTICAL ANALYSIS

All data were calculated using SPSS version 27 (IBM, Armonk, NY, USA). Shapiro-Wilk and Levene's tests were used to verify the data distribution normality and homogeneity. Results were presented as mean $\pm$ SD (see Table 2). Within-group changes (pre- (t_0) vs. post- (t_1)) the intervention were assessed using the paired t-test, with effect size calculated by Cohen's d (trivial: <0.2 ; small: <0.5 ; moderate: <0.8 ; large: >0.8) (Cohen, 2013). Percentage changes were calculated as: $[(\text{pre}-\text{post})/\text{pre}] \times 100$. Between-groups differences were analyzed using ANCOVA (2×2), with effect sizes reported as partial eta-squared (η_p^2) (small: 0.01; medium: 0.06; large: 0.15).

3. RESULTS

All participants followed the assigned intervention conditions as allocated. The final sample size for analysis was reduced to 26 players: a) two players missed the post-intervention test; b) two participants did not fully complete this study due to injury Figure 1. Obtaining an adherence rate of 86.67%, the data were eligible for further analysis.

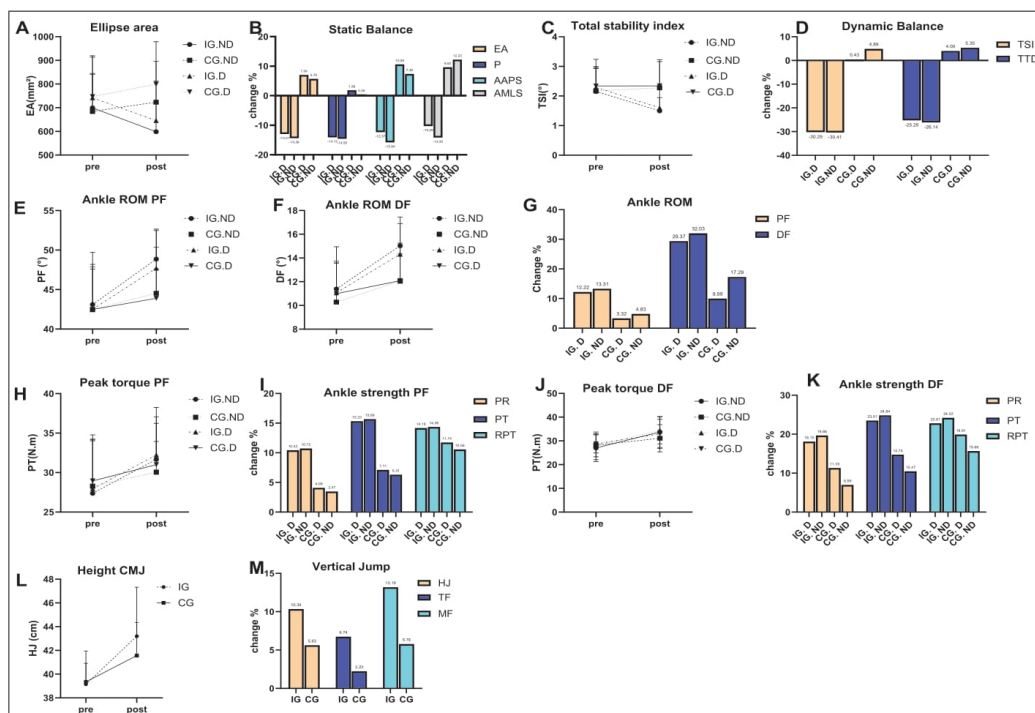
3.1. STATIC AND DYNAMIC BALANCE

IG demonstrated a significant improvement in static balance performance (10–15%, $p = 0.001-0.04$, $d = 0.57-1.14$). Post-test values revealed a significant improvement in static balance parameters: ellipse area (EA) decreased by 96–101 mm², perimeter length (P) reduced by 176–178 mm, and average anterior-posterior/medial-lateral speed (AAPS/AMLS) declined by up to 3 mm/s compared to baseline. Conversely, CG exhibited no significant changes in their training routine, $p = 0.17-0.90$. Between-groups comparison revealed that IG surpassed CG in all variables of static balance with $F = 4.62-18.30$, $p = 0.001-0.04$, $\eta_p^2 = 0.14-0.44$ (Table 2, Figure 3A and B). IG significantly improved in dynamic balance, with a 25–30% reduction in total stability index (TSI) and trunk total deviation (TTD) decrease of $0.62^\circ-0.70^\circ$, $p = 0.002-0.01$, $d = 0.89-1.03$. In contrast, CG exhibited no significant changes in both parameters, $p = 0.68-0.99$. Significant between-groups differences were shown in TSI and TTD with $F = 4.44-7.67$, $p = 0.01-0.04$, $\eta_p^2 = 0.16-0.25$ (Table 2, Figure 3C and D).

Table 2 Statistical results of between-group and within-group differences by presenting mean absolute and relative percentage value for pre- and post- test.

VARIABLE	BALANCE AND PLYOMETRICS TRAINING GROUP				CONTROL GROUP				ANCOVA			
	X1	X2	Δ%	p	d	X1	X2	Δ%	p	d	F	p
Static Balance												
Ellipse area [mm ²] D	741.94 ± 171.49	645.42 ± 166.95	-13.01	0.033*	0.57	746.95 ± 172.73	799.56 ± 179.27	7.04	0.331	0.29	6.620	0.017 [§]
ND	699.28 ± 145.3	598.70 ± 117.76	-14.38	0.045*	0.76	684.39 ± 156.76	723.42 ± 172.75	5.70	0.549	0.23	4.622	0.042 [§]
Perimeter [mm] D	1259.77 ± 169.33	1081.75 ± 138.9	-14.13	0.001*	1.14	1271.87 ± 162.87	1295.56 ± 155.08	1.86	0.641	0.14	18.303	0.001 [§]
ND	1213.68 ± 187.1	1037.44 ± 166.85	-14.52	0.001*	0.99	1282.21 ± 201.04	1288.13 ± 181.33	0.46	0.908	0.03	14.780	0.001 [§]
Anterior-Posterior Speed [mm/s] D	24.70 ± 4.14	21.65 ± 3.7	-12.37	0.015*	0.77	25.44 ± 4.8	28.14 ± 6	10.59	0.172	0.49	10.816	0.003 [§]
ND	23.99 ± 3.62	20.19 ± 3.32	-15.84	0.001*	1.09	25.37 ± 6.14	27.24 ± 5.13	7.38	0.312	0.33	17.794	0.001 [§]
Medial-Lateral Speed [mm/s] D	28.85 ± 3.27	25.88 ± 4.23	-10.29	0.023*	0.78	30.24 ± 5.69	33.15 ± 6.55	9.62	0.286	0.47	10.599	0.003 [§]
ND	27.56 ± 6.57	23.65 ± 4.17	-14.20	0.038*	0.71	27.82 ± 8.55	31.23 ± 6.05	12.23	0.258	0.45	13.521	0.001 [§]
Dynamic Balance												
Total stability index [°] D	2.29 ± 0.63	1.59 ± 0.74	-30.29	0.002*	1.01	2.33 ± 0.9	2.34 ± 0.87	0.43	0.994	0.01	5.793	0.025 [§]
ND	2.15 ± 0.79	1.50 ± 0.44	-30.41	0.013*	1.02	2.17 ± 0.82	2.27 ± 0.78	4.89	0.771	0.12	7.675	0.011 [§]
Trunk Total Deviation [°] D	2.56 ± 0.67	1.91 ± 0.59	-25.59	0.013*	1.03	2.60 ± 0.99	2.70 ± 1.49	4.00	0.721	0.08	4.506	0.045 [§]
ND	2.36 ± 0.67	1.74 ± 0.72	-26.14	0.007*	0.89	2.37 ± 0.97	2.50 ± 1.38	5.35	0.685	0.13	4.444	0.046 [§]
Talocrural Ankle ROM												
Plantarflexion [°] D	42.51 ± 5.09	47.71 ± 4.76	12.22	0.002*	1.05	42.49 ± 5.7	43.90 ± 3.72	3.32	0.474	0.29	5.432	0.029 [§]
ND	43.11 ± 6.61	48.85 ± 3.81	13.31	0.027*	1.06	42.47 ± 5.38	44.53 ± 5.85	4.83	0.322	0.36	4.751	0.040 [§]
Dorsiflexion [°] D	11.07 ± 2.51	14.32 ± 2.57	29.37	0.001*	1.27	10.99 ± 2.75	12.09 ± 2.25	9.99	0.134	0.43	7.645	0.011 [§]
ND	11.39 ± 3.55	15.03 ± 2.41	32.03	0.001*	1.19	10.28 ± 3.29	12.05 ± 2.57	17.29	0.067	0.59	5.284	0.031 [§]
Shin muscle peak Isometric												
Plantarflexor Peak Force [N] D	136.32 ± 33.79	150.52 ± 29.04	10.42	0.006*	0.45	136.71 ± 22.25	142.30 ± 23.35	4.09	0.253	0.24	5.246	0.031 [§]
ND	133.50 ± 35.04	147.81 ± 22.35	10.72	0.038*	0.48	133.70 ± 23	138.34 ± 14.66	3.47	0.433	0.24	3.096	0.092
Plantarflexor Peak Torque [N.m] D	27.93 ± 6.3	32.23 ± 6.02	15.38	0.001*	0.69	28.94 ± 5.83	31.00 ± 6.04	7.11	0.101	0.34	2.156	0.156
ND	27.37 ± 6.77	31.66 ± 4.56	15.68	0.005*	0.74	28.27 ± 5.74	30.05 ± 3.88	6.31	0.232	0.36	2.347	0.139
Plantarflexor Relatif Peak Torque[N.m/kg]D	0.46 ± 0.11	0.52 ± 0.10	14.18	0.001*	0.62	0.46 ± 0.10	0.51 ± 0.13	11.74	0.164	0.46	0.160	0.693
ND	0.45 ± 0.11	0.51 ± 0.09	14.36	0.013*	0.56	0.45 ± 0.1	0.49 ± 0.11	10.56	0.139	0.45	0.268	0.610
Dorsiflexor Peak Force [N] D	135.23 ± 27.71	160.66 ± 27.83	18.80	0.001*	0.91	136.19 ± 15.99	151.65 ± 26.29	11.35	0.049*	0.71	1.434	0.243
ND	131.32 ± 28.34	157.53 ± 32.41	19.96	0.001*	0.86	133.38 ± 21.06	142.70 ± 22.35	6.99	0.119	0.42	5.144	0.033 [§]
Dorsiflexor Peak Torque [N.m] D	27.87 ± 5.84	34.43 ± 5.70	23.51	0.001*	1.13	28.72 ± 3.80	32.95 ± 6.14	14.74	0.014*	0.82	1.435	0.243
ND	27.01 ± 5.78	33.72 ± 6.52	24.84	0.001*	1.08	28.14 ± 4.81	31.09 ± 5.77	10.47	0.025*	0.55	5.075	0.034 [§]
Dorsiflexor Relatif Torque [N.m/kg] D	0.45 ± 0.08	0.55 ± 0.09	22.81	0.001*	1.21	0.45 ± 0.07	0.54 ± 0.12	19.19	0.012*	0.91	0.191	0.666
ND	0.43 ± 0.07	0.54 ± 0.09	24.22	0.001*	1.32	0.44 ± 0.07	0.51 ± 0.13	15.66	0.029*	0.67	1.028	0.321
Countermovement Jump												
Height [cm]	39.15 ± 1.75	43.19 ± 4.12	10.34	0.000*	1.27	39.35 ± 2.59	41.56 ± 2.77	5.63	0.008*	0.82	2.389	0.136
Time Flights [s]	0.55 ± 0.04	0.59 ± 0.05	6.74	0.017*	0.82	0.57 ± 0.02	0.58 ± 0.03	2.23	0.324	0.48	0.543	0.468
Maximum force [N]	1643.62 ± 189.60	1876.79 ± 242.60	14.19	0.004*	1.07	1717.62 ± 154.61	1816.89 ± 185.11	5.78	0.195	0.580	0.774	0.388

Abbreviation: x1 = mean pre-test, x2 = mean post-test, Δ % = percentage change from pre to post test, D = Dominant, ND = Non-dominant, mm² = Millimeter square, mm = Millimeter, mm/s = millimeter per second, ° = degree, s = Second, N = Newton, cm = Centimeter, m = meter, kg = kilograms, m² = Partial eta square. * Significant difference: p < 0.05 between pre- and post-test within groups; § significant difference: p < 0.05 between intervention and control groups.



3.2. ANKLE MOBILITY (RANGE OF MOTION AND STRENGTH)

IG demonstrated significant change in active ankle range of motion (ROM), with an increase of 12–32% in plantarflexion (PF) and dorsiflexion (DF) ($p = 0.001$ – 0.02 , $d = 1.05$ – 1.27). Post-intervention results showed a significant improvement in active ROM for IG, with an increase of 5° – 7° in PF and of 3° – 4° in DF. However, CG exhibited no significant changes from pre- to post-test = 0.06 – 0.47 . IG showed significantly greater than CG in PF ($F = 4.751$ – 7.675 , $p = 0.029$ – 0.040 , $\eta_p^2 = 0.171$ – 0.191) and DF ($F = 5.284$ – 7.645 , $p = 0.011$ – 0.031 , $\eta_p^2 = 0.187$ – 0.249) (Table 2, Figure 3E–G).

