Journal of Human Kinetics volume 104/2026, 231–244 DOI: 10.5114/jhk/214816
Section III – Sports and Physical Activity

Specific Power Training vs. Conventional Resistance Training in the Context of Vertical Jump Performance in Young Handball Players

by
Michał Spieszny [1,], Kamil Zawada [2], Kazimierz Mikołajec [3], Wojciech Wąsacz [1], Krzysztof Kasicki [4], Tadeusz Ambroży [1], Łukasz Rydzik [1]*

The increase in the competitive level and popularity of handball necessitates the optimization of training methods, particularly in the development of explosive strength, which determines jump effectiveness and overall game performance. This study analyzed the impact of specific power training and conventional resistance training on jumping abilities of young handball players. A total of 48 athletes were selected for the experiment and randomly assigned to a power training (PT) group, a resistance training (RT) group, or a control (C) group. The training program included plyometric exercises, dynamic neuromuscular activations, and reaction-time-based stimuli, with their effects evaluated through vertical jump tests (CMJ and SJ). The results indicated significant increases in jump height, maximum power, and relative maximum power in the PT group ($p < 0.05$), suggesting that specific power training more effectively supported the development of dynamic variables than standard resistance training methods. While the RT group demonstrated gains in strength, the corresponding improvements in vertical jump performance were modest and not as substantial as those seen in the power training group. The findings highlight the crucial role of neuromuscular mechanisms in generating explosive power, as well as the importance of training methods based on the stretch-shortening cycle.

***Keywords**: athletes; plyometric training; neuromuscular adaptations; explosive lower limb power*

Introduction

The immense popularity and rapid development of team sports, along with strong international competition, necessitate the continuous refinement of training methodology and the application of scientific advancements in this field. In this context, team sports appear particularly complex, as the characteristics of elite athletes are shaped by multiple factors, with the most significant including somatic structure, motor and cognitive abilities (Blecharz et al., 2022; Heuvelmans et al., 2025; Skalski et al., 2025a; Kyriacou-Rossi et. al., 2024; Michalsik et al., 2015), the latter being trainable through targeted interventions such as real time neurofeedback. Regarding motor abilities, strength serves as the foundation for their development, which, simply put, is the ability to generate maximum external force (Zatsiorsky et al., 2020). According to the ideal model, the developed strength should be a prerequisite for generating the greatest possible forces in the shortest time (Zatsiorsky et al., 2020). This entire process is part of building three key properties of the neuromuscular system that determine performance: the ability to generate high force in a short time, known as the maximum rate of force development (mRFD), the muscle's ability to sustain force production as muscle shortening velocity increases, and the ability to generate high forces at the beginning of the

[1] *Institute of Sports Sciences, University of Physical Culture, Krakow, Poland.*
[2] *Polish Handball Federation, Warszawa, Poland.*
[3] *Institute of Sport Sciences, The Jerzy Kukuczka Academy of Physical Education in Katowice, Katowice, Poland.*
[4] *Department of Physiotherapy, Faculty of Health Sciences, Collegium Medicum, Andrzej Frycz-Modrzejewski Krakow University, Krakow, Poland.*
* Correspondence: michal.spieszny@awf.krakow.pl

CC BY

concentric phase and the end of the eccentric phase (Hoffman, 2011; Miller, 2012). These components together form a complementary profile of an athlete in a given sport discipline.

One of the fundamental performance indicators in sports such as handball is vertical jump efficiency, which determines the ability to execute shots, blocks, and ball interceptions at various stages of the game. In handball, significant attention is given to the development of explosive strength, which is the final outcome of the previously described elements. Furthermore, improvements in performance in this area are described by some authors as crucial for executing fast or positional attacks and performing throws (Abbass and Khalil, 2019; Igor et al., 2023; Karcher and Buchheit, 2014; Wagner et al., 2019). Explosive strength, understood as the ability to generate maximum power in a short time, plays a particularly important role in handball, where players frequently execute jumps either from a stationary position or in motion while simultaneously controlling the body trajectory and throwing technique (Russomanno et al., 2021). Studies indicate that the ability to efficiently utilize explosive strength can influence game effectiveness, especially in situations requiring rapid reactions, such as transitions from defense to offense or jump shots over an opponent's defender (Fernandez-Fernandez et al., 2022; Russomanno et al., 2021; Sáez de Villarreal et al., 2024). During various in-game actions, an athlete may perform a jump shot, where the jump itself must be executed with maximum power to achieve sufficient height for an effective shot (Radovic et al., 2024; Saavedra et al., 2019; Tuquet et al., 2025).

During training, coaches focus on improving players' jump performance in various ways, often assessing effectiveness through countermovement jump (CMJ) or squat jump (SJ) measurements (Gaamouri et al., 2024; McGhie et al., 2020; Spieszny and Zubik, 2018). This may be due to the reliability and validity of such tests, which are widely used in professional sports to evaluate lower limb power (Xu et al., 2024). Analyzing the results obtained from CMJ and SJ tests allows for assessing the effectiveness of applied training programs and identifying areas that require further optimization. Therefore, the CMJ and the SJ are most commonly used in studies assessing power performance.

Nevertheless, these tests are primarily conducted on adult athletes, and research on the effects of power training on vertical jump performance in youth athletes remains relatively limited. Consequently, further studies on the specifics of neuromuscular adaptations across different age categories are necessary (Cadens et al., 2023; Kačúr and Eliaš, 2024). Evidence suggests that for young athletes, implementing training methods based on plyometric exercises, multi-joint movements, and dynamic eccentric-concentric exercises can significantly improve jumping ability (Arede et al., 2025; Jakšić et al., 2023), with recent work demonstrating that neuromuscular training supported by real-time biofeedback can further enhance explosive SSC performance in elite athletes (Prończuk et al., 2025). Additionally, incorporating biomechanical variables, such as the motor unit recruitment rate and muscle contraction sequence optimization, may contribute to more effective development of this motor ability.

