A Combined Balance and Plyometric Training Approach: Effects on Physical Performance Parameters in Youth Male Handball Players: A Randomized Controlled Trial

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Abstract

The physical quality of young male handball players is one of the essential factors that influence team performance. Balance and plyometric training refers to the work of muscle groups related to stabilization located at the meeting of the base of the trunk, spine, pelvis and lower extremities of the human bodyThirty male handball players (age: 16.6±0.5 years) were randomly allocated to either an experi-mental group (n=15) performing combined postural control and plyometric training twice weekly in addition to standard handball training, or a control group (n=15) maintaining regular training alone. Pre- and post-intervention assessments included vertical jump performance (squat jump, countermovement jump), horizontal jump ability (standing long jump), linear sprint speed (5m, 20m), change-of-direction capac-ity (modified T-test, Illinois modified test), repeated change-of-direction ability, and postural control (Stork Balance test, Y-Balance test). The experimental group demonstrated significantly greater improvements compared to controls across multi-ple performance domains. Specifically, superior adaptations were observed in the squat jump ($p<0.05$), countermovement jump ($p<0.01$), and standing long jump ($p<0.05$) performance. Sprint capabilities showed enhanced development in both 5m ($p<0.05$) performance. Sprint capabilities showed enhanced development in both 5m ($p<0.05$; $d=0.56$ [moderate]) and 20m ($p<0.05$) times. Change-of-direction ability improved sub-stantially in both single-effort (T-half test: $p<0.01$; Illinois-MT: $p<0.01$; $d=0.85$ [large]) and repeated-effort contexts ($p=0.05$). Dynamic balance measures showed consistent improvements across all planes of movement ($p<0.05$). Conclusion: Implementing combined postural con-trol and plyometric training twice weekly during the competitive season effectively enhanced multiple aspects of physical performance in youth handball players. The moderate to large effect sizes observed across performance measures suggest this training approach represents an effective strategy for developing athletic capabilities in this population.

Keywords: Acceleration, Agility, Exercise Progression, Motor Control, Muscle Power, Neuromuscular Adaptation, Sports Performance.

Introduction

Modern handball competition demands exceptional physical capabilities from athletes, characterized by repeated high-intensity actions including sprints, jumps, directional changes, throwing motions, and physical confrontations during both offensive and defensive play (Mohoric, Abazovic, & Paravlic, 2022). The physiological demands of

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sustaining peak performance throughout 60 minutes of competitive play necessitate well-developed aerobic and anaerobic energy systems, as noted by Mohoric et al. (2022). It is an intermittent sport that involves many physical contacts and duels between opponents and many tactical and technical elements that work to outdo the opponent (Meier, Schreyer, & Jetzke, 2020). The development of the game itself has brought increased physical demands, both from competitions and daily training sessions (Jakšić et al., 2023). Furthermore, an increase in the number of high-intensity actions over a short duration is observed in the decisive parts of a match. This multifaceted nature of performance has driven extensive research examining the optimization of training methodologies, particularly for developing elite young players who require specialized conditioning protocols targeting high-intensity intermittent effort, speed, agility, and strength development. Understanding individual physical performance profiles enables the implementation of targeted strength and conditioning programs that address specific needs (Fernandez-Fernandez et al., 2022).

Team sports require good explosive strength components, which is evident in almost every handball movement, as it involves many movements that require the efficient recruitment of muscle fibers (Jakšić et al., 2023). According to recent research , approximately 500 high-intensity actions with nearly 300 changes of direction (COD) occur during a match. The performance architecture of handball relies heavily on repeated sprint ability (RSA) and rapid acceleration/deceleration capabilities, highlighting the fundamental importance of muscle strength and power development. Time-motion analyses conducted by Póvoas et al. (2012) have revealed characteristic movement patterns in elite competition, with players covering distances of 16.7 ± 6.88 m during fast running, 18.0 ± 6.91 m in maximal sprints, and 9.0 ± 3.89 m during intense lateral movements. Research by Massuca et al. (2015) has demonstrated strong associations between key performance measures, particularly squat strength, and critical outcomes such as 10- and 30-meter sprint times. This relationship extends to youth players, where half-squat strength and lower extremity power show strong correlations with RSA performance. The dynamic nature of handball necessitates frequent eccentric-concentric muscle actions during jumping and sprinting movements. These actions rely on the stretch-shortening cycle (SSC), where elastic energy stored during eccentric contractions enhances subsequent concentric force production. The efficient utilization of the SSC is fundamental for explosive athletic movements, particularly in sprinting and jumping tasks.

