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SEX-BASED MULTIDIMENSIONAL ANALYSIS OF EXPLOSIVE POWER IN HANDBALL PLAYERS

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ABSTRACT

In this cross-sectional study, we examined sex-based differences in explosive power among 32 second-division handball players (17 women, 15 men). Participants completed five field-based tests of explosive power: 20 m Sprint (S20M), countermovement jump (CMJ), standing long jump (SLJ), supine medicine-ball throw (SUMT), and seated medicine-ball throw (STMT). Descriptive statistics (minimum, maximum, and mean differences) were visualised using box-and-whisker plots, and data normality was confirmed with the Shapiro–Wilk test. A one-way multivariate analysis of variance indicated that sex explained 86% of the combined variance across all tests (Wilks' $\lambda = 0.141$, $F(5, 26) = 31.7$, $p < 0.001$). Follow-up univariate analyses revealed statistically significant differences in every test ($p < 0.001$) with large effect sizes (partial $\eta^2 = 0.46–0.82$). Men outperformed women by 27% in the SUMT and 22% in the STMT, achieved 31% higher CMJ values, completed the S20M 21% faster, and recorded 9% longer SLJ distances. These results demonstrate substantial sex disparities in whole-body power, upper-body power, lower-body power at the sub-elite level. Emphasising short-distance sprinting, jump training, and upper-body throwing exercises in women's conditioning programmes may yield significant performance gains and provide evidence-based benchmarks for talent development.

Key words: sex differences, team-sport athletes, performance profiling, power assessment, multivariate analysis, explosive strength

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INTRODUCTION

Explosive power represents one of the fundamental motor abilities that significantly determines athletic success. This motor ability can be defined as the organism's capacity to generate maximum force in the shortest possible time (Newton & Kraemer, 2006). From a physiological perspective, explosive power represents the product of complex synergy between the nervous system and muscle tissue, where rapid motor unit activation combines with maximal force production by muscle tissue (Cormie et al., 2011a). This motor ability is particularly important in sports involving high-intensity ballistic movements, such as jumping, sprinting, and throwing, making it a key factor in athletic performance (Pereira et al., 2018).

Handball, as a representative of polystructural sports games, is characterised by complex demands that place multidimensional motor and cognitive tasks before players (Bragazzi et al., 2020; Ilić, 2015). These demands encompass the ability to rapidly change direction of movement, execute explosive vertical movements in offensive and defensive phases of the game, as well as perform powerful ball throws toward the goal. The ball projectile velocity during goal shots, which can reach values exceeding 120 km/h in elite players, is directly related to the explosive power of the upper extremity muscles (Gaamouri et al., 2023; Ilić et al., 2020; Petronijević et al., 2025). Simultaneously, the ability to rapidly start, exhibit agility in changing direction of movement, and display explosiveness in jumping activities during attack and defence makes the explosive power of the lower extremities equally crucial for success in handball performance (Aksović et al., 2022; Cormie et al., 2011b; Vila, 2023). These components position explosive power as one of the primary motor determinants that directly influences the efficiency of executing technical and tactical elements in handball.

Effective explosive power development requires periodised training approaches that adapt to the varying demands across the handball season (Spieszny & Zubik, 2018). The preparatory phase emphasises maximal strength development and plyometric exercises, while the competitive period focuses on maintaining power adaptations through reduced-volume, sport-specific training (Cormie et al., 2010; Marques & González-Badillo, 2006).

Contemporary research in the domain of sports science indicates the existence of significant differences in explosive power between males and females. The foundation of these differences lies in complex interactions of anatomical and physiological characteristics. In men, a greater volume of muscle mass and dominance of fast-twitch muscle fibre type II are observed (Hammami et al., 2019; Lu et al., 2024; Stanković et al., 2025). Additionally, elevated concentrations of androgenic hormones stimulate muscle fibre hypertrophy and increase contractile force (Handelsman et al., 2018). The magnitude of these sex differences in explosive power varies within a wide spectrum from 15% to 50% (Coelho-Júnior et al., 2024). These differences are most pronounced in upper-body muscle groups, with less but still significant advantages observed in the lower extremities, all of which favour men (Aouichaoui et al., 2024). Whether this pattern holds in handball, and which specific tests best discriminate between sexes, remains unclear, particularly in second-division contexts where comparative data between sexes are scarce.