Analyzing the current literature, the use of exercises with a more static nature may potentially have a beneficial effect on overall vertical jump performance (Della Corte et al., 2021). Hammami et al. (2022) reported that in a study employing resistance training with contrast methods and resistance bands, statistically significant increases in vertical jump performance and its variations were observed in young female handball players. Similarly, another study examining the use of isometric contractions and the post-activation potentiation enhancement (PAPE) effect in handball players demonstrated improvements in both sprinting and vertical jump performance (Krzysztofik et al., 2023). However, the application of the PAPE effect still requires refinement of specific protocols for each discipline and athlete profile (Kasicki et al., 2024). In another study comparing two training methods—strength training and plyometric training—in relation to change-of-direction (COD) performance (Falch et al., 2022), authors concluded that plyometric training alone was insufficient for improving COD performance in female handball players (Falch et al., 2022). Unfortunately, there is still a lack of detailed comparisons between both training methods, utilizing standard resistance exercises and a specific training program targeting muscle power development. Furthermore, current scientific reports primarily focus on adult

populations or, to a large extent, on female athletes, which does not provide a complete comparison of which method is more effective in developing vertical jump performance in handball players (Akbar et al., 2024).

Therefore, a deeper understanding of the effects of these training methods in younger age groups who differ physiologically and in terms of skill level is needed. Therefore, the aim of this study was to analyze the impact of targeted muscle power training on vertical jump performance in youth handball players and to assess how different training methods could contribute to improving sports performance.

Methods

Participants

The sample size calculation was performed using G*Power software (Düsseldorf, Germany, version 3.1.9.7). An effect size of 0.25, an alpha level of 0.05, and a statistical power of 0.80 were assumed. Considering a 20% dropout rate and potential data loss, it was estimated that 48 participants needed to be recruited for the study, resulting in 16 individuals per each of the three groups; this was also the final number of participants included in the analysis.

A total of 48 male elite handball players were qualified for the study. An analysis of somatic characteristics was conducted for all participants. The average age of the players was 15.6 ± 0.9 years, body mass 78.36 ± 8.97 kg, and body height 186.1 ± 6.4 cm. The BMI ranged from 18.3 to 23.6 kg/m². Body mass was measured using the Tanita BC-601 body composition analyzer (Tanita, Tokyo, Japan), while body height was measured using the SECA 2017 stadiometer (Seca, Hamburg, Germany). Players had average sports experience of 4.1 ± 0.5 years. They belonged to top-tier sports teams competing in junior league championships in Poland. All players belonged to junior teams of the same sports academy and trained together within the same motor preparation system.

The participants and their legal guardians were informed about the research procedures before the commencement of testing, and informed consent from the legal guardians was obtained in accordance with the ethical principles of the Declaration of Helsinki (World Medical Association, 2013). The legal guardians provided informed consent for the players' participation in the study, as all participants were minors. The study received approval from the Bioethics Committee at the Regional Chamber of Physicians in Cracow, Cracow, Poland (protocol code: 205/KBL/OIL/2022; approval date: 16 September 2022).

Design and Procedures

Eighty handball players aged 15–16 initially expressed their willingness to participate in the study. A necessary condition for qualification was the absence of injuries, the non-use of medications or performance-enhancing substances. Detailed inclusion and exclusion criteria are presented in Table 1.

Finally, 48 athletes participated in the experiment and they were randomly assigned to one of the three groups: a control group (n = 16 [C]), a group following power training (n = 16 [PT]), and a group undergoing standard resistance training (n = 16 [RT]). The C group followed a training program resembling most the real-world training conditions in junior clubs, without specific elements aimed at power development. Potential confounding factors (e.g., additional off-field training) were excluded during the qualification process. In all groups, we observed an adherence level of ≥92% (minimum 44 out of 48 sessions). A randomized controlled trial design was applied, with the randomization process conducted using the website randomizer.org (Social Psychology Network). The entire process is presented in the CONSORT diagram (Figure 1).

Characteristics of Power Training

Power training was introduced using light stimuli generated by the Fitlight system, requiring an immediate motor response. Conducted at the end of the week, it was performed using resistance power bands, medicine balls, and the Fitlight Trainer device (FitLight, Warsaw). Training consisted of four categories of exercises, i.e.: lower body, upper body and rotational exercises along with complex exercises including reaction time measurement.

Eight exercises were performed during each training session, organized into three blocks corresponding to a single mesocycle, with changes implemented weekly. The exercise scheme for power training is presented in Table 2.

For the aforementioned exercises, a general maximal effort principle was applied, using a load

Articles published in the Journal of Human Kinetics are licensed under an open access Creative Commons CC BY 4.0 license.

range from 40% to 60% of the one-repetition maximum (1RM) in 4 sets per exercise with 6 to 8 repetitions per set. The resistance used with the bands was estimated based on a previously conducted one-repetition maximum (1RM) test for each specific movement pattern. A set of resistance bands was then selected to provide a load approximating 40–60% of 1RM at the end range of motion (i.e., at the point of the maximum band stretch). The rest interval between sets ranged from 2.5 to 3 min.

Characteristics of Standard Resistance Training

The resistance training session had the same structure as training focused on power development, with modifications in external static contractions appropriate for the targeted goal. Exercises performed at a controlled tempo with an increased time under tension were implemented. A model was adopted in which multi-joint exercises were based on loads of 70–85% of the one-repetition maximum (1RM) for each athlete, while exercises targeting smaller muscle groups were performed at an intensity of 40–50% of 1RM. Rest intervals between exercises ranged from 2.5 to 3 min. The exercises were completed in 4 sets, with 2 to 3 repetitions for multi-joint exercises and 6 to 8 repetitions for the remaining exercises (Table 3).