Plyometric training (PT) has emerged as an effective methodology for enhancing SSC function through systematic jumping exercises (Chen et al., 2023; Kons et al., 2023). The beneficial effects of PT on physical performance parameters in youth handball players are well-documented (Aloui et al., 2020). Contemporary research indicates that combining PT with complementary training modalities such as balance training (BT) (Makhlouf et al., 2018), sprint training, agility training (Aloui et al., 2021; Makhlouf et al., 2018), resistance training (Kooroshfard & Rahimi, 2022), and complex training can amplify adaptations across multiple performance domains including muscle power, strength, joint awareness, and proprioception.

The integration of plyometric and balance training has shown particular promise for enhancing youth athlete development in team sports (Makhlouf et al., 2018). Scholars also demonstrated that 8 weeks of combined postural control and plyometric training significantly improved vertical jump performance, change-of-direction ability, and dynamic postural control in female adolescent basketball players. Similarly, Makhlouf et al. (2018) reported enhanced jump performance, agility, and dynamic movement capabilities following this combined training approach in prepubertal male soccer players. However, the efficacy of this training combination remains unexplored in youth handball players despite its apparent relevance to sport-specific demands. This study aimed to examine the effects of incorporating 8 weeks of combined postural control and plyometric training in place of conventional handball training components on the physical performance of young handball players. We hypothesized that implementing this combined training approach would yield superior enhancements in athletic performance compared to traditional handball training methods alone.

Materials and Methods

Participants

This investigation employed a randomized controlled trial design conducted over 8 weeks during the competitive season. Sample size determination was performed a priori using G*Power software (version 3.1.9.7, University of Düsseldorf, Germany). Based on previously published research examining similar combined training interventions in youth athletes (Ramirez-Campillo et al., 2021), an effect size of 0.50 was anticipated. With $\alpha = 0.05$ and desired power $(1-\beta) = 0.80$, the analysis indicated a minimum requirement of 26 participants to detect meaningful inter-group differences. Thirty male handball players were recruited from a first-division national team. All participants had accumulated a minimum of five years of systematic handball training experience and were actively competing at the elite youth level. Players were excluded if they reported any lower-limb injuries within the previous six months, had underlying medical conditions contraindicating high-intensity exercise, had participated in systematic plyometric or balance training programs within three months before the study, or played as goalkeepers due to their distinct physical demands and training requirements (Wang et al., 2024). Using a computer-generated random sequence (Random.org), participants were allocated to either an experimental group (EG) or a control group (CG).

Table 1

The Demographic Characteristics of the Participants

Days	Age (Years)	Body Mass (kg)	Height (m)	Body Fat percentage (%)	Training Experience (Years)
EG (n=15)	16.7 ± 0.5	68.8 ± 4.9	1.77 ± 0.08	15.3 ± 3.3	6.5 ± 0.7
EG (n=15)	16.6 ± 0.5	69.4 ± 4.4	1.77 ± 0.05	15.7 ± 3.5	6.3 ± 0.5

Analysis of baseline characteristics revealed no significant differences between groups (all $p \geq 0.05$). Following recommendations from the latest position statement on youth resistance training (Krabak et al., 2021), all participants underwent medical screening by the team physician to ensure their readiness for high-intensity training. The study protocol was approved by the Local Ethics Committee Research Laboratory (LR23JS01) "Sports Performance, Health & Society", University of "La Manouba" in conformity with principles identified in the Declaration of Helsinki. Both written informed consent from parents/legal guardians and written assent from the athletes were obtained before participation. All subjects were informed about the potential risks and benefits associated with the investigation, and their right to withdraw from the study at any time without consequence was emphasized. Throughout the intervention period, no participants reported any training-related injuries or adverse events that affected their ability to complete the prescribed program.

Study Design

This investigation employed an eight-week randomized controlled design during the competitive season. Both groups maintained their regular handball training schedule consisting of five 90-minute sessions weekly plus one competitive match. The standard program incorporated a periodized approach following current recommendations for youth team sport athletes (Gaamouri et al., 2023). Weekly training was structured systematically: Two sessions (Tuesdays / Wednesdays) emphasized aerobic conditioning through small-sided games and technical circuits performed at ventilatory threshold intensity, monitored via heart rate. A third session (Thursdays) targeted anaerobic power development through moderate-intensity resistance training (40-60% 1RM) including compound movements such as half-back squats, bench presses, and pull-overs, complemented by bodyweight exercises (jump squats, overhead lunges, pull-ups, push-ups). The final two sessions (Fridays / Saturdays) concentrated on technical-tactical preparation specific to upcoming competition demands. Session rating of perceived exertion (sRPE) was collected 30 minutes after each training session using the modified Borg CR-10 scale to quantify internal training load (Dhahbi et al., 2024). All training sessions were directly supervised by certified strength and conditioning specialists maintaining a coach-to-athlete ratio of 1:8 or better to ensure proper technique and safety. Training compliance was monitored through detailed attendance records, with participants required to complete at least 85% of prescribed sessions to be included in final analyses.