Ankle plantar flexion peak force, absolute and relative torque significantly improved in IG (10–19%, $p = 0.001$ – 0.03 , $d = 0.45$ – 0.91), while dorsiflexion (DF) increased in both groups (10–24%, $p = 0.001$ – 0.04 , $d = 0.55$ – 1.32). Between-group analysis revealed significant differences between IG and CG in peak force of PF for D leg ($F = 5.246$; $p = 0.031$; $\eta_p^2 = 0.186$), peak force of DF for ND leg ($F = 5.144$; $p = 0.033$; $\eta_p^2 = 0.183$), and peak torque of DF for ND leg ($F = 5.075$; $p = 0.034$; $\eta_p^2 = 0.181$) (Table 2, Figure 3H–K).

3.3. EXPLOSIVE STRENGTH OF LOWER LIMBS

Jump height significantly increased in both groups (5–10%, $p = 0.000$ – 0.008 , $d = 0.82$ – 1.27). Furthermore, IG demonstrated significant improvements in time flight (6.74%; $p = 0.017$; $d = 0.82$) and maximum force production (14.19%; $p = 0.004$; $d = 1.07$), while CG showed no significant changes $p = 0.19$ – 0.32 . ANCOVA revealed no significant group $\times$ time interaction for any countermovement jump characteristics, $p = 0.13$ – 0.46 (Table 2, Figures 3L and M).

4. DISCUSSION

This study aimed to evaluate the effect of integrative balance and plyometric training on balance, ankle mobility, and explosive strength in young football players. After eight weeks of balance and plyometric intervention, IG showed improvement in their static and dynamic balance, ankle active range of motion (ROM), shin muscle strength, and vertical jump performance. The control groups (CG) who performed only the training routine improved in shin muscle peak isometric DF force for the non-dominant leg, absolute and relative peak

Figure 3 Absolute (A, C, E, F, H, J, L) and relative percentage (B, D, G, I, K, M) value change (pre-to-post) for all variables test.

Abbreviation: ellipse area [EA], perimeter length [P], average anterior-posterior speed [AAPS], average medial-lateral speed [AMLS], total stability index [TSI], total trunk deviation angle [TTD], Plantar flexion [PF], dorsiflexion [DF], peak force (PR), peak torque (PT), relative peak torque(RPT), height jump [HJ], flight time [FT], maximum force [MF]. IG.D intervention group dominant leg, CG.D control group dominant leg, IG.ND intervention group non-dominant leg, CG.ND control group non-dominant leg.

torque for both legs, and height jump performance. Within-group analysis revealed that the IG achieved significant enhancements across all tests, surpassing the performance of the CG counterparts.

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4.1. STATIC AND DYNAMIC BALANCE

Combination neuromuscular training (e.g., balance, plyometric, resistance exercise) is more effective than stand-alone to enhance balance and muscular fitness in youth athletes (Granacher & Behm, 2023). We conducted an eight-week integrative balance and plyometric training program, which led to improvements in static and dynamic balance ($p = 0.001$ – 0.045 , $d = 0.5$ – 1.14) in young players. IG showed significant improvement in static and dynamic balance compared to CG, with a large effect size. Static balance demonstrated reduced centre of pressure (CoP) displacement (EA) ($\pm 14\%$), perimeter length (P) ($\pm 14\%$), and decreased sway speed in anterior-posterior (AP) and medial-lateral (ML) directions ($\pm 15\%$). In the previous study Dafkou et al. (2021) reported a 33% reduction in CoP sway after eight weeks of eccentric, balance, and core exercises implementation in football training routines. In line with this, improvements in AP and ML CoP velocity (eyes open/closed) following proprioceptive training in taekwondo poomsae athletes (Yoo et al., 2018), and among individuals with functional ankle instability was observed (Surakhamhaeng et al., 2020).

The study conducted by Cè et al. (2018) determined an enhancement in total stability index (TSI) on bipedal ($ES = 2.37$) and unipedal tests ($ES = 1.95$) after 12 weeks of balance training (three times per week, 20 minutes per session) in 11-year-old male football players. These findings support our results, where the improvement in dynamic balance characteristics: total stability index (TSI) and sway trunk deviation (TTD), $p = 0.002$ – 0.013 (0.62° – 0.70° lower than baseline). The current study provides materials (e.g., wobble board, roller balance board, medicine ball, resistance band), surface (e.g., stable/unstable), patterns of intervention (e.g., static and dynamic), dose, and response (Gebel, Prieske, et al., 2020; Schedler et al., 2020) that improve sensory components for center of pressure displacement: proprioceptive (e.g. somatosensory), visual, and vestibular sense acuity. Progression of difficulty levels during balance training (Gebel, Lehmann, et al., 2020; Schedler et al., 2020), as implemented in our intervention (e.g. bipedal/unipedal stance, unstable/stable platform, and sway stability on roller board, with/without arm support), enhance neuromuscular activation required for postural stability. Conversely, plyometric may enhance balance performance, similar to the role of balance training (Ramachandran et al., 2021), but with different training characteristics. Plyometric training resulted in improved motor control and reduced rate of force development, which applied to the reduction of the CoP perturbation during football-specific actions.

4.2. ANKLE MOBILITY (RANGE OF MOTION) AND STRENGTH

Ankle mobility represents a key determinant of balance improvement, as ankle flexibility and increased strength help enhance balance capacity (Kim & Kim, 2018; Trajković et al., 2021). In the present study, following an eight-week balance and plyometric training, the range of motion for plantar flexion increased by 5° (13%), and dorsiflexion by 4° (32%) in the IG ($p = 0.001$ – 0.02). In contrast, there was no significant change in the CG ($p = 0.06$ – 0.47). Furthermore, there is a significant difference in plantar and dorsiflexion between the groups in both the dominant ($p = 0.01$ – 0.002 , $\eta_p^2 = 0.19$ – 0.24) and non-dominant leg ($p = 0.03$ – 0.04 , $\eta_p^2 = 0.17$ – 0.18). Similar to a study conducted by (Alahmari et al., 2021) a 6-week program of strength and balance exercises improves talocrural joint mobility by 3.7° (44.3%) in PF and 3.5° (45.2%) in DF among individuals with functional ankle instability (FAI). Current studies indicate that balance and plyometric training affect ankle proprioception, thereby enhancing sensory feedback related to muscle length changes, joint position sense, and movement speed (Alahmari et al., 2021). This training regimen also induces muscle relaxation to promote increased stretch magnitudes during balance intervention, resulting in larger dorsiflexion ROM, as well as improved functional movement and stability (Lazarou et al., 2018). Kim & Kim (2018) observed that the ROM of ankle dorsiflexion negatively correlated with CoP sway distance in the static balance test, standing on both feet, improving the balance; controversially, the ankle plantar flexion ROM positively correlated with CoP sway distance, worsening the static balance performance.

Maximal voluntary isometric strength of the shin muscle increased in plantar flexor +14 N (10%), absolute torque +5 N/kg (15%), and relative torque +0.6 N.m/kg (14%), with moderate effect size ($p = 0.001$ – 0.038 , $d = 0.45$ – 0.74). Moreover, IG also improved in dorsiflexion strength of +25 N (19%), absolute torque +7 N/kg (24%), and relative torque + 0.10 N.m/kg (22%), with a large effect size. In contrast to CG, only their dominant leg showed an increase in peak force and torque $p = 0.01$ – 0.04 , while relative torques increased in both legs $p = 0.001$ – 0.02 . Significant differences between groups were observed in the plantar flexor of the dominant leg ($p = 0.031$, $\eta_p^2 = 0.18$), and in dorsiflexor force and torque of the non-dominant leg ($p = 0.034$, $\eta_p^2 = 0.18$). One of the most highlighted improvements in shin muscle isometric strength may be explained by combining stable and unstable platforms, enhanced muscle strength and coordination, particularly for joint stability (Anderson & Behm, 2005). Balance training on stable and unstable surfaces, particularly with the addition of band resistance, leads to improved ankle strength and a reduction in valgus deformity of the ankles (Kim et al., 2017). In line with this, a 4-week balance training consisting of dynamic unstable surface exercises (e.g. mini squat on BOSU ball) improves ankle force production in PF (ES = 0.80 [0.25, 1.34]) and DF (ES = 0.75 [0.21, 1.29]) in healthy young adults (Cuğ et al., 2016).

Plyometric exercise with various jump conditions (CMJ, hop, leap, skip) also contributes to improving force production and muscular coordination, which affect ankle joint position sense (Huang et al., 2021). The current study agrees that combining plyometric and balance exercises is more effective in mitigating ankle joint position sense errors and enhancing neuromuscular control, compared to plyometric training alone (Huang et al., 2021), even for athletes with functional ankle instability (Park et al., 2024). Improvement in ankle mobility directly contributes to somatosensory regulation during upright posture and balance control. This occurs through its influence on muscle spindles, Golgi tendon organs, and plantar cutaneous receptors, thereby enhancing balance control (Alahmari et al., 2021; Viseux et al., 2019).

4.3. COUNTERMOVEMENT VERTICAL JUMP

The improvement in jump performance in our study might be attributed to plyometric training, which enhances motor recruitment and stretch-shortening cycle (SSC) (Davies et al., 2015; Sammoud et al., 2024). Incorporating balance and plyometric training over six weeks improves jump height in youth football players ($p = 0.002$, $d = 2.21$) (Muehlbauer et al., 2019). As mentioned in the previous investigations, plyometric exercise variation (e.g., CMJ, hurdle jump, ankle jump, lateral hops) and balance (e.g., standing or squatting on single/bilateral on Swiss ball) lead to improvements in jump performance in young footballers within an eight-week intervention (Chaouachi et al., 2017; Hammami et al., 2016; Makhoulouf et al., 2018). Additionally, variables such as flight time and peak force production also improved in our study. Plyometric training on a stable surface improves neuromuscular adaptation (Granacher & Behm, 2023), including enhanced motor unit recruitment, optimized synergistic muscle activation, and reduced antagonistic muscle activity (Markovic & Mikulic, 2010). Additionally, musculotendinous tissue adaptations (increased tendons' stiffness that is connected to muscle capacity for rapid force production) may further contribute to enhancing jump characteristics in young football players (Arntz et al., 2022; Moran et al., 2023).

4.4. STRENGTHS, LIMITATIONS, AND FUTURE STUDY DIRECTIONS

The present study demonstrated that integrative balance and plyometric training can significantly improve static and dynamic balance, ankle active range of motion, peak isometric strength of the shin muscle, and jump performance in young players. This study has some limitations: 1) small number participant, 2) only specific group of participants (14–16 years old male football payers), meaning the results cannot be generalized to other age and sex groups, 3) mesocycles intervention (8 weeks intervention), where long-term effects of the balance and plyometric training was not evaluated, and 4) lack of methodological approaches that should be included in future studies: (1) monitoring cortical activity via electroencephalography (EEG), (2) analyzing electromyography (EMG) patterns of muscle activation, and (3) employing isokinetic dynamometry. Future studies should consider 1) a larger sample size and various populations, 2) a longer period of intervention, 4) methodological improvements using more precise measurement methods (isokinetic dynamometry, electromyography, etc.), and 4) reformulation of training modalities (dose and response) under different sample conditions.

5. CONCLUSION

Eight weeks of integrative balance and plyometric training resulted in significantly improved static and dynamic balance, active ankle range of motion, and enhanced peak isometric strength of the plantar and dorsal flexor muscles in young football players, as well as improved vertical jump characteristics. To ensure the effectiveness of the training regimen, the progression of balance and plyometric exercises (e.g., volume, duration, and difficulty levels) must increase every two weeks of the intervention period. This training program may be considered for inclusion in training routines as a fundamental to improve balance performance, ankle proprioception, flexibility, and strength. This finding would contribute to improving player performance and overall quality of play in football matches.

ACKNOWLEDGEMENTS

The authors are grateful to players, parents, and coaches. Thanks to Anna Zuša and Miks Laksbergs for helping with data collection.

FUNDING INFORMATION

The research is supported by the project RSU Internal and RSU with LSPA external consolidation No. 5.2.1.1.i.O/2/24/I/CFLA/005.

COMPETING INTERESTS

The authors have no competing interests to declare.

AUTHOR CONTRIBUTIONS

Conceptualization, methodology, writing-original draft, review and editing ARS and IP, Data collection and curation, ARS, AL, AS; Investigation and formal analysis: ARS and KS. All authors read and agreed to the published version of the manuscript.

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TO CITE THIS ARTICLE:

Sinulingga, A. R., Slaidiņš, K., Salajeva, A., Liepa, A., & Pontaga, I. (2025). Effect of Integrative Balance and Plyometric Training on Balance, Ankle Mobility, and Jump Performance in Youth Football Players: A Randomized Controlled Trial. *Physical Activity and Health*, 9(1), pp. 146–160. DOI: <https://doi.org/10.5334/paah.472>

Submitted: 09 May 2025

Accepted: 17 July 2025

Published: 31 July 2025

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Physical Activity and Health is a peer-reviewed open access journal published by Ubiquity Press.





SPORT I TURYSTYKA
Środkowoeuropejskie Czasopismo Naukowe

UNIwersYTET JANA DŁUGOSZA
W CZĘSTOCHOWIE

2025
t. 8, nr 1



Received: 29.02.2024;
Accepted: 12.07.2024

<http://dx.doi.org/10.16926/sit.2025.01.05>

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ANALYSIS OF PEAK POWER OUTPUT, LOWER LIMB EXPLOSIVE STRENGTH AND BALANCE PERFORMANCE OF YOUNG FOOTBALL PLAYERS ACCORDING TO THEIR PLAYING POSITION: A PILOT STUDY

How to cite [jak cytować]: Sinulingga, A.R., Pontaga, I., & Slaidiņš, K. (2025). Analysis of peak power output, lower limb explosive strength and balance performance of young football players according to their playing position: A pilot study. *Sport i Turystyka. Środkowoeuropejskie Czasopismo Naukowe*, 8(1), 97–114.