Measurements of Mechanical Characteristics of the Lower Limbs in the Vertical Jump

Testing was conducted using a validated system for measuring the mechanical characteristics of the lower limbs in the vertical jump (PJS-4P60 by JBA) consisting of a four-sensor force plate (PL-4P80) and MVJ 5v0 software. The four strain gauge force transducers, placed in the corners of the force plate, enabled the measurement of the vertical component of the ground reaction force during the take-off phase of the vertical jump, which was then recorded and analyzed on a computer using the dedicated software. Using the described system, two tests were conducted:

- a CMJ (counter movement jump) test consisted of a vertical two-legged jump from a standing position with an arm swing. The participant stood still and upright on the force plate. Upon the tester's signal, they performed a two-legged vertical jump preceded by a countermovement (lowering of the center of gravity). The participant performed six single jumps, with the first three aimed at achieving maximum jump height (attempting to jump as high as possible) and the next three focused on maximizing take-off power (attempting to push off as quickly as possible). The best attempts were recorded for subsequent analysis.
- a SJ (squat jump) test consisted of a vertical two-legged jump from a standing position without an arm swing, with hands placed on the hips. The participant stood still on the force plate and then performed a half-squat, ensuring the thighs were parallel to the ground. Upon the tester's signal, they performed a vertical jump without lowering their center of gravity before the take-off. The participant completed three single jumps, with a three-minute rest interval in between. The best attempts, where the highest jump height and maximum take-off power were achieved, were recorded for further analysis.

From each test, jump height [m], maximum power [W] and relative maximum power [W/kg] were calculated.

We implemented a double-blind procedure: the individuals analyzing the strength and jump performance data were unaware of the participants' group assignment.

Statistical Analysis

To analyze the obtained results, basic statistical methods were used, including the calculation of the arithmetic mean and standard deviation. The significance of differences among participants from particular groups was calculated using a two-way analysis of variance (ANOVA) in a between-group design. To evaluate the significance of within-group changes (differences in the progression of a given group), the paired samples *t*-test or the non-parametric Wilcoxon signed-rank test for paired observations was applied. To optimize the visualization of the dynamics of changes in the analyzed motor abilities, a percentage growth index (W%) was calculated for each variable using the formula: W% = X_P (final value of the analyzed variable) − X_P (initial value of the analyzed variable) / X_P (final value of the analyzed variable) x 100. The choice of the test was conditioned by checking the conformity of the distribution with the normal distribution, which was verified using the Shapiro-

Wilk test. Furthermore, the effect size was calculated using the Cohen's *d* index ($d = 0.20–0.34$, weak effect; $d = 0.35–0.64$, moderate effect; $d \geq 0.65$, strong effect) (Cohen, 1988). The collected data were analyzed using Statistica software, version 13.3 (Statsoft, Krakow, Poland). The threshold for statistical significance was set at $p < 0.05$.

Results

Table 4 presents the test results (CMJ variables) for the studied groups and their intergroup (PT vs. RT vs. C) and intragroup variation levels.

Relative to the baseline assessment (pre-test), the groups demonstrated a similar level in jump height and relative peak power values in the CMJ. The most favorable results were recorded for the RT group, although without significant differentiation ($p > 0.05$). A different trend was observed for generated peak CMJ power, where the C group showed dominance, and comparative analysis between the groups revealed a significant difference between C vs. PT and RT vs. PT groups ($p < 0.05$).

After the training intervention (post-test), intergroup comparisons did not reveal significant differences in test variable levels ($p > 0.05$). Additionally, the RT group maintained the trend of achieving the most favorable results (jump height, relative peak CMJ power), while the C group exhibited the highest peak CMJ power. Interestingly, the results indicated smaller differences in variable levels (pre-test vs. post-test) when comparing the PT group with RT and C groups, which also resulted in the absence of significant differentiation in peak CMJ power, contrary to the pre-test phase (pre-test PT group: −1216 W deficit compared to the C group; −983 W deficit compared to the RT group, $p < 0.05$ vs. post-test PT: −948 W deficit compared to the C group; −720 W deficit compared to the RT group, $p > 0.05$).

A comparative analysis of intragroup progression demonstrated significant differences (pre-test vs. post-test, $p < 0.05$) in all test variables within the PT group (jump height +7.22%; maximum power +8%; relative power index +8.44% increase). Additionally, moderate effect sizes were observed for the aforementioned variables. However, no significant progression was observed in the RT and C groups for the aforementioned variables ($p > 0.05$).

Table 5 presents the results and the profile of changes for SJ variables, as well as the degree of intergroup and intragroup variation within the studied groups of handball players. The baseline assessment (pre-test) revealed significant differences in peak power and relative peak SJ power in the studied groups ($p < 0.05$). The most effective participants were from the RT group, which additionally demonstrated significant differentiation in comparison with both the PT and C groups. For vertical jump height effects, a similar intergroup level was found across all studied groups ($p > 0.05$).

In the RT group, after the training intervention (pre-test vs. post-test), favorable results for peak SJ power were recorded, with significant differences maintained in comparison with the PT group ($p < 0.05$). Considering SJ height, the PT group presented the best results, while for the relative peak SJ power, the RT group showed the most favorable values. However, the observed intergroup differences were not statistically significant ($p > 0.05$). Similarly to CMJ variables, after the intervention, the PT group recorded more favorable delta (d) values for all test variables, and for relative peak power, there were no significant differences compared to the RT group ($p > 0.05$), which was opposite to the pre-test results ($p < 0.05$). The comparative analysis of efficiency gains within the studied groups demonstrated significant differentiation ($p < 0.05$) for vertical jump height (+10.94%), peak power (+10.15%), and relative peak power (+8.57%) in the PT group. Furthermore, a strong effect size was recorded for SJ height. No such cause-effect relationships were observed in the other groups ($p > 0.05$).

Discussion

The obtained results indicated that both specific power training and conventional resistance training contributed to improving vertical jump performance in youth handball players; however, the nature of these changes differed depending on the applied training method. The power training program, which included dynamic exercises with resistance bands, medicine balls, and reaction time stimulation, led to significant increases in jump height, peak power, and relative peak power in the CMJ test. These results are consistent with previous studies highlighting the impact of targeted plyometric

Articles published in the Journal of Human Kinetics are licensed under an open access Creative Commons CC BY 4.0 license.

training and high-intensity training on the development of explosive lower limb capacity in youth athletes (Faigenbaum, 2018; Fristrup et al., 2024; Lloyd and Oliver, 2013; Stricker et al., 2020).

Table 1. Inclusion and exclusion criteria.