Procedures

Testing Procedures

All assessments were conducted under standardized conditions at the same time of day (±2 hours) to minimize circadian variation effects on performance (Hesketh & Esser, 2024). Testing sessions occurred at least 72 hours after the last competitive match and 5-9 days following the final training session to ensure adequate recovery. A comprehensive familiarization period of two weeks preceded baseline testing, during which participants performed all assessment protocols multiple times to minimize learning effects. The experimental group received additional familiarization with the intervention exercises during this period to optimize movement quality from the outset of training Table 2.

Table 2

Details of General Training Routine During the 8-Week Intervention

Days	Objectives
Monday	Rest
Tuesday	Aerobic capacity training and defensive tactics training
Wednesday	Aerobic power training and defensive tactics training
Thursday	Power anaerobic training and defensive and offensive tactics training
Friday	Technical training and offensive tactics training
Saturday	Technical training and offensive tactics training
Sunday	Official games

Testing was systematically conducted over three non-consecutive days, with 48 hours of recovery between sessions. Day one commenced with anthropometric assessments followed by vertical jump tests and the modified T-test. Day two consisted of a dynamic balance assessment via the Y-balance test, followed by a sprint performance evaluation. The final testing day included a static balance assessment, horizontal jump performance, and the repeated change of direction test. This sequence was designed to minimize the influence of fatigue on subsequent performance measures while optimizing recovery between maximal effort tests.

Anthropometric measurements were conducted in the morning following an overnight fast, with participants wearing minimal clothing and no footwear. Body composition was assessed using multi-frequency bioelectrical impedance analysis (BIA) (BC-602, Tanita Co., Tokyo, Japan), which has demonstrated high reliability in adolescent athletes (intraclass correlation coefficient - ICC = 0.98) (Sitko et al., 2022). Height was measured to the nearest 0.1 cm using a wall-mounted stadiometer (Seca 213, Hamburg, Germany), and body mass was recorded to the nearest 0.1 kg Table 3.

Table 3

Description of the Balance Training Program

Workshop	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
Swiss-ball kneeling hold balancing	4 × 30 (s) (eyes opened)	4 × 30 (s) (eyes opened)	5 × 35 (s) (eyes opened)	5 × 35 (s) (eyes opened)	5 × 40 (s) (eyes closed)	5 × 40 (s) (eyes closed)	6 × 45 (s) (eyes closed)	6 × 45 (s) (eyes closed)
Single-leg standing on a bosu ball progressing to squat exercise	3 × 20 / leg (rps) (eyes opened)	3 × 20 / leg (rps) (eyes opened)	4 × 20 / leg (rps) (eyes opened)	4 × 20 / leg (rps) (eyes opened)	4 × 25 / leg (rps) (eyes closed)	4 × 25 / leg (rps) (eyes closed)	5 × 25 / leg (rps) (eyes closed)	5 × 25 / leg (rps) (eyes closed)
Single-leg standing on an inflated disk (knee angle of approximately 120°)	4 × 25 / leg (s) (eyes opened)	4 × 25 / leg (s) (eyes opened)	5 × 30 / leg (s) (eyes opened)	5 × 30 / leg (s) (eyes opened)	5 × 35 / leg (s) (eyes closed)	5 × 35 / leg (s) (eyes closed)	6 × 40 / leg (s) (eyes closed)	6 × 40 / leg (s) (eyes closed)

All physical performance tests were conducted on an indoor synthetic court under controlled environmental conditions (temperature: 20-22°C; relative humidity: 45-55%). A standardized warm-up protocol preceded each testing session, consisting of 10 minutes of submaximal running, dynamic stretching, and sport-specific movement preparation. Qualified sport scientists conducted all assessments, maintaining consistent verbal encouragement across participants. The same examiner administered each specific test during both pre- and post-intervention assessments to ensure procedural consistency Tables 4 and 5.

Table 4

Description of the Plyometric Training Program

Workshop	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
Hurdle jump (0.5 m)	6 × 3	6 × 3	8 × 3	8 × 3	10 × 3	10 × 3	12 × 3	12 × 3
Lateral hurdle jump (0.5 m) (alternating between right and left)	6 × 3	6 × 3	8 × 3	8 × 3	10 × 3	10 × 3	12 × 3	12 × 3
Bouncy stride	6 × 3	6 × 3	8 × 3	8 × 3	10 × 3	10 × 3	12 × 3	12 × 3
Bilateral horizontal jump	6 × 3	6 × 3	8 × 3	8 × 3	10 × 3	10 × 3	12 × 3	12 × 3
Total (Contact)	72	72	96	96	120	120	144	144

Comprehensive descriptions of the sprint performance (5m and 20m), jumping protocols (SJ, CMJ, SLJ), change of direction tests (T-Half test, Illinois-MT), balance assessments (Y-balance test, Stork Balance test), and repeated change of direction test have been detailed in previous publications and were strictly followed in this investigation. All performance measures demonstrated high test-retest reliability in our population (ICC > 0.90, coefficient of variation - CV < 5%).