Analiza szczytowej mocy wyjściowej, eksplozywnej siły kończyn dolnych i równowagi młodych piłkarzy w zależności od pozycji gry: badanie pilotażowe

Streszczenie

Promowanie wysokiego poziomu siły, mocy i kontroli postawy w określonych pozycjach gry ma kluczowe znaczenie w całej fazie dojrzewania u młodych piłkarzy. W badaniu tym zbadano moc szczytową, siłę eksplozywną kończyn dolnych i zachowanie równowagi wśród młodych piłkarzy na różnych pozycjach gry. W badaniu wzięło udział czterdziestu trzech młodych piłkarzy (wiek: 15,81 ± 1,33 lat), podzielonych na cztery pozycje: 5 bramkarzy, 12 obrońców, 20 pomocników i 6 napastników. Zaobserwowano istotne różnice w szczytowej mocy wyjściowej pomiędzy grającymi na pozycjach ($p = 0,003$, $\eta^2 = 0,226$), z przewagą napastników nad pomocnikami ($p = 0,011$). Jednakże nie stwierdzono żadnych znaczących rozbieżności w charakterystyce skoku pionowego. Stwierdzono różnice w charakterystyce równowagi statycznej średniej prędkości środkowo-bocznej (AAPS) dla nogi niedominującej i dominującej ($p = 0,025$, $\eta^2 = 0,211$; $p = 0,033$, $\eta^2 = 0,198$),

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przy niższej prędkości kołysania u bramkarzy ($p = 0,022$) w porównaniu z napastnikami ($p = 0,040$). Jednakże badanie nie wykazało znaczących różnic w innych charakterystykach działania wagi statycznej ani równowagi dynamicznej. Podsumowując, badanie podkreśla znaczące różnice w szczytowej mocy wyjściowej w zależności od pozycji gracza, ale nie w przypadku siły eksplozywnej kończyn dolnych i zachowania równowagi pomiędzy grupami.

Słowa kluczowe: moc szczytowa, skok pionowy, równowaga statyczna i dynamiczna, piłka nożna.

Abstract

Promoting a high level of strength, power, and postural control in specific playing positions is crucial throughout the puberty phase in young football players. This study explored peak power, lower limb explosive strength, and balance performance among youth football players across their playing positions. Forty-three young male football players (age: 15.81 ± 1.33 years) participated, categorized into four positions: 5 goalkeepers, 12 defenders, 20 midfielders, and 6 forwards. Significant differences were observed in peak power output among playing positions ($p=0.003$, $\eta^2=0.226$), with forwards superior over midfielders ($p=0.011$). However, no meaningful disparities were found in vertical jump characteristics. Variations in center of body pressure sway speed medial-lateral direction were identified for nondominant and dominant leg ($p=0.025$, $\eta^2=0.211$; $p=0.033$, $\eta^2=0.198$), with the lower sway speed in goalkeepers ($p=0.022$) in comparison with forwards ($p=0.040$). However, the study found no significant differences in the other characteristics of static balance performance, nor in the dynamic balance. In conclusion, the study emphasizes significant variations in peak power output across player positions but not for lower limb explosive strength and balance performance among groups.

Keywords: peak power, vertical jump, static and dynamic balance, football.

Introduction

Strength, power, and endurance play a significant role in performing sprinting, passing, shooting, jumping, and changing direction throughout a football game (Helgerud et al., 2011; Malina et al., 2024; Martinho et al., 2024). Power and strength development are important for improving the physical performance of young footballers (Barbalho et al., 2018; França et al., 2024). Moreover, enhancing youth football players' physical and physiological performance is emphasized according to their playing position (Joo & Seo, 2016; Toselli et al., 2022).

The evaluation of anaerobic performance has been extensively used to assess short-term power action (Cossio-Bolaños et al., 2021; Gross & Lüthy, 2020; Haugen et al., 2013; Ostojic et al., 2010). It contributed to repeated sprinting, jumping, shooting, and dueling against the opponent, known as short-burst activity. Development of power for a short period of time is a fundamental aspect of the young's physical capacity that increases during growth and maturation (Baker & Davies, 2002). The vertical jump is a test frequently employed for estimating the strength and power of the inferior limb (Rodríguez-Rosell et al., 2017; Chamari et al., 2004) and impulsive ability. It has also been used to evaluate

physical performance in young football players (Petridis et al., 2019; Rodríguez-Rosell et al., 2017). The cycling ergometer test evaluated peak power output by the six-second peak power test (Herbert et al., 2015; Wehbe et al., 2015), and the Wingate test investigated the short-term strength endurance of young players' leg muscles (Nikolaidis & Knechtle, 2021; Nikolaidis et al., 2016).

Balance performance is the capacity to maintain a support base with restricted movement while doing tasks in a steady postural stance (Bressel et al., 2007). In football, balance plays a crucial role in enhancing the technical skills of players (Evangelos et al., 2012; Teixeira et al., 2011) and injury prevention, particularly in adolescent football players (Bressel et al., 2007; Malliou et al., 2004; Teixeira et al., 2011). Paillard et al. (2019), Pau and Attene (2014) confirmed that football players' balance ability is strongly linked to maturation and the level of playing experience.

A great number of research articles on football players' playing positions (AlTaweel et al., 2022a; Bortnik et al., 2024; Harry et al., 2018; Jadcak et al., 2019; Mahmoudi et al., 2023) have been examined to analyze physiological performance and motor skills in football players. However, peak power production, lower body explosive strength, and static and dynamic balance performance characteristics have not been investigated on a wide scale in adolescent unmatured footballers playing in different positions. Therefore, the objective of this study was to examine the differences in anaerobic power production, explosive strength of the lower body, and static and dynamic balance based on player position. We hypothesized that young players would have smaller peak power production, explosive strength, and balance variations based on their playing position than adult footballers.

Methods and Materials

Subjects

Forty-three young male football players (age = 15.81 ± 1.33 years) from various football clubs, who attended regular training sessions and competitions at the weekends, were selected for this study. The players had less than eight years of experience in football training. The maturation of the adolescent players was estimated using the Tanner method (Beunen et al., 1992) by the physician, only participants classified as Tanner stage 3 – 4 were included in the investigation. The players were classified into four groups according to playing positions: Goalkeepers (GK) (N=5, body height 185.42 ± 2.20 , body mass = 76.20 ± 9.85), Defenders (D) (N=12, body height 182.48 ± 2.20 , body mass = 73.70 ± 4.73), Midfielders (MD) (N=20, body height 174.89 ± 5.03 , body mass = 63.77 ± 6.92), Forwards (F)

($N=6$, body height 184.00 ± 3.69 , body mass $=75.28 \pm 12.25$). None of the participants has experienced injury in the previous six months. Parents and participants were briefed on the study's protocols, risks, and advantages. The parents submitted the informed consent form to allow their sons to participate in the study. The research that pertains to human use has followed all pertinent national regulations and institutional policies, adhered to the principles of the Declaration of Helsinki, and was approved by the Ethics Committee of the Latvian Academy of Sport Education (Meeting Protocol No. 6, decision No. 1/51813 of February 24, 2023).

Data Collection

Before the tests, the participants engaged in warm-up sets for approximately 30 minutes, involving jogging and dynamic stretching. Anthropometric assessments of young football players wearing briefs were performed using SECA 220 for height measurement with an accuracy of up to 1 mm and SECA 874 for weight measurement with an accuracy of up to 0.05 kg (SECA, Hamburg, Germany). Body mass index (BMI) was calculated as weight in kilograms (kg) divided by the square of height in meters (m^2).

All devices and platforms used in this research have demonstrated validity and reliability in measuring peak power output on bicycle ergometer (Herbert et al., 2015; Wehbe et al., 2015), short-term strength endurance on bicycle ergometer (Nikolaidis & Knechtle, 2021; Nikolaidis et al., 2016), vertical jump for muscle strength and power investigation (Bellicha et al., 2022; Attia et al., 2017) and static and dynamic balance (Srishti et al., 2023). With a flying start, the six-second peak power test was performed using a cycling ergometer (Wattbike Pro, Nottingham, UK). The Wattbike was 'zeroed' before the testing to ensure reliability by the manufacturer's recommendations. Initially, the players selected saddle height and handlebar position based on their preferences. The Wattbike test guide recommended body mass-based resistance levels. The WattBike Pro cycle ergometer's performance computer calculated power via a load cell located next to the chain. As force is exerted through the cranks, the load cell calculates power by the sum of all forces applied during one complete pedal revolution. After completing the test, the power output in Watts (W) shown on the WattBike monitor is calculated using the following equation: $P(W) = (F[N] \cdot l[m]) / T[s]$, where F -the forces applied in N multiplied by the distance covered in meters (m) and divided by the time T in seconds (s). Peak power (W), mean power (W), relative peak power (W/kg), and distance completed (m) throughout the six-second WattBike test were recorded. Before starting the test, the participants could pedal for 20 to 30 seconds without any load. Subsequently, an investigator raised the resistance to the chosen level, then the sub-

jects pedaled as strong as possible during six-seconds. The participants were encouraged verbally to exert maximal effort. Throughout testing, the investigator stabilized the Wattbike to prevent ergometer shifting (Herbert et al., 2015; Hopper et al., 2010).

The vertical jump was widely used in health care and athletes to measure lower limb muscle strength and power (Vanegas et al., 2021). The subjects' arms were allowed to move freely during the vertical jump assessment (Petrigna et al., 2019). The players start a countermovement and jump maximally in one motion after a verbal command. The best jump test result (the highest jump) was used for analysis after three jump trials, one minute of passive recovery was given between each trial of jumps. An **Optojump (Microgate, Srl., Bolzano, Italy)** measured jump height and time flight, and a force plate **BTSP-6000 (BTS Bioengineering, Garbagnate Milanese, Italy)** measured the peak force.

The subjects stood on the balance platform **ProKin 252 stabilometry platform (TecnoBody, Dalmine, Italy)**, accurately measuring pressure sway in all directions. The participants were instructed to keep balance in a one-leg stance, concentrate on a screen for thirty seconds, set hands on their hips and the opposite leg at a 45-degree knee flexion. A smaller perimeter length of the center of pressure movements' area indicated better static balance (Donath et al., 2012). The body center of pressure which sways an ellipse area (mm^2) is a well-defined elliptical form encompassing at least 90% or 95% of the chaotic sway lines. Smaller ellipse areas indicated better balance (Asseman et al., 2004). The ProKin 252 stabilometric platform also assessed the dynamic balance ability as a total stability index and the trunk deviation angle in degrees. The total stability index was categorized as normative for trained subjects with a value of 0 – 0.83, normal for nonathletes between 0.84 and 2.32, and poor postural control if it exceeded 2.33. A greater score of the total stability index and the trunk deviation angle meant a worse sense of trunk position (Toprak Celenay et al., 2019).

Statistical Analysis

The statistical analyses were performed using SPSS version 26.0 for Windows, developed by SPSS Inc. in Chicago, IL, USA. Shapiro-Wilk's and Levene's test of equality of error variances ($p > 0.05$) verified that the data was normal and homotent. The variable did not follow a normal distribution; the Kruskal-Wallis H test was performed to compare peak power output, explosive strength of the lower limb, and balance characteristics based on the subjects' playing position. Multiple comparisons used Post hoc Dunn's tests when groups were significantly different. Eta-squared (η^2) was used to calculate the effect sizes: 0.01 small, 0.06 medium, and 0.14 large (Richardson, 2011).

Results

Table 1 shows that the goalkeepers were the tallest among all outfield positions compared to the other groups (185.42 ± 2.20 cm, $p=0.00$). Furthermore, the forwards demonstrated greater body mass (76.20 ± 9.85 kg) compared to the defenders (63.77 ± 6.92 kg), the midfielders (63.77 ± 6.92 kg), and the strikers (75.28 ± 12.25 kg), $p = 0.000$. Nevertheless, there were no disparities in BMI and age among all outfield positions, as indicated by p-values of 0.263 and 0.203, respectively.

Table 1

Anthropometric characteristics of the football players based on their playing positions

Parameters	Players	Mean	Std. Deviation	95% confidence interval for mean		p-value	eta-square (η^2)
				Lower Bound	Upper Bound		
Height (cm)	GK	185.42	2.20	182.69	188.15	0.000*	0.523
	D	182.48	4.12	179.86	185.09		
	MD	174.89	5.03	172.53	177.24		
	F	184.00	3.69	180.13	187.87		
Weight (kg)	GK	76.20	9.85	63.97	88.43	0.000*	0.373
	D	73.70	4.73	70.70	76.70		
	MD	63.77	6.92	60.54	67.01		
	F	75.28	12.25	63.43	89.14		
BMI (kg/m ²)	GK	22.17	2.89	18.59	25.75	0.263	0.096
	D	22.14	1.19	21.39	22.89		
	MD	20.85	2.15	19.85	21.86		
	F	22.54	3.64	18.72	26.35		
Age (years)	GK	16.40	1.14	14.98	17.82	0.203	0.110
	D	16.33	1.61	15.31	17.36		
	MD	15.45	1.19	14.89	16.01		
	F	15.50	1.05	14.40	16.60		

Abbreviation: BMI = Body Mass Index, GK (Goal Keeper), D (Defender), MD (Midfielder), F (Forward).