Inclusion criteria	Exclusion criteria
Participation in regular handball training at least three times per week for the past six months.	History of severe musculoskeletal injuries in the past six months that required medical intervention.
No prior participation in interventional studies on training methods within the last 12 months.	Regular use of medications affecting physical performance or hormonal balance (e.g., anabolic steroids).
Willingness to participate in the full research cycle.	Training experience of less than 3 years.
Signed consent from parents or legal guardians, as well as the participants, for participation in the study.	

Table 2. Structure of the training session in the muscle power development program with specification of exercises.

	1	2	3
1	Squat with a power band (PB)	Lunge with a PB	Bulgarian split squat with a PB
2	Overhead press with both hands using a PB	Push-up with PB resistance	Diagonal PB press in a kneeling position
3	Single-leg deadlift with a jump and a medicine ball	Drop jump from a bench with a medicine ball	Box jump with a medicine ball
4	One-handed medicine ball chest pass	Overhead medicine ball throw	Medicine ball throw upwards against a wall
5	Pallof press with a PB	PB press with torso rotation	Diagonal PB pull-down
6	Medicine ball rotational throw against the wall toward the illuminated light disk	Medicine ball chest pass with a forward jump on a light disk signal	Medicine ball chest pass with a 5-m sprint on a light disk signal
7	Lateral step with PB resistance and reaction to the light disk	Lateral step with a medicine ball overhead and a jump toward the light disk	Sit-ups from a supine position with a medicine ball toward the light disk
8	Forward and backward movement with PB resistance toward the light disk	Lateral step with a medicine ball overhead and an overhead jump throw toward the light disk.	Reaction to light disks while holding a medicine ball

PB: powerband

Table 3. Structure of the training session in the standard resistance training program with specification of exercises.

	1	2	3
1	Overhead press	Squat low bar	Bulgarian split squat
2	Romanian deadlift	Single-arm bent-over row	Front foot elevated split squat
3	Single leg step up	Cossac lunge	Hip thrust with a barbell
4	Nordic curls	Dumbell hammer biceps curl	Wall sit holds
5	Isometric split squat	Chest supported T-bar row	Chin up with a neutral grip
6	Turkish get up	Banded dumbell chest press	Kickstand trapbar deadlift
7	Lat pull-down	One leg lying hamstring curl	Banded power rows
8	Farmer walk	Single leg drop	Weighted sissy squat

Table 4. Statistical characteristics of the results for the CMJ variables and their intergroup and intragroup variability in the studied groups (PT vs. RT vs. C) of handball players (n = 48).

Measurement	PT Group (n = 16)	RT Group (n = 16)	C Group (n = 16)	d Δ (group)	p_1
	$\tilde{x}$ ± sd	$\tilde{x}$ ± sd	$\tilde{x}$ ± sd		
CMJ: vertical jump height [cm]					
I pre-test	39.47 ± 6.33	45.21 ± 8.63	43.44 ± 5.43	2: +5.74 (vs. 1), +1.77 (vs. 3); 2: +3.97 (vs. 1)	>0.05
II post-test	42.54 ± 6.82	45.87 ± 7.52	44.31 ± 5.55	2: +3.33 (vs. 1), +1.56 (vs. 3); 3: +1.77 (vs. 1)	>0.05
W%	7.22	1.44	1.96	-	-
p_2	<0.05†	>0.05	>0.05	-	-
d_c	0.47[a]	0.08	0.16	-	-
CMJ: peak jump power [W]					
I pre-test	3760 ± 887	4743 ± 703	4976 ± 881	3: +1216 (vs. 1), +233 (vs. 2); 2: +983 (vs. 1)	3–1; 2–1*
II post-test	4085 ± 896	4805 ± 696	5033 ± 897	3: +948 (vs. 1), +228 (vs. 2); 2: +720 (vs. 1)	>0.05
W%	8.00	1.29	1.13	-	-
p_2	<0.05†	>0.05	>0.05	-	-
d_c	0.36[a]	0.09	0.06	-	-
CMJ: relative jump power [W/kg]					
I pre-test	53.18 ± 8.91	64.67 ± 7.18	60.95 ± 7.73	2: +11.49 (vs. 1), +3.72 (vs. 3); 3: +7.77 (vs. 1)	>0.05
II post-test	58.08 ± 8.18	65.43 ± 6.76	61.46 ± 7.54	2: +7.35 (vs.1), +3.97 (vs. 3); 3: +3.38 (vs. 1)	>0.05
W%	8.44	1.16	0.83	-	-
p_2	<0.05†	>0.05	>0.05	-	-
d_c	0.57[a]	0.11	0.07	-	-

*PT: players following power training; RT: players following resistance training; C: players following standard training; $\tilde{x}$: arithmetic mean; sd: standard deviation; I: first measurement period (pre-test); II: second measurement period (post-test); W: watt (1W = 1 joule/second). Inter-group differentiation: dΔ: difference between means (delta); p_1: level of significance (intergroup); *: a statistically significant level of differentiation ($p < 0.05$); group designation: 1: PT group, 2: RT group, 3: C group. Intra-group differentiation: W%: progression coefficient; p_2: level of significance (intra-group); †: a statistically significant level of differentiation; d_C: effect size expressed using Cohen's d coefficient (intra-group); [a] moderate effect; [b] strong effect*

Articles published in the Journal of Human Kinetics are licensed under an open access Creative Commons CC BY 4.0 license.

Table 5. Statistical characteristics of the results for the SJ variables and their intergroup and intragroup variability in the studied groups (PT vs. RT vs. C) of handball players (n = 48).