Recovery intervals between individual trials were strictly controlled: 3 minutes for sprint and jump tests, 5 minutes for change of direction assessments, and 2 minutes for balance measures. These intervals were established through pilot testing to ensure optimal performance while minimizing fatigue effects. Environmental conditions and testing equipment were standardized across all sessions to maximize measurement precision and reliability.

Table 5

Details of the Plyometric Training Program

Week	Workshop 1	Workshop 2	Workshop 3	Workshop 4	Total (contact)
1	3 Repetitions	3 Repetitions	3 Repetitions	3 Repetitions	72
2	3 Repetitions	3 Repetitions	3 Repetitions	3 Repetitions	72
3	4 Repetitions	4 Repetitions	4 Repetitions	4 Repetitions	96
4	4 Repetitions	4 Repetitions	4 Repetitions	4 Repetitions	96
5	5 Repetitions	5 Repetitions	5 Repetitions	5 Repetitions	120
6	5 Repetitions	5 Repetitions	5 Repetitions	5 Repetitions	120
7	6 Repetitions	6 Repetitions	6 Repetitions	6 Repetitions	144
8	6 Repetitions	6 Repetitions	6 Repetitions	6 Repetitions	144

Training Protocol

The experimental group performed specialized training twice weekly, strategically replacing portions of the technical-tactical sessions to avoid interference with primary conditioning work. This combined intervention was structured based on recent meta-analyses examining optimal loading parameters for youth athletes. Each specialized session began with a standardized 15-minute dynamic warm-up incorporating locomotor patterns, joint mobilization, and progressive activation exercises. The main training component consisted of three progressive balance workshops (15-30 minutes) immediately followed by four plyometric workshops (15 minutes), with the session concluding with a 10-minute cool-down focused on flexibility and light aerobic activity. Training load progression followed established principles of progressive overload while respecting the recovery capabilities of youth athletes (Krabak et al., 2021). Ground contacts increased systematically from 72 to 144 per session over the eight weeks. Exercise complexity evolved through three key mechanisms: manipulation of the base of support (from bilateral to unilateral stance), introduction of unstable surfaces (from firm to foam surfaces), and advancement of movement patterns (from static to dynamic tasks). Repetitions per set increased from 6 to 12 while maintaining three sets per exercise to optimize the volume-intensity relationship. Rest intervals were precisely controlled based on contemporary research examining optimal recovery periods for power development in adolescent athletes, with 30 seconds provided between balance sets and 90 seconds between plyometric sets. For plyometric exercises, participants were instructed to minimize ground contact time while maximizing jump height or distance, emphasizing explosive triple extension of the ankle, knee, and hip joints.

Statistical Analyses

Statistical analyses were performed using SPSS version 28.0 (IBM Corp., Armonk, NY, USA) and G*Power version 3.1.9.7 (University of Düsseldorf, Germany). All data are presented as means ± standard deviations unless otherwise specified. Data nor-mality was assessed using Shapiro-Wilk tests and visual inspection of Q-Q plots. Levene's test evaluated the homogeneity of variance. Baseline between-group compar-isons were conducted using independent t-tests or Mann-Whitney U tests, as appro-priate based on data distribution. The primary analysis employed a mixed-model analysis of variance (ANOVA) with repeated measures, using a 2 (Group: experi-mental, control) × 2 (Time: pre-test, post-test) design. Effect sizes were calculated using partial eta-squared ($\eta 2p$) and subsequently converted to Cohen's d to facilitate com-parison with existing literature. Following contemporary reporting guidelines (Brydges, 2019), ef-fect sizes were interpreted as trivial ($d < 0.20$), small ($d = 0.20$-0.49), moderate ($d = 0.50$-0.79), or large ($d \geq 0.80$). When significant interaction effects were identified, Bonferroni-adjusted post-hoc analyses were conducted to locate specific differences. Relative percentage changes were calculated for all performance variables using the formula: ([post-test value - pre-test value] / pre-test value) × 100. The reliability of performance measures was assessed through intraclass correlation coefficients (ICC2,1) with 95% confidence intervals and coefficients of variation (CV). Following recommendations from recent methodological reviews (Hopkins, 2000), acceptable reliability was defined as ICC > 0.80 and CV < 5%. Statistical significance was set at $p \leq 0.05$ (two-tailed), and exact p-values were reported.

Results

Preliminary analyses confirmed the reliability of all performance measures through ICC ranging from 0.82 to 0.96 and CV below 5% across all variables, with 95% confidence intervals Table 6. Initial between-group comparisons revealed no signifi-cant differences in any measured parameter at baseline (all $p > 0.05$), indicating suc-cessful randomization.