Notes: * Significant difference among the players' positions ($p < 0.05$)

Table 2 exhibits a significant comparison of anaerobic peak power production based on the subjects' playing positions ($p=0.018$, $\eta^2=0.226$). However, cadence peak and time to peak did not differ significantly among the groups. The post hoc Dunn test demonstrated considerable disparities in peak power characteristics between the forwards and the midfielders ($p=0.011$). However, no distinctions were observed among the other groups regarding peak power output. Moreover, Table 2

indicates no statistically significant differences in jump height, flight time, and peak force in vertical jump performance among the players in different positions.

Table 2

The six-second peak power output and explosive strength of lower limbs determined by a counter-movement jump in young football players

6s cycling sprint	Position	Mean	Std. Deviation	95% confidence interval for mean		p-value	Eta-square (η^2)
				Lower Bound	Upper Bound		
PPO (W)	GK	855	46.24	797.57	912.42	0.003*	0.226
	D	816.75	109.65	747.08	886.41		
	MD	690.54	198.97	597.42	783.66		
	F	885.83	77.18	804.82	966.83		
CP(Rpm)	GK	151.6	14.94	133.04	170.15	0.904	0.009
	D	150.91	10.16	144.45	157.37		
	MD	152.55	14.54	145.74	159.35		
	F	154.83	14.51	139.6	170.06		
TP(s)	GK	1.59	0.99	0.35	2.83	0.782	0.053
	D	1.34	0.65	0.93	1.76		
	MD	1.33	0.6	1.05	1.61		
	F	1.78	1	0.72	2.84		
Vertical jump	Position	Mean	Std. Deviation	95% confidence interval for mean		P value	Eta-square(η^2)
				Lower Bound	Upper Bound		
JH (cm)	GK	42.84	2.56	39.66	46.02	0.316	0.055
	D	40.27	5.19	36.97	43.56		
	MD	39.37	5.98	36.57	42.17		
	F	38.63	2.81	35.68	41.58		
TF (s)	GK	0.59	0.02	0.57	0.61	0.272	0.070
	D	0.57	0.04	0.55	0.6		
	MD	0.57	0.04	0.55	0.59		
	F	0.56	0.02	0.53	0.58		
PF (N)	GK	1850.14	222.01	1574.48	2125.8	0.111	0.175
	D	1824.36	270.82	1652.29	1996.43		
	MD	1571.48	270.38	1444.93	1698.02		
	F	1819.3	439.45	1358.12	2280.48		

Abbreviation: PPO (Peak power output), CP (cadence peak), TP (Time to peak), W (watt), Rpm (Revolution per minutes, JH (Jump height), TF (Time flight), PF (Peak force), cm (centimeters), s (Seconds), N (Newton). Notes: * Significant difference among the players' positions ($p < 0.05$)

Table 3 shows that a minor difference was observed in the average medial-lateral speed parameter (AMLS) between the nondominant leg ($p=0.025$, $\eta^2=0.211$) and the dominant leg ($p=0.033$, $\eta^2=0.198$) based on the players' positions. In addition, Dunn's posthoc test identified disparities between the goalkeepers and the forwards in their non-dominant leg ($p=0.022$) and dominant average medial-lateral speed ($p=0.040$). However, characteristics of static balance: a center of body pressure deviations ellipse area (EA), perimeter (P), and average Anterior – Posterior speed (AAPS) exhibited no significant differences among the players across playing positions. No statistical significance was identified in assessing the dynamic balance of the young football players in unipedal stances based on their positions.

Table 3

Static and dynamic balance characteristics in unipedal stance among the groups of football players

Static Balance	Position	Mean	Std. Deviation	95% confidence interval for mean		P value	Eta-square (η^2)
				Lower Bound	Upper Bound		
EA (mm ²) ND	GK	860.4	214.96	593.49	1127.3	0.324	0.109
	D	743.22	320.5	539.58	946.85		
	MD	847.02	401.06	659.32	1034.72		
	F	1172.82	593.81	549.65	1795.99		
EA (mm ²) D	GK	985.62	331.99	573.4	1397.84	0.456	0.042
	D	823.11	221.02	682.68	963.53		
	MD	896.3	432.26	694	1098.6		
	F	1034.64	254.33	767.73	1301.54		
P (mm) ND	GK	1215.62	190.36	979.26	1451.99	0.171	0.171
	D	1476.71	369.31	1242.06	1711.35		
	MD	1596.23	520.65	1352.56	1839.91		
	F	2036.29	793.06	1204.02	2868.56		
P (mm) D	GK	1369.26	235.62	1076.7	1661.82	0.423	0.089
	D	1639.68	509.22	1316.14	1963.22		
	MD	1584.23	454.16	1371.68	1796.78		
	F	1923.35	666.94	1223.44	2623.26		
AAPS (mm/s) ND	GK	24.18	3.24	20.16	28.2	0.406	0.09
	D	29.33	8.06	24.21	34.45		
	MD	31.89	11.9	26.33	37.46		
	F	36.87	17.25	18.76	54.98		
AAPS (mm/s) D	GK	26.24	5.34	19.61	32.87	0.307	0.102
	D	32.34	9.25	26.46	38.22		
	MD	29.46	9.46	25.03	33.88		
	F	37.32	13.7	22.94	51.69		

Table 3
Static and dynamic balance characteristics (cont.)

Static Balance	Position	Mean	Std. Deviation	95% confidence interval for mean		P value	Eta-square (η^2)
				Lower Bound	Upper Bound		
AMLS (mm/s) ND	GK	27.29	5.34	20.66	33.92	0.025*	0.211
	D	32.94	9.05	27.19	38.69		
	MD	35.43	10.65	30.44	40.41		
	F	47.21	17.02	29.34	65.08		
AMLS (mm/s) D	GK	31.37	5.94	23.99	38.75	0.033*	0.198
	D	36.77	13.11	28.44	45.1		
	MD	36.77	9.97	32.11	41.44		
	F	52.29	20.5	30.78	73.81		
Dynamic Balance	Position	Mean	Std. Deviation	95% confidence interval for mean		p value	Eta-square (η^2)
				Lower Bound	Upper Bound		
TSI (°) ND	GK	2.57	0.87	1.5	3.65	0.571	0.047
	D	2.18	0.73	1.72	2.64		
	MD	2.33	0.83	1.94	2.72		
	F	2.67	0.66	1.98	3.36		
TSI (°) D	GK	2.7	1.25	1.14	4.25	0.619	0.027
	D	2.37	1.01	1.73	3.01		
	MD	2.23	0.91	1.81	2.66		
	F	2.4	0.43	1.95	2.85		
TTD (°) ND	GK	2.01	0.8	1.02	3.01	0.168	0.12
	D	3.43	2.61	1.77	5.09		
	MD	2.31	1.35	1.68	2.94		
	F	3.86	2.47	1.27	6.45		
TTD(°) D	GK	3.29	2.53	0.15	6.43	0.483	0.06
	D	3.03	2.43	1.49	4.57		
	MD	2.28	1.85	1.41	3.14		
	F	3.62	2.04	1.48	5.76		

Abbreviation: EA (Ellipse area), P (Perimeter), AAPS (Average Anterior – Posterior speed), AMLS (Average Medial – Lateral speed), TSI (Total Stability Index), TTD (Trunk Total Deviation), (°) (Degree). ND (Nondominant leg), D (Dominant leg)

Notes: *. Significant difference among the players' positions ($p < 0.05$)

Discussion

The study purposed to compare peak power output, explosive strength of the lower limb, and balance performance across football player positions. Prior research has emphasized variations in anthropometric characteristics among football players depending on their specific positions (Slimani & Nikolaidis, 2019; Towilson et al., 2017). Our data research indicated that the goalkeepers had the highest average height and body mass in comparison to other groups' positions (AlTaweel et al., 2022; Bujnovsky et al., 2019; Leão et al., 2019). Nevertheless, the adolescent football players presented significant differences in body composition and physique compared to adult players. Effect size revealed that age and body mass index had a small effect on alactic anaerobic profile for all groups, confirming no significant differences among football players in all positions (Nikolaidis et al., 2014; Nikolaidis et al., 2021).

The peak power output was based on the maximum force value and its rate of production, which were influenced by the growth and maturation of adolescent athletes (Armstrong et al., 2001; Bar-Or & Rowland, 2004; Nobari et al., 2023). Our findings revealed that the forwards exhibited the highest, but the midfielders had the lowest peak power production (AlTaweel et al., 2022). The forwards and the midfielders demonstrated a difference in large effect size. Former studies have argued about the highest peak power between defenders and goalkeepers (AlTaweel et al., 2022; Joo & Seo, 2016; Nikolaïdis, 2014), but the midfielders had the lowest peak power output.

Vertical jump tests were commonly used to assess athletes' lower body explosive strength by measuring jump height and mechanical power (Hübner et al., 2013). The study reported no statistically significant differences in jump height, flight time, or peak force among different players' positions. These results consistently agreed with previous studies on elite Slovak football players (Pivovarnicek et al., 2015), national collegiate athletic association (NCAA) (Harry et al., 2018), and young football players in five groups (Silva et al., 2022). Our findings indicated a trend in which jump height is a result of force production during vertical jump. In line with this, Miller et al. (2022) found that peak reaction force development is a significant predictor of vertical jump height.

The medial-lateral sway speeds of the nondominant and dominant legs are significantly different across the playing positions, but there was no difference for another variable of static balance. This finding is consistent with earlier research that reported the assessment of static balance based on the body center of pressure (COP) displacement (Teixeira et al., 2013), 95% COP elliptical area, standard deviation (King & Wang, 2017), total path length area, and deviation speed in anterior-posterior/mediolateral directions (Huurnink et al., 2014). Regarding dynamic balance, no significant differences were identified among the

players' positions in TSI and TTD parameters. Previous studies have also found no differences in dynamic balance performance with different platforms of balance tests and sports disciplines (Sinulingga et al., 2024; Ateş, 2019; Cuğ et al., 2016). Balance performance is influenced by environmental and experimental conditions, as well as intrinsic factors. Additionally, balance is organized by individual factors like body somatotype, muscle strength, awareness of body position, and brain hemisphere dominance (Paillard & Noé, 2020).

The study's limitations should be acknowledged. The participation number was limited and the distribution of players across different playing positions was unequal. Full defenders (right and left) and wide midfielders (right and left) should be included to provide a more comprehensive analysis. Nevertheless, the data collected from the individuals provided a valuable insight into the future endeavors of young footballers.

The hypothesis that young players' peak power production, explosive strength of the lower limbs, and balance variations according to their playing position would be smaller in comparison with adult footballers is confirmed. This is possible to explain by a large amount of conditioning exercises in young athletes training sessions which are the same for players of different positions, and with smaller training experience in particular positions.

Conclusion

The study manifested significantly higher peak power output of the six-second peak power test on bicycle ergometer in the forwards than in the midfielders. Static and dynamic balance characteristics did not exhibit differences (with one exception: average medial-lateral speed was significantly lower in the goalkeepers in comparison with the forwards), as well as a countermovement vertical jump based on the group's playing position.

Directions for future research

Considering the age groups, puberty's effects are critical factors characterized by substantial physical and physiological changes, growth spurts, and hormonal fluctuations, needing investigation in future studies. The findings could be useful for coaches and trainers in identifying adolescent football players' strengths and weaknesses, enabling the development of specific training programs for individuals and groups.

Acknowledgments

We express our gratitude to all players and their coaches who took part in our research.

STATEMENT OF ETHICS

The research that pertains to human use has followed all pertinent national regulations and institutional policies, adhered to the principles of the Declaration of Helsinki, and has been approved by the Ethics Committee of the Latvian Academy of Sport Education (Meeting Protocol No. 6, Decision No. 1/51813 of February 24, 2023).

DECLARATION OF CONFLICTING INTERESTS

The authors declared no potential conflicts of interests with respect to the research, authorship, and/or publication of the article *Analysis of peak power output, lower limb explosive strength and balance performance of young football players according to their playing position: A pilot study*.

FUNDING

The authors received no financial support for the research, authorship, and/or publication of the article *Analysis of peak power output, lower limb explosive strength and balance performance of young football players according to their playing position: A pilot study*.

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An assessment of static and dynamic balance effectiveness in one-leg stance of young footballers

original paper

DOI: <https://doi.org/10.5114/hm/186752>

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ABSTRACT

Purpose. Balance allows multidirectional lower limb movements that improve technical football skills and reduce injury caused by match activities. This study aimed to evaluate the static and dynamic balance of preferred and nonpreferred legs during unipedal stance in young footballers and investigate correlations between the two types of balance across each parameter.

Methods. Forty-three youth players (mean age = 15.81 ± 1.33 years, height = 179.50 ± 6.14 cm, body mass = 69.73 ± 9.35 kg) were involved in this study. Static balance was assessed via ellipse area (EA), perimeter length (P), anterior-posterior deviation (APD), medial-lateral deviation (MLD), trunk deviation (TD), average anterior-posterior speed (AAPS), and average medial-lateral speed (AMLS). The total stability index (TSI) and trunk total deviation (TTD) dynamic parameters were also examined.

Results. None of the static balance parameters showed significant differences between standing on the preferred and nonpreferred legs. Similarly, no meaningful distinctions were observed between the preferred and nonpreferred legs in terms of dynamic balance parameters. Overall, static and dynamic balances indicated no correlation, although minor connections were found between parameters: TTD and EA ($r = 0.332$; $p = 0.03$), TTD and MLD ($r = 0.335$; $p = 0.02$), and TTD and TD ($r = 0.423$; $p = 0.01$).

Conclusions. The balance evaluation in young football players should incorporate dynamic and static assessments because the postural control outcomes in these two tasks are independent. Participants underwent testing for both static and dynamic balance, revealing no noticeable differences between their preferred and nonpreferred legs.