Measurement	PT Group (n = 16)	RT Group (n = 16)	C Group (n = 16)	d (group)	p_1
	$\tilde{x}$ ± sd	$\tilde{x}$ ± sd	$\tilde{x}$ ± sd		
SJ: vertical jump height [cm]					
I pre-test	35.32 ± 6.08	36.11 ± 4.11	33.51 ± 3.22	2: +0.79 (vs. 1), +2.60 (vs. 3); 1: +1.81 (vs. 3)	>0.05
II post-test	39.66 ± 5.39	36.61 ± 4.66	34.20 ± 2.87	1: +3.05 (vs. 2), +5.46 (vs. 3); 2: +2.41 (vs. 3)	>0.05
W%	10.94	1.37	2.02	-	-
p_2	<0.05†	>0.05	>0.05	-	-
d_c	0.76[b]	0.11	0.23	-	-
SJ: maximum jump power [W]					
I pre-test	3366 ± 1063	5061 ± 929	3749 ± 1054	2: +1695 (vs. 1), +1312 (vs. 3); 3: +383 (vs. 1)	2–1; 2–3*
II post-test	3746 ± 1166	5023 ± 871	3802 ± 1023	2: +1277 (vs. 1), +1221 (vs. 3); 3: +56 (vs. 1)	2–1*
W%	10.15	−0.76	1.39	-	-
p_2	<0.05†	>0.05	>0.05	-	-
d_c	0.34	0.04	0.05	-	-
SJ: relative jump power [W/kg]					
I pre-test	48.73 ± 14.76	66.99 ± 11.47	48.64 ± 10.22	2: +18.26 (vs. 1), +18.35 (vs. 3); 1: +0.09 (vs. 3)	2–1; 2–3*
II post-test	53.30 ± 15.75	67.06 ± 11.38	50.04 ± 9.83	2: +13.76 (vs. 1), +17.02 (vs. 3); 1: +3.26 (vs. 3)	>0.05
W%	8.57	0.10	2.80	-	-
p_2	<0.05†	>0.05	>0.05	-	-
d_c	0.30	0.01	0.14	-	-

*PT: players following power training; RT: players following resistance training; C: players following standard training; $\tilde{x}$: arithmetic mean; sd: standard deviation; I: first measurement period (pre-test); II: second measurement period (post-test); W: watt (1W = 1 joule/second). Inter-group differentiation: d: difference between means (delta); p_1: level of significance (intergroup); *: a statistically significant level of differentiation ($p < 0.05$); group designation: 1: PT group, 2: RT group, 3: C group. Intra-group differentiation: W%: progression coefficient; p_2: level of significance (intra-group); †: a statistically significant level of differentiation; d_C: effect size expressed using Cohen's d coefficient (intra-group); [a] moderate effect; [b] strong effect*

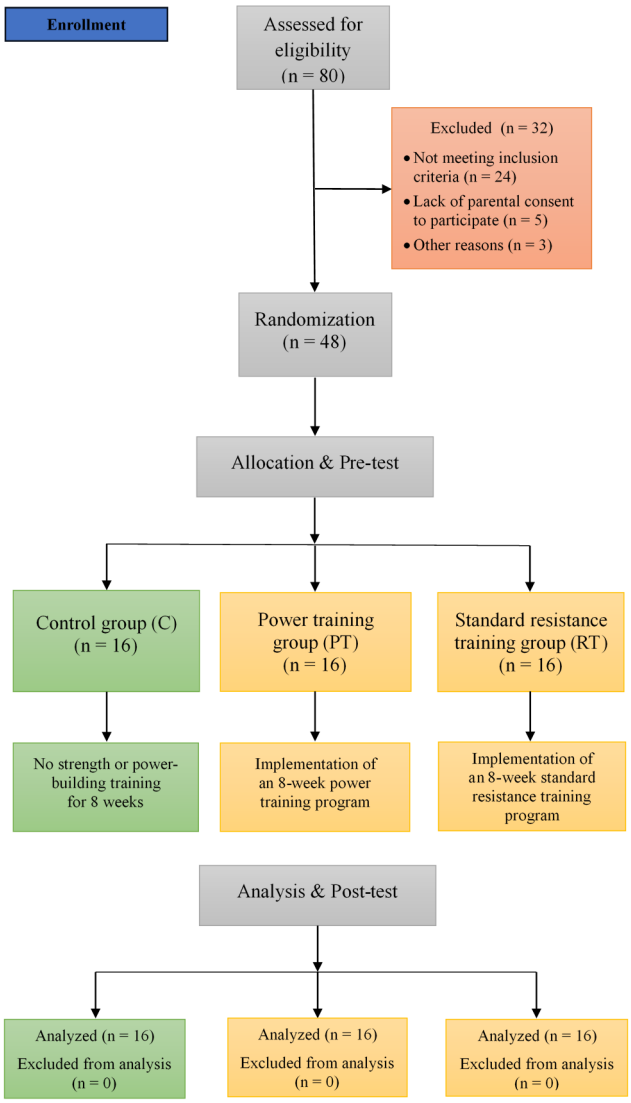

Figure 1. CONSORT flow diagram presenting the course of the study.

Regarding the mechanisms underlying these results, while the power training group showed improvements in explosive performance, the specific contribution of nervous system stimulation and more effective motor unit recruitment in movements requiring rapid force generation remain speculative, as these factors were not directly assessed. Nevertheless, this interpretation is aligned with previous evidence on post-activation potentiation enhancement (PAPE), which increases the muscle's ability to generate greater force in a short time, particularly after isometric muscle contractions (Hammami et al., 2018; Kasicki et al., 2024; Maroto-Izquierdo et al., 2020; Stastny et al., 2024). It is also possible that exercises included in the specific power training program, particularly those engaging reaction time and neuromuscular coordination, contributed to

Articles published in the Journal of Human Kinetics are licensed under an open access Creative Commons CC BY 4.0 license.

improved muscle synchronization and the efficiency of explosive movements (Prończuk et al., 2025).

The intragroup progression analysis demonstrated that in the group following power training, jump height and generated power increased significantly to a greater extent than in other groups. This suggests that training focused on explosive abilities and neuromuscular response is more effective in improving jump performance than standard resistance training, which, while promoting maximal strength development, does not always translate into dynamic sports performance efficiency (Beato et al., 2019; Chaouachi et al., 2014; Mcweeny et al., 2020; Tricoli et al., 2005). Interestingly, these results may indicate that conventional resistance training is less effective in improving jump performance compared to power-focused training, although some improvements were still observed, which may result from the dominance of hypertrophic over neural adaptations and the reduced involvement of the stretch-shortening cycle in this type of training.