Analysis of jumping performance revealed significant group × time interactions for both vertical and horizontal measures. The experimental group demonstrated su-perior improvements compared to controls in squat jump ($p < 0.05$; d = 0.69), counter-movement jump ($p < 0.01$; d = 0.75), and standing long jump ($p < 0.05$; d = 0.54) per-formance Table 7. Sprint capabilities showed similar intervention effects, with the experimental group achieving greater enhancements in both 5-meter ($p < 0.05$; d = 0.56) and 20-meter ($p < 0.05$; d = 0.64) sprint times relative to controls Table 7.

Change-of-direction performance exhibited significant training effects favoring the experimental group across multiple assessments. The modified T-test revealed sub-stantial improvements ($p < 0.01$; d = 0.76), as did the Illinois modified test ($p < 0.01$; d = 0.85). The repeated change-of-direction test demonstrated significant group × time in-teractions across most parameters, including fastest time ($p = 0.05$; d = 0.52), mean time ($p = 0.05$; d = 0.53), and total time ($p = 0.05$; d = 0.53), though the fatigue index remained unchanged.

Table 6

Test-Retest Reliability for all Performance Tests

	ICC (95% CI)	CV (95%CI) [%]
	Sprint times	
5 m (s)	**0.95** (0.91-0.97)	**1.8** (1.3-2.2)
20 m (s)	**0.96** (0.92–0.98)	**1.5** (1.2-1.8)
	Change of direction test	
T-Half (s)	**0.91** (0.88-0.94)	**1.6** (1.3-2.0)
Illinois-MT (s)	**0.89** (0.86-0.93)	**1.9** (1.6-2.4)
	Vertical jump	
SJ (cm)	**0.96** (0.92-0.98)	**2.1** (1.7-2.6)
CMJ (cm)	**0.97**(0.94-0.99)	**2.4** (2.0-2.9)
	Horizontal jump	
SLJ (m)	**0.96**(0.93-0.99)	**3.8** (3.0-4.6)
	Stork Balance test	
Right leg (s)	**0.83** (0.68-0.90)	**3.3** (2.5-4.2)
Left leg (s)	**0.80** (0.65-0.87)	**3.4** (2.6-4.4)
	Y-balance test	
	Right support leg	
Anterior direction (cm)	**0.95** (0.90-0.98)	**4.7** (4.1-5.0)
Posteromedial direction (cm)	**0.91** (0.88-0.96)	**4.8** (4.0-5.2)
Posterolateral direction (cm)	**0.89** (0.86-0.95)	**4.8** (3.9-5.2)
	Left support leg	
Anterior direction (cm)	**0.95** (0.90-0.98)	**4.5** (3.8-5.0)
Posteromedial direction (cm)	**0.94** (0.89-0.98)	**4.7** (4.3-5.4)
Posterolateral direction (cm)	**0.93** (0.89-0.97)	**4.6** (4.0-5.3)

ICC (95% CI) = Interclass correlation coefficient with 95% confidence intervals; CV (95%CI) [%] = coefficient of variation; SLJ = standing long jump; SJ = squat jump; CMJ = countermovement jump.
Note: ICC > 0.75 and CV <10% marked in bold.

Balance assessments indicated comprehensive improvements in postural control within the experimental group Table 8. The Stork balance test showed significant intervention effects for both right ($p = 0.05$; d = 0.53) and left ($p = 0.05$; d = 0.52) leg performance. Dynamic balance, assessed via the Y-balance test, demonstrated similar improvements across all reach directions. The right support leg showed enhanced reach distances in anterior ($p < 0.05$; d = 0.55), posteromedial ($p < 0.05$; d = 0.67), and posterolateral ($p < 0.05$; d = 0.55) directions. Left leg performance improved comparably in anterior ($p < 0.05$; d = 0.57), posteromedial ($p < 0.05$; d = 0.66), and posterolateral ($p < 0.01$; d = 0.75) reach distances.

Table 7

Different Physical Performance Parameters in the Experimental and Control Groups Before and After An 8-Week Intervention