Key words: postural stability, unipedal stances, youth footballers

Introduction

Balance refers to the physiological capacity of the human body to maintain the centre of gravity on the base of support [1] to prevent falling. The complex task comprises sensory, central, and motor components that integrate somatosensory, vestibular, and visual inputs to change muscle activity and joint position to maintain the centre of mass inside the support base [2, 3]. Because the human body is unstable, a postural control system must be employed to stand upright. The proficiency of postural balance is affected by morphology,

muscle strength, power, proprioception, and hemisphere laterality [4, 5]. Moreover, other factors, such as anthropometry, age, sex, and activity level, influence the postural control [6, 7]. Maintaining static or dynamic balance is a prerequisite for successful human movement [8] and improves sports performance [9–11]. Static balance pertains to vertically sustaining the centre of gravity in alignment with the support base, with minimal movement [12] or unperturbed environments [13]. In contrast, dynamic balance refers to maintaining or re-establishing equilibrium through rapid and successive position changes [14, 15].

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Received: August 01, 2023

Accepted for publication: April 04, 2024

Citation: Sinulingga AR, Pontaga I, Slaidiņš K. An assessment of static and dynamic balance effectiveness in one-leg stance of young footballers. Hum Mov. 2024;25(2):97–104; doi: <https://doi.org/10.5114/hm/186752>.

HUMAN MOVEMENT

A.R. Sinulingga, I. Pontaga, K. Slaidiņš, Balance performance

Promoting balance is one of the most important aspects of a successful football performance [16], such as duelling opponents, postural control on slick grass, adjustment to the ball's orbit, moving around, and changing direction [17]. Early researchers recognised the significance of balance ability in football for enhancing specific skills, reducing injuries [11, 18, 19] and minimising falls during a match [4, 20]. The preferred leg is used for most techniques in football, ranging from shooting, passing, juggling the ball in the air, dribbling, and receiving the ball [21, 22], while the non-preferred leg is employed for supporting the body weight [23, 24].

Numerous studies across diverse samples have revealed significant differences between the left and right lower extremities in unilateral positions [25], emphasising a bilateral asymmetry in the control of equilibrium across the preferred and non-preferred legs [26]. Some authors declared no difference between the preferred and non-preferred legs, whereas others disagree [5]. In football, the consistency of players' employment of the dominant leg preference often leads to the emergence of bilateral asymmetry [27, 28] as a result of quadriceps muscles being primarily used concentrically in kicks, jumps, and passes in football [29, 30].

Previous research has examined postural balance in football players, including static and dynamic balance performance by playing position [9], balance differences among athletes of various sports [23], and static and dynamic balance in age groups [31]. To the best of our knowledge, there were limited studies evaluating static and dynamic balance that focus on young footballers. Therefore, this study aimed to assess the static and dynamic balance of preferred and nonpreferred legs during unipedal stance in young footballers. The second aim was to investigate correlations between the two types of balance in each parameter. We hypothesised that we should not see any differences in the two legs' capacities for maintaining balance in a single-leg stance. Furthermore, there was no connection among variables related to static and dynamic balance.

Materials and methods

Study design and participants

This study employed a cross-sectional design. All participants were thoroughly informed about the methods and provided written informed consent before participation. Consent was obtained from the coaches and parents on behalf of the adolescent participants. Data collection was conducted in Latvia on March 2023, at the onset of the beginning of the season. Forty-three

young male football players from different football clubs in Riga city, who had regular training and competition timetables, were selected. These players had a mean age = 15.81 ± 1.33 years, height = 179.50 ± 6.14 cm, body mass = 69.79 ± 9.35 kg, body mass index = 21.59 ± 2.39 kg/m², training experience = 9.48 ± 2.48 years, and completed an average of 8.4 ± 2.1 hours of training per week. The reported training hours and experiences reflect the participant's regular training sessions pertinent to physical changes and physiological adaptations. Moreover, focusing on chronological and biological age was essential for functional performance assessment, especially when evaluating preferred or nonpreferred leg usage in young footballers.

Inclusion criteria for the young football players were: (1) age from 14 to 16 years; (2) participants perform balance exercises during the training season to integrate the training models with the specific demands of football games, such as (a) Squats on one/both legs standing on a BOSU ball; 4×10 , time recovery 30 s; (b) Multidirectional leg swinging while standing on one foot on a BOSU ball; 4×10 per limb, time recovery 30 s. The type of balance training model aligns with the specific qualities and demands of the football game. The critical training components focused on improving the lower limbs' coordination, strength, and stability by combining other training programs. Players who experienced painful legs during the investigation had lower extremity or back injuries, had previous surgery in the year before the study, had vestibular disorders, had treatment for the inner ear, or had a concussion within three months preceding the study start were excluded after direct inquiry.

Assessment procedures

Before undergoing postural balance tests, players identified their preferred and non-preferred lower limbs using the 'Waterloo Footedness Questionnaire-Revised' (WFQ-R) [32]. Participants were warmed up for 10 min by cycling on a cycle ergometer (Wattbike Pro Ltd, Nottingham, UK) at 55–65 revolutions per minute and performing static and dynamic stretches for their lower extremities and core muscles. To assess the anthropometric characteristics of the adolescent football players, we used a SECA 220 stadiometer (SECA Deutschland, Hamburg, Germany) to measure the height with a precision of up to 1 mm, and SECA 874 scale (SECA Deutschland, Hamburg, Germany) for body mass measurement with a precision of up to 0.05 kg.

To evaluate static and dynamic balance, we used a ProKin 252 stabilometric platform (TecnoBody, Dal-

HUMAN MOVEMENT

A.R. Sinulingga, I. Pontaga, K. Slaidiņš, Balance performance



Figure 1. Static and dynamic balance assessment

mine, Italy). The trunk sensors were attached to the chest in the middle of the sternal bone. The longitudinal axis of the foot was determined by establishing a tangent line connecting the midpoint of the middle toe with the central point of the heel. The supporting leg produced a knee flexion of 30° , while the contralateral leg demonstrated a knee angle of 45° in a bent position [33]. The participants' hands were set on their hips and instructed to direct their attention toward a screen in front of them (see Figure 1).

The participant performed three practice trials of standing on each leg before formal testing to decrease the learning effect on the measurements. The trial sessions were completed on days 1 and 2, with at least a 30-minute break between balance tests. The formal test was conducted on days 3 and 4, with a time lag of

48 hours after the trial. Based on previous test protocols [34, 35], two trials were performed, one on each lower extremity with eyes open for a 30-s test duration. If subjects failed to complete the 30 s without error, they were given one additional trial to complete the test. In this study, all players succeeded in the first trial, and the best score was used for analysis. Regarding data acquisition, after the subject conducted the test, the results of both the right and left legs were displayed on the Prokin 252's screen (see Figure 2 A, B). The investigator then saved and captured the test results using a camera phone to ensure no data was lost. In addition, this study provides a form for collecting the results of the static and dynamic balance tests.

Static balance test

Players were instructed to maintain a balanced one-leg stance, looking straight ahead at a screen for 30 s with their eyes open and focusing on a stationary target. When these measures were done, the device presented data of the parameters: ellipse area (EA) of the body centre of gravity movements, perimeter (P) of the centre of gravity, distances of sway in the anterior-posterior deviation (APD), medial-lateral deviation (MLD), and trunk deviation (TD), average anterior-posterior sway speed (AAPS), and average medial-lateral sway speed (AMLS). The total length of the circumference of the disorganised lines of the centre of gravity sway was used to determine the player's body sway area's perimeter (P). Shorter perimeter lengths (P) indicate better postural balance [36]. Furthermore, the area of the body's centre of gravity sways (ellipse area) was an established elliptical form that covered at least 90 or 95 percent of the chaotic sway lines. Balance performance is better with smaller ellipse areas (EA) [37].

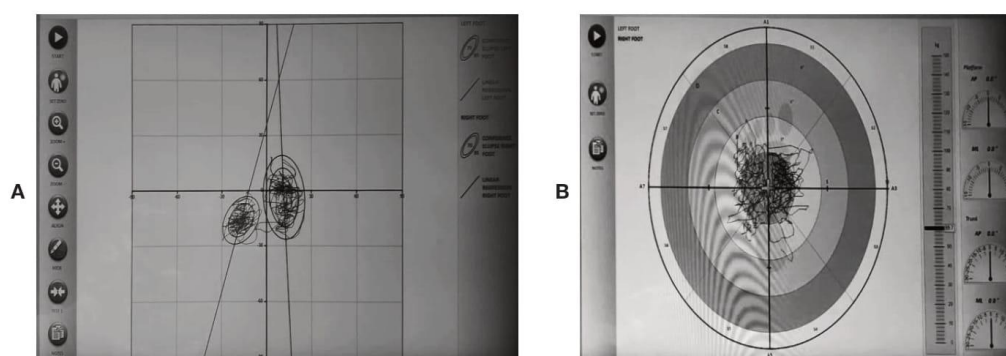


Figure 2. Sample of the results of (A) the static balance test and (B) the dynamic balance test on the unipedal stance with a duration 30 s

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Dynamic balance test

The dynamic balance test is the system's movable dynamic balance platform that uses air piston servo motors to measure the body's centre of gravity sways in unstable conditions in all directions at 15°. The participant had to maintain balance in a one-leg stance on the platform with their preferred or non-preferred leg while their hands were on their hips and their eyes were open. The subject was tested with a single-leg stance on an unstable surface for 30 s on each leg. After these tests, the device displayed the parameters of total stability index (TSI) and trunk total standard deviation (TTD). The TSI value of 0–0.83 was categorised as the norm for athletes, while the norm for healthy participants was 0.84–2.32, and poor postural control if it exceeded 2.33. Trunk position sense was worse if its value was higher [38].

Statistical analysis

The statistical examinations were conducted using the SPSS 26.0 for Windows software program (SPSS Inc., Chicago, IL, USA), with a significance level of $p < 0.05$. The mean values and standard deviations for each characteristic were calculated. The Shapiro–Wilk and Levene tests assessed the equality of error variances, with a significance level of $p > 0.05$. However, only the MLD parameter had a normal distribution, while the EA, P, APD, TD, AAPS, AMLS, TSI, and TTD parameters revealed no normal distribution. Therefore, the Mann–Whitney (non-parametric) test was used to compare the footballers' static and dynamic balance abilities on the preferred and non-preferred legs. Furthermore,

effect sizes (ES) from the Mann–Whitney comparisons were evaluated using partial eta-squared (η_p^2). Small, medium, and large ES were defined as 0.01, 0.06, and 0.14, respectively [39]. On the other hand, Spearman's correlation rho was used to assess the relationship between static and dynamic balance parameters.

Results

The results of the WFQ-R questionnaire revealed that 39 of the football players used their right leg as the dominant, while 4 players used their left leg as dominant. The data in Table 1 was obtained from the best value of each parameter during 30 s of preferred and non-preferred leg stances with the eyes open. Static balance of the preferred and non-preferred leg for the parameters EA ($Z = -0.816$, $p = 0.414$, $\eta_p^2 = 0.004$), PA ($Z = -0.428$, $p = 0.669$, $\eta_p^2 = 0.002$), APD ($Z = -0.350$, $p = 0.726$, $\eta_p^2 = 0.001$), MLD ($Z = -0.890$, $p = 0.437$, $\eta_p^2 = 0.013$), TD ($Z = -0.808$, $p = 0.419$, $\eta_p^2 = 0.017$), AAPS ($Z = -0.229$, $p = 0.819$, $\eta_p^2 = 0.000$), and AMLS ($Z = -0.967$, $p = 0.333$, $\eta_p^2 = 0.013$) showed no statistically significant differences at $p > 0.05$.

In the same way, the dynamic balance results revealed no significant differences between the preferred and non-preferred leg for the parameters: TSI ($Z = -0.337$, $p = 0.736$, $\eta_p^2 = 0.000$) and TTD ($Z = -0.268$, $p = 0.789$, $\eta_p^2 = 0.001$) at $p > 0.005$.