Additionally, the lack of significant differences among groups in terms of changes in body mass and lean muscle mass suggests that the eight-week training intervention had a greater impact on neuromuscular adaptations than structural changes. These results are consistent with previous research indicating that explosive training yields greater benefits for dynamic development in youth athletes than traditional strength training aimed at muscle hypertrophy (Molina-López et al., 2020). However, it should be noted that a longer strength training intervention could lead to more pronounced structural adaptations, which may also influence explosive abilities in the long run.

In summary, the results of this study confirm the importance of selecting appropriate training methods in the athletic preparation of youth handball players. The effectiveness of interventions based on dynamic exercises targeting power and speed is supported by previous research on plyometric training and high-intensity eccentric-concentric contraction methods (Haff and Haff, 2019; Lloyd et al., 2016). Future studies should focus on the long-term effects of different training methods and their impact on performance stability over the course of a competitive season.

Limitations of the Study

A limitation of the study is the relatively short, eight-week intervention period, which may not have allowed for the full observation of long-term adaptations, particularly in terms of structural changes, such as muscle mass gain. Additionally, the lack of assessment of biological maturity among participants may represent a significant factor influencing the results, as individual maturation rates could have affected the body's response to the applied training methods.

Although the sample size was sufficient for statistical analyses, it may have limited the detection of subtle differences among groups and individual responses to training. Furthermore, the study did not include detailed biomechanical and physiological variables, such as muscle activation, movement dynamics, or fatigue levels, which could have provided more comprehensive insights into the mechanisms responsible for the observed effects. Future studies incorporating surface EMG should follow current methodological standards for signal normalization and analysis (Skalski et al., 2025b).

Another limitation is the lack of long-term monitoring, making it unclear whether the improvements in jump performance and muscle power persisted after the intervention. Future research should consider assessing biological age, increasing sample size, and analyzing the long-term sustainability of adaptations.

Future Recommendations

Future studies should extend the intervention beyond eight weeks—ideally to at least twelve weeks—to allow sufficient time for both neuromuscular and hypertrophic adaptations to manifest. It is also essential to assess biological maturity (for example, by estimating peak height velocity) so that inter-individual differences in growth and maturation can be accounted for when evaluating the effects of PAPE protocols. Finally, incorporating follow-up testing post-intervention will help determine the durability of any performance gains observed.

Conclusions

1. Specific power training demonstrated significant effectiveness in improving explosive

lower limb capacity, which may contribute to better vertical jump performance in youth handball players.
2. Conventional resistance training enhanced maximal strength, but its impact on jump performance was not as pronounced as in training focused on power.
3. The lack of significant changes in body mass and lean muscle mass suggests that the eight-week training intervention primarily influenced neuromuscular adaptations rather than structural changes.
4. The obtained results confirmed the validity of implementing power training in the motor preparation programs of youth athletes, especially in sports where jumping and explosiveness are crucial for game performance.

Practical Implications

Power-oriented training more effectively improves jump performance in youth handball players than conventional resistance training. Dynamic exercises, plyometrics, and reaction time drills should be permanent components of motor preparation. Traditional strength training should be supplemented with methods that enhance explosiveness. Individualizing training based on the biological maturity of athletes may increase adaptation effectiveness. Longer-term monitoring of effects would provide a better assessment of the durability of the observed changes.

Author Contributions: Conceptualization: M.S., K.Z. and K.M.; methodology: M.S., K.Z. and Ł.R.; software: M.S., K.Z. and W.W.; validation: M.S., T.A. and Ł.R.; formal analysis: M.S., K.Z. and Ł.R.; investigation: M.S. and K.Z.; resources: M.S. and K.Z.; data curation: M.S., K.Z. and K.K.; writing—original draft preparation: M.S., K.Z., W.W. and K.K.; writing—review & editing: M.S., K.Z., T.A. and Ł.R.; visualization: W.W. and K.K.; supervision: M.S. and Ł.R.; project administration: M.S.; funding acquisition: M.S. All authors have read and agreed to the published version of the manuscript.

ORCID iD:

Michał Spieszny: https://orcid.org/0000-0002-9934-6911

Kazimierz Mikołajec: https://orcid.org/0000-0002-5234-1339

Wojciech Wąsacz: https://orcid.org/0000-0002-7392-5229

Krzysztof Kasicki: https://orcid.org/0009-0008-9231-8353

Tadeusz Ambroży: https://orcid.org/0000-0001-7361-9478

Łukasz Rydzik: https://orcid.org/0000-0001-7956-7488

Funding Information: This research received no external funding.

Institutional Review Board Statement: This study was conducted following the principles of the Declaration of Helsinki, and approved by the Bioethics Committee at the Regional Chamber of Physicians in Cracow, Cracow, Poland (protocol code: 205/KBL/OIL/2022; approval date: 16 September 2022).

Informed Consent: Informed consent was obtained from all participants included in the study.

Conflicts of Interest: The authors declare no conflict of interest.

Received: 02 March 2025

Accepted: 27 November 2025

Articles published in the Journal of Human Kinetics are licensed under an open access Creative Commons CC BY 4.0 license.

References

Abbass, M., & Khalil, M. (2019). Comparing Some Biomechanical Variables of One Leg and Two Legs Jump Shot In Handball. *Journal of Physical Education*, *31*(2), 215–222.

Akbar, S., Kim Geok, S., Bashir, M., Jazaily Bin Mohd, N. N., Luo, S., & He, S. (2024). Effects of Different Exercise Training on Physical Fitness and Technical Skills in Handball Players. A Systematic Review. *Journal of Strength and Conditioning Research*, *38*(11), e695–e705.

Arede, J., Sevin, I. P., Williams, M., Mikolajec, K., Birrento, R., & Schöllhorn, W. (2025). Velocity and Acceleration-Based Differential Plyometric Training Effects on Young Basketball Players. *Journal of Human Kinetics*, *96*(Spec Issue), 145–161.

Blecharz, J., Wrześniewski, K., Siekańska, M., Ambroży, T., & Spieszny, M. (2022). Cognitive Factors in Elite Handball: Do Players' Positions Determine Their Cognitive Processes? *Journal of Human Kinetics, 82*, 213–221.