Parameter	Experimental (n=15)			Paired t-test		Control (n=15)			Paired t-test		ANOVA (group x time)		ANOVA (group)	ANOVA (time)
	Pre	Post	% Δ	p	d	Pre	Post	% Δ	p	d	p	d	p	p
Vertical jump														
SJ (cm)	27.0 ± 2.74	32.1 ± 2.94	18.9 ± 2.31	<0.001	1.79	27.1 ± 2.72	28.4 ± 3.01	3.74 ± 1.19	<0.001	0.44	0.012	0.69 (medium)	0.019	<0.001
CMJ (cm)	29.9 ± 2.64	35.1 ± 2.86	17.7 ± 1.75	<0.001	1.92	29.7 ± 2.56	31.0 ± 2.86	4.60 ± 1.78	<0.001	0.49	0.007	0.75 (medium)	0.004	<0.001
Horizontal jump														
SLT (m)	1.81 ± 0.20	2.07 ± 0.19	14.3 ± 2.84	<0.001	1.32	1.80 ± 0.18	1.86 ± 0.10	3.10 ± 2.61	<0.01	0.30	0.047	0.54 (medium)	0.025	0.002
Sprint														
5 m (s)	1.20 ± 1.06	1.06 ± 0.08	-11.7 ± 0.94	<0.001	1.72	1.19 ± 0.12	6.16 ± 0.12	-2.68 ± 1.09	<0.001	0.27	0.042	0.56 (medium)	0.117	0.002
20 m (s)	3.41 ± 0.13	3.13 ± 0.12	-8.21 ± 0.84	<0.001	2.21	3.39 ± 0.19	3.31 ± 0.20	-2.22 ± 0.74	<0.001	0.38	0.020	0.64 (medium)	0.051	<0.001
Change of direction Performance														
T-Half (s)	6.23 ± 0.27	5.68 ± 0.26	-8.80 ± 0.78	<0.001	2.06	6.21 ± 0.27	6.05 ± 0.25	-2.57 ± 0.46	<0.001	0.61	0.006	0.76 (medium)	0.014	<0.001
Illinois-MT (s)	12.5 ± 0.28	11.7 ± 0.34	-5.65 ± 0.62	<0.001	2.26	12.4 ± 0.27	12.2 ± 0.27	-1.83 ± 0.25	<0.001	0.84	0.003	0.85 (large)	0.016	<0.001

SLJ = standing long jump; SJ = squat jump; CMJ = countermovement jump; d = Cohen's effect size; % Δ = percentage difference.

Table 8

Repeated Change of Direction and Balance Test Performances in the Experimental and Control Groups Before and After An 8-Week Intervention

Parameter	Experimental (n=15)			Paired t-test		Control (n=15)			Paired t-test		ANOVA (group x time)		ANOVA (group)	ANOVA (time)
	Pre	Post	% Δ	p	d	p	p	% Δ	p	d	p	d	p	p
Repeated Change of Direction parameters														
Fastest time (s)	6.95 ± 0.37	6.44 ± 0.34	-7.29 ± 0.49	<0.001	1.43	6.88 ± 0.38	6.75 ± 0.39	-1.84 ± 0.73	<0.001	0.33	0.052	0.53 (medium)	0.217	0.002
Meantime (s)	7.09 ± 0.36	6.58 ± 0.34	-7.19 ± 0.63	<0.001	1.45	7.01 ± 0.39	6.88 ± 0.40	-1.84 ± 0.65	<0.001	0.33	0.053	0.53 (medium)	0.257	0.002
Total time (s)	42.5 ± 2.17	39.5 ± 2.03	-7.19 ± 0.63	<0.001	1.45	42.1 ± 2.34	41.3 ± 2.39	-1.84 ± 0.65	<0.001	0.33	0.053	0.53 (medium)	0.258	0.002
Fatigue index (%)	2.04 ± 0.68	2.16 ± 0.78	6.25 ± 16.7	0.221	0.16	1.91 ± 0.61	1.91 ± 0.56	1.31 ± 10.4	0.990	0	0.740	0.09 (small)	0.277	0.738
Stork Balance test														
Right leg (s)	12.8 ± 7.45	23.2 ± 13.5	82.4 ± 4.05	<0.001	0.96	12.9 ± 7.76	13.8 ± 8.10	6.65 ± 2.52	<0.001	0.10	0.053	0.53 (medium)	0.068	0.025
Left leg (s)	11.9 ± 7.07	20.3 ± 12.0	70.9 ± 10.2	<0.001	0.85	11.6 ± 4.47	12.2 ± 4.64	5.62 ± 3.86	<0.001	0.14	0.055	0.52 (medium)	0.040	0.027
Y-balance test - Right support leg														
Anterior direction (cm)	85.5 ± 5.85	95.0 ± 5.74	8.93 ± 2.16	<0.001	1.46	87.2 ± 6.12	89.3 ± 5.96	2.40 ± 1.46	<0.001	0.32	0.043	0.55 (medium)	0.108	0.001
Posteromedial direction (cm)	110 ± 6.15	120 ± 7.79	8.44 ± 2.16	<0.001	1.76	111 ± 5.88	113 ± 6.17	2.16 ± 0.99	<0.001	0.57	0.015	0.67 (medium)	0.129	<0.001
Posterolateral direction (cm)	56.5 ± 6.60	64.3 ± 6.95	12.2 ± 1.98	<0.001	1.15	57.2 ± 3.76	59.0 ± 4.39	2.97 ± 2.23	<0.001	0.91	0.042	0.55 (medium)	0.112	0.002
Y-balance test - Left support leg														
Anterior direction (cm)	88.7 ± 7.04	98.7 ± 8.06	10.1 ± 1.84	<0.001	0.35	89.3 ± 6.26	91.7 ± 6.10	2.64 ± 1.10	<0.001	0.39	0.038	0.57 (medium)	0.084	0.001
Posteromedial direction (cm)	108 ± 8.72	121 ± 7.77	10.0 ± 3.46	<0.001	0.41	110 ± 8.31	112 ± 8.38	2.19 ± 1.48	<0.001	0.30	0.017	0.66 (medium)	0.133	0.001
Posterolateral direction (cm)	55.5 ± 3.83	63.0 ± 4.07	11.9 ± 2.55	<0.001	0.44	58.1 ± 4.29	59.7 ± 4.40	2.55 ± 2.03	<0.001	0.35	0.007	0.75 (medium)	0.757	<0.001