Data Table 2 was obtained from each parameter's average preferred and non-preferred leg during 30 s with the open eyes. Although small positive statistically significant correlations were determined between TTD and EA ($r = 0.332$; $p = 0.03$), TTD and MLD ($r = 0.335$; $p = 0.02$), and TTD and TD ($r = 0.423$; $p = 0.005$), in

Table 1. Static and dynamic balance value

	Non-preferred (means $\pm$ SD)	Preferred (means $\pm$ SD)	Z	p-value	Partial eta-squared
Static balance					
EA (mm ²)	858.09 $\pm$ 383.88	905.56 $\pm$ 347.33	-0.816	0.414	0.004
PA (mm)	1580.02 $\pm$ 534.23	1622.02 $\pm$ 490.72	-0.428	0.669	0.002
APD (mm)	8.46 $\pm$ 2.83	8.58 $\pm$ 2.50	-0.350	0.726	0.001
MLD (mm)	5.39 $\pm$ 1.15	5.64 $\pm$ 1.02	-0.890	0.437	0.013
TD (°)	1.93 $\pm$ 0.90	1.72 $\pm$ 0.73	-0.808	0.419	0.017
AAPS (mm/s)	30.97 $\pm$ 11.36	30.98 $\pm$ 9.89	-0.229	0.819	–
AMLS (mm/s)	35.43 $\pm$ 11.81	38.31 $\pm$ 13.36	-0.967	0.333	0.013
Dynamic balance					
TSI (°)	2.35 $\pm$ 0.78	2.35 $\pm$ 0.90	-0.337	0.736	–
TTD (°)	2.72 $\pm$ 1.97	2.87 $\pm$ 2.09	-0.268	0.789	0.001

EA – ellipse area, PA – perimeter, APD – anterior-posterior deviation, MLD – medial lateral deviation, TD – trunk deviation, AAPS – average anterior-posterior speed, AMLS – average medial-lateral speed, TSI – total stability index, TTD – trunk total deviation

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Table 2. Correlation between dynamic and static balance parameters

	EA (mm ²)	PA (mm)	APD (mm)	MLD (mm)	TD (°)	AAPS (mm/s)	AMLS (mm/s)
TSI (°)	0.136	-0.062	0.147	0.101	0.161	-0.006	-0.032
	0.386	0.693	0.345	0.518	0.301	0.969	0.837
TTD (°)	0.332*	0.045	0.267	0.335*	0.423**	0.092	0.043
	0.03	0.773	0.083	0.028	0.005	0.557	0.784

EA – ellipse area, PA – perimeter, APD – anterior-posterior deviation, MLD – medial lateral deviation, TD – trunk deviation, AAPS – average anterior-posterior speed, AMLS – average medial-lateral speed, TSI – total stability index, TTD – trunk total deviation

* indicates $p < 0.05$, ** indicates $p < 0.01$

general, no statistically meaningful correlation was determined between static and dynamic balance for the parameters: TSI and EA ($r = 0.13$; $p = 0.38$), TSI and PA ($r = -0.06$; $p = 0.69$), TSI and APD ($r = 0.14$; $p = 0.34$), TSI and MLD ($r = 0.10$; $p = 0.51$), TSI and TD ($r = 0.16$; $p = 0.30$), TSI and AAPS ($r = -0.00$; $p = 0.96$), TSI and AMLS ($r = -0.03$; $p = 0.83$), TTD and PA ($r = 0.04$; $p = 0.77$), TTD and APD ($r = 0.26$; $p = 0.08$), TTD and AAPS ($r = 0.09$; $p = 0.55$), TTD and AMLS ($r = 0.04$; $p = 0.78$).

Discussion

This research aimed to investigate the differences in static and dynamic balance characteristics between the preferred and non-preferred legs of young football players. The most important discovery made by this research was that the preferred and non-preferred legs did not significantly contrast in terms of static and dynamic postural balance assessment. The second objective was to investigate the associations between static and dynamic balance parameters. As a result, no statistically meaningful correlation was identified between the two balance characteristics.

Static balance was assessed using a test where the participants were required to maintain a one-leg stance for thirty seconds with their eyes open. Interestingly, no noticeable distinctions were seen between the preferred and non-preferred leg in terms of primary parameters of static balance, namely the ellipse area/sway area (mm²) and perimeter/sway path lengths (mm). Other parameters, such as trunk deviation, anterior-posterior/mediolateral deviation, and anterior-posterior/mediolateral average speed, did not affect the preferred or non-preferred leg. In prior studies on the lower extremities, the static postural stability on one leg was assessed by measuring a specific area from the centre of pressure (COP) deviations. However, the COP-based parameters, such as sway area [40], COP excursion [41], 95% COP elliptical area, standard deviation [42], total path

length area [40] and velocity anterior-posterior/mediolateral [43], did not confirm the existence of a preferred leg effect.

The dynamic balance test measures the subject's capacity to respond effectively to the base of support displacements or external mechanical stimuli [14]. This experiment's findings indicated no statistically significant differences between the preferred and non-preferred legs in terms of the total stability index and trunk deviation parameters. Other studies found no differences in laterality among football players during a 60-second one-legged balance test and in earlier studies investigating dynamic balance across different sports [44–46].

Football players frequently favour their preferred leg for kicking and passing manoeuvres. Nonetheless, it was critical to recognise that, during regular training sessions, players face numerous situations where they must utilise both legs equally [47]. Furthermore, football coaches and trainers focus on technical and neuromuscular aspects to improve balance throughout puberty. The staff also considers designing a variety of exercises to remediate any imbalance and monitoring strength development to achieve high-level performance, physiological adaptation to level competition, and injury prevention of the lower limbs. Atkins [48] reported a 'trigger point' in early adolescence, where noticeable bilateral imbalances emerge. However, these differences tend to decrease as individuals progress through later adolescence.

The static and dynamic balance characteristics were attributed to similar structures, such as the cerebral cortex, basal ganglia, cerebellum, brainstem, and spinal cord. However, the lack of significance in the relationships may be attributed to the different roles these variables play under single- or dual-task conditions [49]. This study discovered no significant evidence supporting the correlation between static and dynamic balance. However, minor exceptions were observed regarding the relationships between TTD to EA, TTD to MLD,

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and TTD to TD. In line with the findings of Pau et al. [31], no significant associations were observed between the static and dynamic balance parameters, except for the relationship between vertical time to stabilisation and centre of pressure displacements in the anteroposterior direction. Several previous investigations on staff and students with no history of musculoskeletal disorders [50] and healthy adults [51] found no relationship among the parameters of both balances. It is essential to highlight that both types of balance tests propose distinct information that contributes to the comprehensive evaluation of young football players.

Assessment of the two types of balance performance can provide valuable insight into maintaining mobility and stability through the kinetic chain. Static balance tests are manageable, but poor static balance represents a risk factor for lower limb injuries. As in Pau's study [31], players may only partially represent their abilities to recover and maintain balance after a dynamic task, as is commonly experienced during training or competitions. Thus, these findings suggest that young footballers should have static and dynamic balance ability to improve their technique and mobilisation. The design of intervention training programs should prioritise the development of postural control among young players to enhance their careers in the future.

This study had some drawbacks that need to be acknowledged. First, the stages of puberty for young male footballers aged 14–16 years were not assessed, which is very important for understanding physiological development, improving physical performance, and preventing injury. Next, control groups (age, sex, untrained subjects or subjects with other sports specialties) were not included, which influences the value of the balance test. And finally, there was no training intervention that could modify the athlete strategies during the control of static postural balance in different sensory conditions. Future studies should include balanced training interventions and consider the maturity stage of the subjects.

Conclusions

Understanding the importance of maintaining postural control on the preferred leg is prominent for young football players' physical performance, skill development, and injury prevention. In investigating young footballers' static and dynamic balance, a notable lack of disparity was revealed between the performance of their preferred and non-preferred legs. The balance evaluation in adolescent football players should incorporate dynamic and static assessments, although out-

comes in these two tasks are independent. Investigating kinematics and muscular activation could provide insights into how young players enhance their balance and whether postural control ability can be conditioned over the training season.

Acknowledgements

We thank all the young football players who participated in this study, as well as their coaches.

Ethical approval

The research related to human use has complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the Ethics Committee of the Latvian Academy of Sport Education (approval No.: 1/51813, date of approval: February 24th, 2023).

Informed consent

Informed consent has been obtained from the parents of all participants included in this study.

Conflict of interest

The authors state no conflict of interest.

Disclosure statement

No author has any financial interest or received any financial benefit from this research.

Funding

This research received no external funding.

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A Review of the Effect of Resistance Exercise on Development of Anaerobic and Balance Performance in Adolescent Footballers

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ARTICLE INFO

Article history

Received: August 15 2024

Revised: September 12 2024

Accepted: October 20 2024

Published: October 30 2024

Volume: 12 Issue: 4

Conflicts of interest: No conflicts of interest in the manuscript.

Funding: This research received no external funding

ABSTRACT

Background: The resistance exercises underpin the strength and power development of muscle activation in adolescent footballers. **Objective:** The study purposed to review the effectiveness of different resistance exercise models on improving anaerobic and balance characteristics among young football players. **Methods:** A systematic search of Scopus, SPORT Discus, and the Web of Science was undertaken to identify the study content using a combination of searches related to resistance exercise, balance, and anaerobic performance. Titles and abstracts were used to search for keywords, and data were extracted using the subject characteristics, training intervention, measurement, and outcomes. **Results:** Fourteen studies were identified that investigated the effects of resistance programs on the anaerobic and balance characteristics. A combination of plyometric and regular football training significantly improved the anaerobic characteristics, and balance performance in young footballers. Based on high-quality evidence, anaerobic and balance performance enhancement appears after conducting resistance exercises for approximately eight weeks, with two to three sessions on alternate days a week. The volume consists of 2-3 sets per exercise, 6-12 repetitions per set, and intensity was classified as moderate to high, with one repetition maximum. **Conclusion:** Integrating resistance exercise into the regular training sessions improves the anaerobic performance of young footballers, such as jumping, sprinting, and changing direction, while improving balance ability, indicated by reducing the center of pressure area side-asymmetry and sway speed during unipedal and bipedal leg stance.

Key words: Resistance Exercise, Anaerobic, and Balance Performance, Young Football Players

INTRODUCTION

Resistance exercise has been a priority of attention for improving physical performance and preventing injury in young athletes. Resistance training is defined as a training method that focuses on gradually increasing levels of resistance and using different training types to improve overall health, fitness, and athletic performance (Faigenbaum et al., 2009; Harries et al., 2012; Lloyd et al., 2014; Zwolski et al., 2017). Moreover, resistance exercise intervention is related to changing teenagers' body composition, physical fitness, and lifestyle behavior (Duarte Junior et al., 2024). The effectiveness of various resistance exercises, levels of resistance, numbers of sets and repetition, and the interval between sets of work (González-Badillo et al., 2015; Naclerio et al., 2013) have proved to enhance and maintain the physical and physiological adaptation of adolescent athletes (Harries et al., 2012).

Implementing resistance exercise into regular training can considerably affect the physical demands of football

players (Fernández-Galván et al., 2022; Nuñez et al., 2022). For instance, a combination of resistance exercises enhanced muscle strength in various jumps and sprints (linear or changing direction) for young footballers (Otero-Esquina et al., 2017; Zghal et al., 2019). Furthermore, several training methodologies have been employed to improve body composition (Suarez-Arrones et al., 2019), vertical jump, and sprinting abilities by using a combination of plyometric (Falces-Prieto et al., 2021), jumping, sprinting, and peak power in power training (Loturco et al., 2020), and electrostimulation to improve jumping and kicking skills (Billot et al., 2010).

As mentioned above, consistent scientific studies have revealed that resistance exercise positively impacts adolescent athletes' muscular power and motor skill performance. Developing muscular strength to enhance anaerobic performance (Nikolaidis et al., 2018) and postural balance (Steinberg et al., 2016) is crucial throughout the puberty

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<http://dx.doi.org/10.7575/aiac.ijkss.v.12n.4p.8>

phase. Nobari et al. (2021) raised attention to the evidence that anaerobic profiles might substantially impact the performance of elite young football players. Football matches require the performance of anaerobic characteristics like sprints, jumps, and cutting maneuvers (Evangelos et al., 2016). Anaerobic capacity and power play a crucial role, where high-intensity action occurs 150 to 250 times throughout a match (AlTaweel et al., 2022; Bangsbo et al., 2007).

Along with anaerobic characteristics, balance is important for successful actions and technique in a football match (Butler et al., 2012). Balance performance is needed for duels with opponents, maintaining balance on a slippery field, adjusting to the ball's trajectory, and changing direction (Evangelos et al., 2012). Studies by Bishop et al. (2018), Brown et al. (2018), Paillard (2017), and Zemková and Zapletalová (2022) have shown that football players who can maintain their balance on the field are better in their match performance, minimizing injuries and falling during games. The strong correlation between anaerobic parameters and balance performance (Cinarli et al., 2022; Falces-Prieto et al., 2022; Lockie et al., 2018; Wilczyński et al., 2021) emphasizes the crucial role of lower limb strength and power. Furthermore, repetitive anaerobic activities can lead to general and localized fatigue, which can subsequently cause disruptions in balance performance (Pau et al., 2014; Steinberg et al., 2016).

The current review (Martinez-Perez & Vaquero-Cristobal, 2021) revealed that resistance training enhances preadolescent and adolescent football players' physical performance. Plyometric training, followed by strength and isoinertial training, has emerged as the predominant type of exercise for football players due to its effectiveness in enhancing their physical development and motor skills. Based on our current understanding, there has yet to be a review of the optimization of anaerobic and balance performance through exercise intervention. Thus, this review aimed to review the resistance exercise model's effectiveness in improving young football players' anaerobic and balance characteristics.

METHODS

Research Design and Ethics

The systematic review was registered on PROSPERO-CRD42024572885 (https://www.crd.york.ac.uk/prosperto/display_record.php?RecordID=572885) and completed following the PRISMA criteria.

Literature Search

The systematic review search of the Scopus, Sport Discus, and WOS databases covered papers published in the last five years. Papers meeting the criteria were considered for inclusion until December 31st, 2023. The search method used by the operators AND OR, along with the following keywords: ("resistance training" OR "strength training" OR "traditional exercise" OR "weight training" OR "ballistic exercise" OR "plyometric training" OR "eccentric training" OR "weight lifting" OR "Olympic exercise" AND ("Static balance" OR

"Dynamic Balance" OR "Balance "star excursion" OR "Y-balance test" OR "Romberg test" OR "single-leg stance" OR "limits of stability" OR "postural stability" OR "timed up and go") AND ("anaerobic power" OR "anaerobic capacity" OR "peak power" OR "sprint test" OR "vertical jump" OR "counter movement jump" OR "squat jump" OR "Wingate test") AND ("football" OR "soccer" OR "young" OR "Adolescent" OR "Children" OR "Youth" OR "Teenager" OR "boys"). The studies were restricted to the full-text original articles written in English.