Mcweeny, D. K., Boule, N. G., Neto, J. H. F., & Kennedy, M. D. (2020). Effect of high intensity functional training and traditional resistance training on aerobic, anaerobic, and musculoskeletal fitness improvement. *Journal of Physical Education and Sport*, *20*(4), 1791 –1802.

Beato, M., Bigby, A. E., De Keijzer, K. L., Nakamura, F. Y., Coratella, G., & McErlain-Naylor, S. A. (2019). Post-activation potentiation effect of eccentric overload and traditional weightlifting exercise on jumping and sprinting performance in male athletes. *PloS One*, *14*(9), e0222466.

Cadens, M., Planas-Anzano, A., Peirau-Terés, X., Benet-Vigo, A., & Fort-Vanmeerhaeghe, A. (2023). Neuromuscular and biomechanical jumping and landing deficits in young female handball players. *Biology*, *12*(1), 134.

Chaouachi, A., Hammami, R., Kaabi, S., Chamari, K., Drinkwater, E. J., & Behm, D. G. (2014). Olympic weightlifting and plyometric training with children provides similar or greater performance improvements than traditional resistance training. *The Journal of Strength and Conditioning Research*, *28*(6), 1483–1496.

Cohen, J. (1988). Statistical Power Analysis for the Behavioral Sciences (2nd ed.). Hillsdale, NJ: *Lawrence Erlbaum Associates*, Publishers.

Della Corte, J., de Souza, R. A., da Silva, J. B., Neves, E. B., Torres, J. P. B., de Castro, J. B. P., & e Silva, L. D. L. (2021). Performance of Brazilian university handball players in the vertical jump after maximum strength training. *Bioscience Journal*, *37*, e37058.

Faigenbaum, A. D. (2018). Youth resistance training: The good, the bad, and the ugly–The year that was 2017. *Pediatric Exercise Science*, *30*(1), 19–24.

Falch, H. N., Haugen, M. E., Kristiansen, E. L., & van den Tillaar, R. (2022). Effect of strength vs. plyometric training upon change of direction performance in young female handball players. *International Journal of Environmental Research and Public Health*, *19*(11), 6946.

Fernandez-Fernandez, J., Granacher, U., Martinez-Martin, I., Garcia-Tormo, V., Herrero-Molleda, A., Barbado, D. & Garcia-Lopez, J. (2022). Physical fitness and throwing speed in U13 versus U15 male handball players. *BMC Sports Science, Medicine and Rehabilitation*, *14*(1), 1–3.

Fristrup, B., Krustrup, P., Petz, A. K., Bencke, J., Zebis, M. K., & Aagaard, P. (2024). Effects of Off-Season Heavy-Load Resistance Training on Lower Limb Mechanical Muscle Function and Physical Performance in Elite Female Team Handball Players. *Journal of Functional Morphology and Kinesiology*, *9*(4), 268.

Gaamouri, N., Hammami, M., Cherni, Y., Oranchuk, D., van den Tillaar, R. & Chelly, M. S. (2024). Rubber Band Training Improves Athletic Performance in Young Female Handball Players. *Journal of Human Kinetics*, *92*, 227–238.

Haff, G. G., & Haff, E. E. (2019). Weightlifting for young athletes. In: *Strength and Conditioning for Young Athletes* (pp. 155–187). Routledge.

Hammami, M., Gaamouri, N., Cherni, Y., Chelly, M. S., Hill, L., & Knechtle, B. (2022). Effects of contrast strength training with elastic band program on sprint, jump, strength, balance and repeated change of direction in young female handball players. *International Journal of Sports Science and Coaching*, *17*(5), 1147–1157.

Hammami, R., Sekulic, D., Selmi, M. A., Fadhloun, M., Spasic, M., Uljevic, O., & Chaouachi, A. (2018). Maturity status as a determinant of the relationships between conditioning qualities and preplanned agility in young handball athletes. *Journal of Strength and Conditioning Research*, *32*(8), 2302–2313.

Heuvelmans, P., Gokeler, A., Benjaminse, A., Baumeister, J., & Büchel, D. (2025). Agility in Handball: Position- and Age-Specific Insights in Performance and Kinematics Using Proximity and Wearable Inertial Sensors. *Sensors, 25*(9), 2728.

Hoffman, J. (2011). *NSCA's guide to program design*. Human Kinetics.

Igor, I., Slavka, D., Saša, B., Bojan, B., Nikola, A., & Tatiana, D. (2023). Impact of Explosive Strength on Shot Speed in Handball. *Gymnasium*, *24*(2), 109–119.

Jakšić, D., Maričić, S., Maksimović, N., Bianco, A., Sekulić, D., Foretić, N., & Drid, P. (2023). Effects of additional plyometric training on the jump performance of elite male handball players: A systematic review. *International Journal of Environmental Research and Public Health*, *20*(3), 2475.

Kačúr, P., & Eliaš, T. (2024). Age-related and experience-related differences in selected motor cognitive abilities of soccer players. *Journal of Kinesiology and Exercise Sciences, 34*(108), 1–9.

Karcher, C., & Buchheit, M. (2014). On-court demands of elite handball, with special reference to playing positions. *Sports Medicine*, *44*, 797–814.

Kasicki, K., Rydzik, Ł., Ambroży, T., Spieszny, M., & Koteja, P. (2024). The Impact of Post-Activation Performance Enhancement Protocols on Vertical Jumps: Systematic Review. *Applied Sciences*, *14*(21), 9664.

Krzysztofik, M., Spieszny, M., Trybulski, R., Wilk, M., Pisz, A., Kolinger, D., Filip-Stachnik, A., & Stastny, P. (2023). Acute effects of isometric conditioning activity on the viscoelastic properties of muscles and sprint and jumping performance in handball players. *Journal of Strength and Conditioning Research*, *37*(7), 1486–1494.

Kyriacou-Rossi, A., Hadjicharalambous, M., & Zaras, N. (2024). The Influence of Strength Level on Handball-Specific Fitness Elements Between Stronger and Weaker Professional Players. *Journal of Strength and Conditioning Research, 38*(5), 966–975.