d = Cohen' effect size; % Δ = percentage difference.

Discussion

The present study aimed to evaluate the effectiveness of an 8-week combined postural control and plyometric training program in enhancing athletic performance measures among elite adolescent handball players. The findings revealed that replacing conventional training with the combined postural control and plyometric program resulted in noteworthy enhancements in vertical and horizontal jump performance, sprinting, change-of-direction ability, repeated change-of-direction ability, and postural control.

Jump performance significantly improved in our study, aligning with findings by Makhlouf et al. (2018) and Muehlbauer et al. (2019) who observed similar enhancements after combining postural control and plyometric training in young soccer players. While prior studies reported no jump improvements in youth female basketball players after 8 weeks combined balance and plyometric training program, these discrepancies likely stem from differences in training protocols and participant characteristics. Consistent with previous research (De Jesus-Leite et al., 2020; Deng et al., 2023; Grgic, Schoenfeld, & Mikulic, 2021), these jump improvements are likely attributed to neuromuscular adaptations such as increased neural drive, enhanced muscle-tendon stiffness, and changes in muscle fiber characteristics. Additionally, improved balance may have contributed by reducing postural sway during takeoff (Zech et al., 2010) and enhancing proprioceptive feedback, leading to quicker and stronger muscle activation during jumps (Aagaard et al., 2002). Sprint performance also significantly improved in our study, consistent with findings from Makhlouf et al. (2018) in youth soccer players after combination of agility and plyometric training program and combination of balance and plyometric training program. While a prior study observed improvements only in 10m sprints, our study demonstrated significant improvements in both 5m and 20m sprints after 8 weeks plyometric training program program. These findings are supported by a prior study which attributed sprint improvements to neural adaptations such as increased muscle activation, enhanced spinal reflexes, and improved muscle-tendon unit stiffness. Enhanced sprint performance is crucial for handball players, as it directly influences their ability to rapidly transition between offensive and defensive phases and ultimately impacts ball-throwing speed (Granados et al., 2007).

In handball, players need to run, change directions with or without the ball, respond to opponents, and make quick decisions during offensive and defensive actions (Shahbazi et al., 2011). Our findings suggest that a combined postural control and plyometric training regimen during the season can be advantageous for young male handball players, which is consistent with prior research (Makhlouf et al., 2018; Muehlbauer et al., 2019). For example, in a study by Muehlbauer et al. (2019), an 8-week blocked postural control and plyometric training program led to noteworthy enhancements in a change of direction (COD) ability (T-test) among male adolescent soccer players. Likewise, Makhlouf et al. (2018) observed substantial progress in COD ability (4-m × 9-m shuttle run test) among prepuberal male soccer players following an 8-week combined balance postural control and plyometric training program. In a related context, prior literature reported significant improvements in the COD ability (Modified Illinois change of direction test) of female adolescent basketball players after participating in a postural control and plyometric training program during 8-weeks. Improved motor unit recruitment and neural adaptations are potential mechanisms that may contribute to enhanced reactive COD (Aagaard et al., 2002). Moreover, resistance training programs may have improved both concentric and eccentric lower-limb muscle strength, which is an important prerequisite to improving change of direction movements (Sheppard & Young, 2006).