The references to systematic reviews found in the database were searched manually and carefully. We looked for articles and published randomized, multi-arm-controlled trials in all resistance exercise types and their impact on anaerobic and balance characteristics in young football players. The retrieved literature was imported into Mendeley reference manager 1.19.8 to eliminate duplicates. The two writers (ARS and IP) independently conducted the database search. The authors conducted parallel screenings of authors, year of publication, samples, intervention characteristics, assessment, and outcomes from each paper. If there were any potential differences between the two authors during the search and review process, they were resolved through consensus by presenting an external validator.

Eligibility Criteria

Based on Methley et al. (Methley et al., 2014), the study employed the PICOS tool to establish clear criteria for including and excluding participants. The study focused on young males aged 10 to 19 for the population (P). Studies with neurological or musculoskeletal illnesses such as Parkinson's disease, multiple sclerosis, osteoarthritis, or persistent pain were excluded based on specific criteria. Intervention (I) criteria included an experimental group engaged in resistance exercise, while studies without RE interventions were excluded. Comparator (C) was an active control group, where one experimental group and the other performed regular training. The outcome (O) was testing balance and anaerobic characteristics. Lack of baseline and follow-up data before and after intervention was excluded. The study design (S) was multi-arms trials and randomized control trials. The systematic review, cohort study, cross-section, and case-control study were all eliminated.

The current systematic review evaluated only complete original articles that contained full text. References from books, chapters, and abstracts at the conference were excluded. Furthermore, cross-sectional studies and RE programs that deal with athlete physical performance, psychological intervention, a general sample, and injury prevention and rehabilitation, were excluded.

Quality Assessment

This review used the Physiotherapy Evidence Database (PEDro) scale to analyze each article. A '+' score signifies the fulfillment of the PEDro scale criteria, whereas a '-' score indicates non-fulfillment. The PEDro scales of 0-3, 4-5, 6-8, and 9-10 indicate poor, moderate, good, and excellent,

respectively (Morton de, 2009; Maher et al., 2003; Yamato et al., 2017). Details of PEDro scoring items are shown in Table 1.

Data Analysis and Synthesis

The studies included in the review were sourced from restricted subjects (only adolescents of football players), applying different resistance exercise interventions, and employing a range of various dosages of training that might affect the outcome. The strength of the evidence was assessed using the best evidence synthesis method (Burns et al., 2011; Yu et al., 2023). Quantity of studies, method quality, and consistency of findings throughout all evidence were assessed. 1) substantial evidence from more than two high-quality studies with consistent significant results; 2) intermediate evidence using one high-quality research and several low-quality trials with consistent results; 3) limited evidence if only one study was available or two contained contradictory outcomes; 4) conflicting evidence when more than two studies had incompatible results; and 5) no evidence when there were no case-control analyses.

RESULTS

Study Selection

The search approach identified a total of 668 studies across three databases. The PRISMA flow employed the study selection approach (Page et al., 2021)(see Figure 1). Following the reduction of duplicate research ($n = 82$), a total of 586 were re-examined. After evaluating the abstract and title, 299 papers were excluded. After thoroughly reading 287 publications, 211 studies were rejected for selected reasons, including the absence of RE intervention. In the end, 14 publications were selected as eligible for inclusion in this systematic review.

Population Characteristics, Puberty Stage, and Maturity Status

The cumulative sample size of the research considered in this analysis was 568 young male adolescent football players. The sample sizes ranged from 6 to 104 participants. The study included participants with an average age of 15.27 ± 0.4 years. The participants' maturity status and puberty stage were not reported in the largest number of studies ($n = 8$ studies). Subjects' biological maturity in pre-peak height velocity (PHV) $n = 1$ study (-0.25 ± 0.3 years from PHV), approaching -peak height velocity $n = 3$ studies (-1.95 ± 0.3 years from PHV), and $n = 2$ studies were late post-peak height velocity (2.5 ± 0.6 years from PHV). Furthermore, a study conducted by Zghal et al. (2019) reported the puberty stage of players (puberty stages 3-4) according to the Tanner method (Beunen et al., 1992), before and after intervention resistance exercise by the same investigator (a medical doctor). The maturity offset was estimated by operating the formula developed by Moore et al. (2015), anthropometry assessment (Mirwald et al., 2002), and the puberty stage was determined by the Tanner method in observing pubic hair growth and genital development (Beunen et al., 1992).

Study Quality Assessment

Table 1 explains how the PEDro scale evaluates the quality of research. Out of the total number of studies, $n=1$ received 5 points on the PEDro scale, indicating moderate quality, while $n=13$ received a score of 6-8 points, a score considered excellent quality. Across the board, the studies met the threshold for minimal risk of bias (mean quality score = 6.85 ± 0.83). The rating score reveals a varied quality of research, with a significant proportion of studies being of high quality. Most of the analyzed trials failed to fulfill the blinding of the subjects, therapists, and assessors. Given this situation, future studies must be performed at a higher quality and evidentiary level.

Table 1. Physiotherapy evidence database (PEDro) scores of reviewed studies

Study	1	2	3	4	5	6	7	8	9	10	11	Total score
(Aloui et al., 2022)	+	+	-	+	-	-	-	+	+	+	+	7
(Muehlbauer et al., 2019)	+	+	-	+	-	-	-	+	-	+	+	6
(Hammami M. et al., 2020)	+	+	+	+	-	-	-	+	-	+	+	7
(Chaalali et al., 2022)	+	+	-	+	-	-	-	+	+	+	+	7
(Zghal et al., 2019)	+	+	+	+	+	-	-	-	-	+	+	7
(Barbalho et al., 2018)	+	+	-	+	-	-	+	+	+	+	+	8
(Jlaid et al., 2019)	+	+	-	+	-	-	-	+	+	+	+	7
(Hammami R. et al., 2023)	+	+	-	+	-	-	-	+	+	+	+	6
(Seong et al., 2022)	+	-	-	+	-	-	-	+	+	-	+	5
(Arslan et al., 2021)	+	+	+	+	-	-	-	+	+	-	+	7
(Aloui et al., 2021)	+	+	-	+	-	-	+	+	+	+	+	8
(Makhlouf et al., 2018)	+	+	-	+	-	-	-	+	+	+	+	7
(Dafkou et al., 2021)	+	+	-	+	-	-	+	+	+	+	+	8
(Gasim et al., 2022)	+	+	-	+	-	-	-	+	+	-	+	6

1. Eligible to participate, 2. Random allocation, 3. Concealed allocation, 4. Group similar at baseline, 5. Blind subject, 6. Blind Therapist, 7. Blind assessor, 8. Dropout<15%, 9. Intention to treat method, 10. Comparison between groups, 11. Point measure and variability

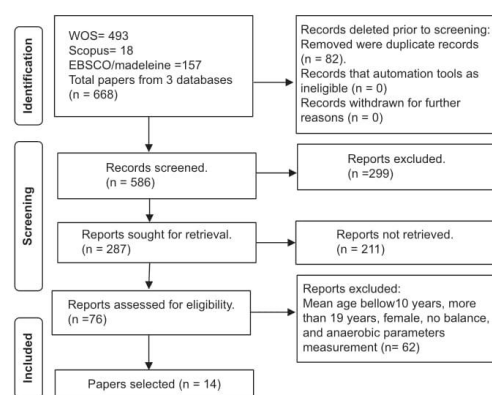


Figure 1. The flowchart is based on the process of searching and selecting studies

The Intervention of Resistance Exercise Characteristics

The study included different resistance exercise models for multiple activities. The variety of jumps in varied heights (20-80 cm) (Jlid et al., 2019), running with resistance (Chaalali et al., 2022), diverse balance exercises (Muehlbauer et al., 2019), weight lifting (Zghal et al., 2019), small-sided games (Arslan et al., 2021), core strength training (Gasim et al., 2022), and change of direction drills (Aloui et al., 2021). All studies indicate that integration into exercise models enhances anaerobic and balance performance among adolescent footballers. Regarding the characteristics of interventions (Table 2), the studies performed the programs from 2 to 15 weeks, with an average (7.71 ± 2.68) weeks. One study had a shorter duration of 2 weeks (Seong et al., 2022), while another had a longer duration of 15 weeks (Barbalho et al., 2018). Resistance exercise programs were conducted 2 or 3 times weekly (2.64 ± 0.97) on alternate days. The volume training consists of 2-3 sets of 6-12 repetitions of each activity, with moderate to high intensity. The type of plyometric training was applied 54-144 ground contacts per session.

Assessment of Anaerobic Performance

The preceding field tests employed to assess anaerobic power in athletes were the vertical jump tests, sprints, and hopping (Çakir-Atabek, 2014; Gross & Lüthy, 2020; Haugen et al., 2013; Nikolaidis, 2011). Furthermore, Bongers et al. (2015) determined that the repeated sprint anaerobic test (RAST) is a valid and non-sophisticated field test for evaluating anaerobic performance in healthy children and adolescents. The studies employ various jump tests (squat jump test, standing long jump test, drop jump test, countermovement jump test, five jump test, single leg hop test, triple leg hop test, and different types of sprint (linear sprint test, change of direction test, sprints backward and forward, repeated shuttle sprint ability) to evaluate anaerobic power and capacity in young football players.

Assessment of Balance Performance

Static and dynamic tests should be provided to evaluate balance, as postural control performance in both is unrelated (Pau et al., 2015). Both types of balance tests independently assess the participants' motor experience-related balance performance situations (Paillard & Noé, 2020). The current study operated the star excursion balance test (SEBT, $n = 1$), the Y-balance test (YBT, $n = 7$) in maximum reach distance from the center of pressure to anterior, posteromedial, and posterolateral to evaluate dynamic balance, and the stork balance test (SBT, $n = 3$) to test static balance ability. Two studies applied a stabilization device (Dafkou et al., 2021; Seong et al., 2022), which provided more valuable information about anterior-posterior, right/left lateral, right/left anterolateral, and right/left posterolateral to evaluate postural balance.

DISCUSSIONS

The primary purpose of this study was to review the literature on the effects of resistance exercise on improving anaerobic and balance performance among adolescent football players. Moreover, this study provided an interpretation of the principles for selecting the most effective exercise based on the quality of evidence. The study review analyzed different resistance exercise models, type of exercise, frequency, resistance levels, number of sets and repetitions per set, and duration of relief between the sets.

The literature reveals that incorporating core strength and plyometric exercises during the off-season, alongside aerobic programs, improved core dynamic balance and reduced asymmetry between legs (Seong et al., 2022). The experimental study combines core strength and small-side game (Arslan et al., 2021), hamstring eccentric and core stability training (Dafkou et al., 2021) that showed growth in lower body strength and balance standing on the non-dominant and dominant leg. Moreover, combining different resistance exercise models and plyometric training (Aloui et al., 2021, 2022; Gasim et al., 2022; Hammami M. et al., 2020; Jlid et al., 2019; Makhoul et al., 2018; Muehlbauer et al., 2019) can improve static and dynamic balance characteristics while minimizing the center of pressure, anterior-posterior, and medial-lateral sway speed. Improvement of static balance was followed by a decreasing score of the sway speed center of pressure (COP) in the non-dominant and dominant leg, advancements in lower extremity muscle co-contraction, and change in proprioception and neuromuscular control. Indeed, balance improvement through the training session could be linked to a more precise contraction of the muscles in the lower extremities (Kim & Chou, 2022) or changes in proprioception and neuromuscular control (Kim & Chou, 2022).

The present study highlights the importance of integrating resistance exercise with regular football training, considering factors such as age group, competitive level, and duration of the training program. The findings showed that implementing resistance exercises for approximately eight weeks significantly improved static and dynamic balance performance. In line with a previous review (Sarabon &

Table 2. Resistance exercise of the studies included

No	Study	Subject	Type RE	Training Intervention	Measurement	Result
1	(Aloui et al., 2022)	IG, n = 17, age: 14.6 ± 0.5 years CG, n = 17, age: 14.6 ± 0.4 years	PT + SPT	8 weeks, 4 sessions x biweekly, ground contacts per session rose steadily from 72 to 144, and the number of sets for each workshop increased from 3 to 6 sets. The training session included various jumps and strides, followed by a short sprint.	SJ, CMJ, 5JT, and LST = 10-30 m, CoD (sprint 90° turns (S90°), SBF = 9-3-6-3-9, RSSA, and YBT	Anaerobic, jumping, dynamic balance, and the ability to change directions and sprint significantly improved from before to after intervention.
2	(Muehlbauer et al., 2019)	IG, N = 10, age: 13.0 ± 0.9 CG, N = 10, age: 13.1 ± 0.1	BT + PT	6 weeks, 4 x per week, 15 to 26 min and including submaximal running, BT (beam walking forward and backward, unipedal stance on perturbation devices, et al), PT (skipping, hip in/out, submaximal multidirectional jumps)	YBT, SJ, CMJ, DJ, LST = 15m (with split time), and T-test	Significant pre to post-improvement in dynamic postural stability, power of lower limb, speed, and agility
3	(Hammami M. et al., 2020)	IG, N = 12, age: 16.2 ± 0.2 years, IG, N = 14, age: 16.3 ± 0.4 years CG, N = 12, age: 16.4 ± 0.2 years	UPT * LPT	10 weeks, 2 x per week, 2-6 repetitions, (sprint, 36-98 unilateral jumps, and 12-36 bilateral jumps. LPT positioned above the ankle joint had a mass of 2.5 percent of the total body weight.	LST = 40 m, CoD = sprint 180° turns (S180°), SBF = 9-3-6-3-9, RSSA = 4 × 5 m sprints, CMJ, SJ, 5JT, YBT and SBT	Significant improvements in sprint, change direction, jump, repeat of changes direction, static and dynamic balance before to after the intervention.
4	(Chaalali et al., 2022)	N = 12, age: 16.6 ± 0.2 years IG, N = 6 CG, N = 6	RST + NRST	6 weeks, 2x per week, 2 sessions, 3 minutes interval set, 3-4 repetitions, sprint 10-30 m, distance cover per set 90-360 m., intensity 100%. (RST) The first stage consists of sprinting half the distance in four seconds before their partner releases the player to complete the second stage.	CMJ, SJ, 5JT, LST = 30 m (5, 10, 20m split times), and analysis of kinematics	Improvement in sprinting, strides frequency, lower-limb explosive force, and jump performance from before to after intervention.
5	(Zghal et al., 2019)	N = 30, age: 14.5 ± 0.52 years IG, N = 13	RT + PT * PT	7 weeks, 2x per week. Leg extension and press (60-80%	CMJ, SJ, DJ, knee extensor (KE) MVIC, LST = 5, 10, 20 m and CoD	Significant pre to post-improvement in peak torque, rate of torque development (RTD), RTD

(Contd...)