Lloyd, R. S., & Oliver, J. (2013). *Strength and conditioning for young athletes*. Abingdon: Taylor & Francis.

Lloyd, R. S., Cronin, J. B., Faigenbaum, A. D., Haff, G. G., Howard, R., Kraemer, W. J., Micheli, L. J., Myer, G. D., & Oliver, J. L. (2016). National Strength and Conditioning Association position statement on long-term athletic development. *Journal of Strength and Conditioning Research*, *30*(6), 1491–1509.

Maroto-Izquierdo, S., Bautista, I., & Rivera, F. (2020). Post-activation performance enhancement (PAPE) after a single-bout of high-intensity flywheel resistance training. *Biology of Sport*, *37*(4), 343–350.

McGhie, D., Østerås, S., Ettema, G., Paulsen, G., & Sandbakk, Ø. (2020). Strength determinants of jump height in the jump throw movement in women handball players. *Journal of Strength and Conditioning Research*, *34*(10), 2937–2946.

Michalsik, L. B., Madsen, K., & Aagaard, P. (2015). Technical match characteristics and influence of body anthropometry on playing performance in male elite team handball. *Journal of Strength and Conditioning Research*, *29*(2), 416–428.

Miller, T. A. (2012). *NSCA's Guide to Tests and Assessments*. Human Kinetics.

Molina-López, J., Barea Zarzuela, I., Sáez-Padilla, J., Tornero-Quiñones, I., & Planells, E. (2020). Mediation effect of age category on the relationship between body composition and the physical fitness profile in youth handball players. *International Journal of Environmental Research and Public Health*, *17*(7), 2350.

Prończuk M, Skalski D, Łosińska K, Maszczyk A and Gołaś A (2025) Neuromechanical adaptations to EMG-guided SSC training in elite badminton players: a predictive multivariate approach. *Front. Sports Act. Living* 7:1634656. doi: 10.3389/fspor.2025.1634656

Articles published in the Journal of Human Kinetics are licensed under an open access Creative Commons CC BY 4.0 license.

Radovic, K., Cabarkapa, D., Aleksic, J., Cabarkapa, D. V., Mirkov, D. M., Knezevic, O. M., & Fry, A. C. (2024). Vertical jump neuromuscular performance of professional female handball players–starters vs. non-starters comparison. *Frontiers in Sports and Active Living*, *6*, 1–6.

Russomanno, T. G., Lam, H., Knopp, M., Huang, H., Stadtlander, T., & Lames, M. (2021). Within-match performance dynamics–Momentary strength in handball. *Journal of Human Kinetics*, *79*(1), 211–219.

Saavedra, J. M., Halldórsson, K., Kristjánsdóttir, H., Þorgeirsson, S., & Sveinsson, G. (2019). Anthropometric charachteristics, physical fitness and the prediction of throwing velocity in handball men young players. *Kinesiology*, *51*(2), 253–260.

Sáez de Villarreal, E., Bago Rascón, P., Ortega-Becerra, M., Calleja-Gonzalez, J., Alcaraz, P. E., Feito-Blanco, J. & Ramirez-Campillo, R. (2024). Effects of Sand Surface Plyometric and Sprint Training on Physical and Technical Skill Performance in Beach Handball Players. *Journal of Human Kinetics*, *90*, 227–237.

Skalski, D., Prończuk, M., Stastny, P., Łosińska, K., Drozd, M., Toborek, M., Aschenbrenner, P., & Maszczyk, A. (2025a). Evaluation of the Impact of External Conditions on Arm Positioning During Punches in MMA Fighters: A Comparative Analysis of 2D and 3D Methods. *Sensors, 25*(11), 3270.

Skalski DT, Pronczuk M, Losinska K, Lulinska E, Motowidlo J, Aschenbrenner P, Zurowska-Cegielska J, Bartosz-Jefferies M, Maszczyk A. (2025b). Electromyography normalization and assessment methods for muscle activity: A systematic review and meta-analysis. *Balt J Health Phys Act. 17*(3), 2-18.

Spieszny, M., & Zubik, M. (2018). Modification of strength training programs in handball players and its influence on power during the competitive period. *Journal of Human Kinetics*, *63*(1), 149–160.

Stastny, P., Kolinger, D., Pisz, A., Wilk, M., Petruzela, J., & Krzysztofik, M. (2024). Effects of Eccentric Speed during Front Squat Conditioning Activity on Post-activation Performance Enhancement of Hip and Thigh Muscles. *Journal of Human Kinetics, 91*, 5–18.

Stricker, P. R., Faigenbaum, A. D., & McCambridge (2020). Resistance Training for Children and Adolescents. *Pediatrics*, *145*(6), e20201011.

Tricoli, V., Lamas, L., Carnevale, R., & Ugrinowitsch, C. (2005). Short-term effects on lower-body functional power development: weightlifting vs. vertical jump training programs. *Journal of Strength and Conditioning Research*, *19*(2), 433–437.

Tuquet, J., Mainer Pardos, E., Cartón-Llorente, A., Roso-Moliner, A., García-Buendía, G., & Lozano, D. (2025). Importance of Jumping Ability in Handball Throwing Speed and Accuracy. *Journal of Visualized Experiments, 218,* e67443.

Wagner, H., Sperl, B., Bell, J. W., & Von Duvillard, S. P. (2019). Testing specific physical performance in male team handball players and the relationship to general tests in team sports. *Journal of Strength and Conditioning Research*, *33*(4), 1056–1064.

World Medical Association. (2013). *World Medical Association Declaration of Helsinki: Ethical principles for medical research involving human subjects*. WMA.

Xu, J., Turner, A., Comyns, T. M., Chavda, S., & Bishop, C. (2024). The Countermovement Rebound Jump: Between-Session Reliability and a Comparison with the Countermovement and Drop Jump Tests. *Journal of Strength and Conditioning Research, 38*(4), e150–e159.

Zatsiorsky, V. M., Kraemer, W. J., & Fry, A. C. (2020). *Science and practice of strength training*. Human Kinetics.