In handball, players engage in intermittent high-intensity activities that demand a combination of aerobic and anaerobic capacity (Buchheit et al., 2009). Having good aerobic capacity and the ability to execute and recover from repeated high-intensity activities over a prolonged period is deemed a crucial physiological necessity for successful handball (Chıttıbabu, 2014). As far as we are aware, our study is the first to explore the impact of combined postural control and plyometric training on Reactive Change of Direction (RCOD) ability. Our findings reveal that the intervention had a significant effect on all RCOD parameters except for the fatigue index. The effects of plyometric training on repeated sprint ability (RSA) performance are well-documented in young team sport players (Aloui et al., 2020). Less is known specifically in young male handball players (Aloui et al., 2020; Mazurek et al., 2018) and even less is known concerning balance training effects on RSA. Mazurek et al. (2018) investigated the effects of 5-week plyometric training in male adolescent handball players and reported improvement in RSA performances assessed using a bicycle ergometer. Researchers also studied the impact of 8-week plyometric training on RCOD ability in adolescent female handball players and found significant improvements in both RCOD best and RCOD total performances. These findings are in line with previous research which suggests that factors such as increased recruitment of motor units, improved motor unit synchronization, enhanced firing frequencies, improved stretch-shortening cycle efficiency, or increased musculo-tendinous stiffness may contribute to the improvements in high-intensity task performance, including RCOD. Furthermore, improvement in repeated sprint ability performance was likely related to the fact that the change in explosive performance after a plyometric training program may contribute to change of direction improvement during repeated sprint ability tests with change of direction or running economy (Marta et al., 2013).

Our study demonstrated improvements in dynamic postural control, aligning with findings from Makhlouf et al. (2018), and Muehlbauer et al. (2019), who observed similar enhancements in young soccer and basketball players after combined postural control and plyometric training. These improvements likely resulted from a combination of factors. Plyometric training can enhance neuromuscular control by increasing inter-muscular coordination, neural stimulation, and muscle-tendon stiffness (Markovic & Mikulic, 2010). Furthermore, postural control training can improve anticipatory postural adjustments (APAs) by promoting proactive muscle contractions before perturbations (Gantchev & Dimitrova, 1996; Marigold & Patla, 2002; Pavol & Pai, 2002). Improved dynamic postural control is crucial for handball players, as it can reduce postural sway and potentially decrease the risk of knee and ankle injuries, which are common in this sport (Higashi et al., 2015; Zech et al., 2010).

Conclusions

This investigation provides compelling evidence that integrating combined pos-tural control and plyometric training into standard handball practice enhances multi-ple aspects of physical performance in elite youth players. The experimental interven-tion induced superior adaptations in lower-limb power production, as evidenced by enhanced vertical (SJ and CMJ) and horizontal jump (SLT) performance. Significant improvements were also observed in linear sprint capabilities across acceleration (5 m) and maximal velocity (20 m) phases. Furthermore, the combined training approach led to substantial enhance-ments in change-of-direction ability in both single-effort (T-Half test and Illinois-MT test) and repeated-effort (Repeated change of direction test) contexts, while simultaneously improving static and dynamic postural control across multiple planes of movement (Stork Balance test and Y Balance test). These comprehensive improvements suggest that combined training offers superior adaptations compared to traditional handball training alone in developing youth athletes.

Study Limitations and Future Directions

Several methodological considerations warrant discussion when interpreting the present findings. The absence of direct neuromuscular measurements, including sur-face electromyography and force plate analyses, limits our understanding of the un-derlying mechanistic adaptations. Additionally, while improvements in isolated physical performance tests were observed, the transfer of these adaptations to competitive play remains unclear due to the lack of systematic match analysis. Future research should incorporate both biomechanical assessments and in-game performance metrics while comparing the efficacy of isolated versus combined training approaches through multi-arm trial designs.

Practical Recommendations

The findings from this study have direct implications for training prescription in youth handball programs. Coaches and practitioners should consider incorporating structured balance and plyometric elements into their regular training regimens, particularly during the competitive season when maintaining physical performance is crucial. The demonstrated effectiveness of twice-weekly combined training sessions suggests this frequency is sufficient to induce meaningful adaptations without compromising other aspects of handball preparation. Implementation should follow care-ful progression principles, beginning with foundational balance and plyometric exercises before advancing to more complex movement patterns. Additionally, monitoring recovery and fatigue responses is essential when introducing this training modality to youth athletes. Finally, practitioners should ensure proper exercise technique and supervision to maximize training benefits while minimizing injury risk in this developing population.

Abbreviations

EG: Experimental group; CG: Control group; SJ: Specifically the squat-jump; SJ: Squat jump; CMJ: Countermovement-jump; SLJ: Standing long jump; RCOD: Repeated change of direction; RSA: Repeated sprint ability; SSC: Stretch-shorten cycle; PT: Plyometric training; BT: Balance training; One-repetition maximum: 1RM; Illinois-MT: Illinois modified test; T-Half test: Modified agility T-test; Bioelectrical impedance analysis: BIA; Coefficients of variation: CV; ICC: Intraclass correlation coefficients; SD: Standard deviation; COD: Change of direction; APAs: Anticipatory Postural Ad-justments; CI: Confidence intervals. This section is not mandatory but can be added to the manuscript if the discussion is unusually long or complex.

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L.D.H.; writing—review and editing, G.A., W.D., H.İ.C., V.S., A.A., M.M., L.D.H., and S.H.; supervision, H.İ.C., and W.D.; All authors have read and agreed to the published version of the manuscript.

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