Table 2. (Continued)

No	Study	Subject	Type RE	Training Intervention	Measurement	Result
		IG, N = 9 CG, N = 8		1 RM, 2-3 sets x 6-8 rep.), Half squat, vertical hurdle, jump/sprint, stride hurdle (2-4 sets x 6-8 rep)		normalized to torque (RTDr, speed, and jump ability)
6	(Barbalho et al., 2018)	IG, N = 11, age: 19.1 ± 0.9 years CG, N = 12, age: 18.8 ± 0.8 years	RT	15 weeks. 3 x per week, weeks 1, 5, 9, and 13 (12–15 RM with 30–60 s intervals), weeks 2, 6, and 10 and 14, (4–6 RM, 3–4 mins intervals), weeks 3, 7, 11 and 15 (10–12 RM, 1–2 mins interval), weeks 4, 8, and 12 (6–8 RM at 2–3 min intervals). Leg presses at 45 degrees, free squats with a bar, seat leg curls, and calf stands on the machine are some of the lower limb exercises, while the upper limb exercises consist of seat low row, bench press, shoulder press, triceps pulley, and biceps curl, and lateral pull down.	1 RM, LST = 40-yard, T-test, CMJ, SLJ	Significant pre-to post increase in 1 RM, Power lower max (CMJ and SLJ), speed, and agility
7	(Jlilid et al., 2019)	IG, N = 14, age: 11.8 ± 0.4 years CG, N = 14, age: 11.6 ± 0.5 years	MPT	8 weeks, 2 x per week, 20–25 min, 54-124 ground contacts, alternating jumps and jumps with feet together, progressing in volume and intensity over the weeks	SJ, CMJ, T test, CoD, SEBT	Significant improvement in SJ, CMJ, CoD, and dynamic balance from pre to post-test
8	(Hammami R. et al., 2023)	IG, N = 12, age: 15.7 ± 0.6 years CG, N = 12; age: 15.4 ± 0.8 years	NT	8 weeks, 2 x per week, 2-3 sets, 5-10 reps. INT of 5 workouts in rest between sets (60-120s), and exercise (balance, half squat, side lunge with a medical ball 2 kg, plyometrics, CoD. The difficulty and intensity of INT	YBT, 1RM, 5 JT, SLH, CMJ, LST 10 and 30m, CoD with Ball	Dynamic balance, muscle strength, speed and jump performance pre-to post improvement.

(Contd...)

Table 2. (Continued)

No	Study	Subject	Type RE	Training Intervention	Measurement	Result
9	(Seong et al., 2022)	IG, N = 75, age: 14.28 ± 0.98 years CG, N = 104, age: 17.33 ± 0.84 years	RT + Aerobic	were regularly adjusted every two weeks, while the training volume remained consistent. 2 weeks off-season, 5 x per week with 150 mins, core muscle on interval/circuit training (20 repetitions, 3–4 sets, 30 sec), Aerobic (80% 1RM HRmax, 30 seconds, 3–4 sets, 1-minute recovery). Inferior of body functional exercise (step, ladder coordination, jumps, turns, acceleration, and deceleration with rope at 60-70% of 1RM, 20 reps, 3–4 sets, 30 seconds recovery)	CDBT, SLJ, PTT, SLJ, and CoD	Improvement from pre to post in jump, speed, dynamic balance, back extensor, and flexor muscle strength, and reduction of differences between left and right leg
10	(Arslan et al., 2021)	N = 38, age: 16.50 ± 0.51 years IG, N = 20 CG, N = 18	CST + SSG	6-weeks, 3x per week, 3 x 25-50 sec, work relief 1:1, CST (push-up, push-up rotation, bird dog crunch, scissor kick, mountain climbing, full squat), SSGs (2-4 min, number of bouts 4, rest 3 mins.	LST = 5–20m, CMJ, SJ, TLH, ZA with or without ball, TCRT, YBT	Speed, agility, lower limb muscles power and strength, and balance improvement from pre-to post.
11	(Aloui et al., 2021)	IG, N = 18, age: 16.6 ± 0.5 years CG, N = 16, age: 16.6 ± 0.5 years	PT + SCoD	8 weeks, 2x per week, PT + SCoD of 4 workshop x 3 rep each workshop/ week. Ground contacts per session rose steadily from 72 to 144, and the number of sets for each workout increased from 3 to 6 sets.	SJ, CMJ, SLJ, LST = 5m, 20, CoD, RSA, SBT	Improvement from pre to post in jump performance, speed, agility, anaerobic performance, and static balance
12	(Makhlouf et al., 2018)	IG, N = 21, age: 11.29 ± 0.85 years IG, N = 20, age: 11.06 ± 0.75 years CG, N = 16, age: 10.98 ± 0.80 years	PT + BT * Agility + PT	8 weeks. 2x per week. BT (stand on Swiss ball by knee, unilateral and bilateral standing on an inflated disk progressing to squat, etc., 1-2 set/30-45 s or 8-15/ leg, PT (lateral hops, vertical, horizontal,	CMJ, TLH, RSI, MVIC, RSSA, Illinois, CoD, YBT, SBT, LST = 10–30 m	Improvement from pre to post in jump, back extensors, knee extensors muscle strength, agility, speed, static and dynamic balance

(Contd...)

Table 2. (Continued)

No	Study	Subject	Type RE	Training Intervention	Measurement	Result
13	(Dafkou et al., 2021)	IG, N = 11 age: 17.7 ± 1.15 years CG, N = 10 age: 18.1 ± 0.57 years	EBCM	drop, jumps, etc., 1-2 set x 8-15 rep) 8 weeks, 2 x per week, 16 sessions, 2-4 set x 6-10 rep. A hamstring eccentric exercise, 4 core-muscle, 5 single-leg balance variations (4-6 set x 30-45 sec)	Strength tests (3 subs and three maximum concentric and eccentric at 30°/s, 180°/s, and 240°/s), balance test, and bridge test (trunk movement stability)	Significant increase of isokinetic, concentric hamstring strength, reduction in center of pressure sways in a stance on the non-dominant leg.
14	(Gasim et al., 2022)	IG, N = 6, age: 17.2 ± 0.4 years IG, N = 6, age: 17.3 ± 0.5 years CG, N = 6, age: 17.7 ± 0.5 years	PT + CST	8 weeks, 2x per week, PT = 1-2 sets x 6-10 rep (1-4 weeks), 1-2 sets x 8-12 rep. (5 -week), CST = 1-4 sets x 15 reps. or sec (1-4 weeks), 2-4 sets x 15 reps. or sec(5-8 weeks) CST (plank + side, crunch on Pilates ball, back extension on Pilates, hip raise, dog kick (right & left)	YBT	Significant improvement pre to post in anterior and posteromedial directions in the dominant leg, anterior, posteromedial, and posterolateral in the non-dominant leg.

Abbreviation and symbols: IG = Intervention Groups, CG = Control Groups, PT = Plyometric Training, RT = Resistance Training, SPT = Short Sprint Training, BT = Balance Training, UPT = Unloaded Plyometric Training, LPT = Loaded Plyometric Training, RST = Resisted Sprint Training, NRST = No resisted Sprint Training, MPT = Multidirectional Plyometric Training, INT = Integrative Neuromuscular Training, CST = Core Strength Training, SSG = Small-Sided Games, SCoD = Sprint With Change-Of-Direction, EBCM = Eccentric Balance and Core Muscles Exercises, SJ = Squat Jump test, SLJ = Standing Long Jump test, DJ = Drop Jump test, CMJ = Countermovement Jump test, 5JT = 5 jump test, SLH = single leg hop test, TLH = Triple Leg Hop test, LST = Linear Sprint Test, CoD = Change of Direction test, SBF = Sprints Backward And Forward, RSSA = repeated shuttle sprint ability, RSA = Repeat Sprint ability, YBT = Y balance test, SBT = Stork Balance test, SEBT = Star Excursion Balance Test, CDBT = Core dynamic balance test, RSI = Reactive Strength Index, MVIC = Maximal Voluntary Isometric Contraction, 1 RM = one repetition maximum, PTT = Peak Torque Test, ZA = Zigzag Agility Test, TCRT = Three Corner Run Test. Symbol = (+) Combination, (*) Versus

Kozinc, 2020), training interventions to enhance balance ability should be of sufficient duration (at least four weeks) and follow general resistance exercise principles.

Resistance exercise significantly improves strength and power in the lower body of young footballers by integrating with football-specific training. The evaluation of anaerobic performance has been extensively used to assess short-term power action (Cossio-Bolaños et al., 2021; Gross & Lüthy, 2020; Haugen et al., 2013; Ostojić et al., 2010). Anaerobic characteristics in football include explosive actions in various jumps, sprints, changes of movement directions, acceleration, and other short intense actions. The simultaneous use of resistance and plyometric exercises improved strength, sprinting, and jumping performance compared to plyometric alone (Zghal et al., 2019). Unilateral lower limb plyometric training significantly enhanced the strength and power of football players compared to bilateral or football training alone (Drouzas et al., 2020). Combinations of multiple resistance models (Aloui et al., 2022; Arslan et al., 2021), agility and plyometric training (Makhlouf et al., 2018), aerobic

and resistance training (Seong et al., 2022), and resistance and plyometric training (Hammami et al., 2020; Zghal et al., 2019), demonstrated improvements in anaerobic performance, including short explosive force, sprinting, jumping, change of direction, and repeated sprint ability.

A crossbreed of morphological and neural factors supports muscular strength development (Suchomel et al., 2018). Moreover, the baseline of strength (Buckner et al., 2017), the quality of resistance exercise, and genetics (Yang et al., 2003) influence the improvement of anaerobic performance. The relationship between maturity and training-related neuromuscular adaptations remains ambiguous (Silva et al., 2022; Kumar et al., 2021). Growth and maturation significantly affect muscle-tendon and neuromuscular adaptations (Radnor et al., 2018) (Hiort, 2002). However, contrary evidence (Perroni et al., 2024) stated that physical performance might be negatively associated with chronological age, relative age, and pubertal status.

In this review, the combination of resistance exercise models may have the most significant potential to increase

muscular strength and power. Resistance exercise models propose the flexibility to manage loads and intensities within a single training session. The various exercises can provide a new stimulus when training is tedious and needs a new variation and challenge. Through various resistance exercise models, instructors and coaches could present high-load exercises to maintain or increase strength and low-load training to build power and speed. Future research should look into these links, especially the possibility of using integrated resistance exercises to improve anaerobic performance, and static and dynamic balance considering football players' chronological ages and puberty stages.

The review article provides valuable insights into the impact of resistance exercise on anaerobic and balance performance in adolescent football players. However, we need to address some methodological limitations. The selection of studies may be biased due to the exclusion of abstracts, titles, or studies published in non-peer-reviewed journals. The anaerobic and balance of young male players aged 10 to 19 consistently improve with resistance exercise interventions, and these results must be carefully chosen before application to the specific population group.

Strength and Practical Implication

According to the findings of the articles reviewed in the present study, various resistance exercise models positively improve the characteristics of anaerobic and balance in adolescent football players. In addition, the plural type of exercise is plyometric, which has multiple movements such as jumping and sprinting that align well with the demands of football games. Integrating resistance exercise into regular training is more beneficial than stand-alone. Young football players should undergo training intervention for about eight weeks, 2-3 times weekly on developing anaerobic and balance performance. In addition, strength and conditioning coaches should prescribe these, considering specific resistance exercise loads in young football players.

CONCLUSION

Interventions of different resistance exercise models improve young footballers' anaerobic and balance performance, encompassing muscular strength and power development. Incorporating the resistance exercise into routine football training sessions was highly recommended due to safety and efficiency for young football players. Moreover, resistance exercise presents diverse movements and technical advantages that improve other physical demands in football games. Resistance programs took place two or three times each week throughout eight weeks. The volume training consists of 2-3 sets of 6-12 repetitions, with moderate to high intensity. The study provided practical insights for trainers and coaches to enhance anaerobic and balance performance and overall physical fitness in young football players. However, current findings should be considered cautiously due to methodological limitations, high variability in assessing anaerobic and balance parameters, and training dosages among studies.

ACKNOWLEDGMENTS

The article has been published via funding of the project "RSU internal and RSU with LSPA external consolidation", No. 5.2.1.1.i.0/2/24/1/CFLA/005.

DATA AVAILABILITY

The data presented in this study are available on request from the corresponding author.

ETHICAL APPROVAL

Ethical approval was not required because the study is unrelated to humans or animals.

AUTHOR CONTRIBUTIONS

Conceptualization, ARS, and IP. Methodology, ARS, and IP. Software, ARS, Investigation, ARS, and IP. Manuscript writing, ARS, and IP. Visualization, ARS. Supervision, IP. All authors have read and approved the final versions of the manuscripts.

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