In handball, sex differences in explosive power gain additional complexity due to the specific demands of this sport (Ilić et al., 2023; Thibault et al., 2010). Research emphasises that male handball players achieve superior results in standardised explosive power tests, including vertical jump, medicine ball throw, and short-distance sprints. These differences are manifested during gameplay, where men demonstrate higher ball throwing velocities and better performance in situations requiring explosive muscle activation (Pereira et al., 2018). However, it is essential to emphasise that these differences cannot be universally applied to all segments of handball performance. Female handball players often compensate for lower explosive power through superior technique execution, tactical understanding, and movement coordination, allowing them to meet the sport's physical demands effectively (Michalsik & Aagaard, 2015). It is also important to note that most available data are derived from elite or youth-level athletes (Ilić et al., 2014). Little is known about sub-elite competitors, where talent pathways and training resources differ significantly (Osborne et al., 2025; Pereira et al., 2018). Establishing sex-specific reference values at this level is therefore essential for athlete profiling and training program design guidance (Wagner et al., 2019).

This study aims to examine sex-based differences in the explosive power of handball players competing in the second-highest Serbian handball league.

METHODS

Participants

A purposive sampling strategy was used to select 32 competitive handball players: 17 women (age 21.88 ± 0.92 years, body height 173.53 ± 3.52 cm, body mass 59.00 ± 3.74 kg), and 15 men (age 26.00 ± 2.90 years, body height 179.27 ± 4.74 cm, body mass 78.69 ± 16.47 kg). All players represented clubs competing in the second-highest tier of the national handball league system in Serbia. Eligibility required ≥ 5 years of playing experience and regular training of ≥ 4 sessions per week during the current season. All participants were free of musculoskeletal injury or medical conditions and were not taking performance-affecting medication. Players, coaches, and medical staff received detailed information about the study and provided written informed consent prior to data collection. The study was approved by the Ethics Committee of the Faculty of Sport and Physical Education, University of Priština in Kosovska Mitrovica (approval No. 03-541) and conducted according to the principles of the Helsinki Declaration.

Variables

Grouping variable

- Sex (SEX): coded as female for women and male for men.

Explosive-power test variables

- 20 m Sprint (S20M) – time required to cover 20 m on an indoor court, recorded to the nearest 0.01 second (s);
- Countermovement jump (CMJ) – vertical jump height achieved with an arm-swing countermovement, measured in centimetre (cm);
- Standing long jump (SLJ) – horizontal distance jumped from a standing start, measured to the nearest centimetre (cm);
- Supine medicine-ball throw (SUMT) – distance of a two-handed chest pass while supine, measured in centimetres (cm);
- Seated medicine-ball throw (STMT) – distance of a two-handed chest pass while seated, measured in centimetres (cm).

Procedures

Explosive power testing was performed under controlled conditions during regular afternoon training sessions in the competitive season with male and female handball players. All tests were completed within a single day at an indoor sports facility, where air temperature was maintained between 20–22 °C to standardise environmental conditions. Participants wore standard athletic attire consisting of shorts, T-shirts, socks, and athletic shoes to minimise external factors influencing performance. The attire standardisation aimed to eliminate potential external factors that could influence testing results.

Participants received detailed written instructions describing test process three days before testing. Before beginning the warm-up, participants received additional verbal instructions and practical demonstrations for each specific test to ensure comprehension. This two-stage instructional approach was designed to maximise participant familiarity with the test protocols.

Testing followed a workstation format. A team of ten researchers, two on each workstation, oversaw the testing procedures. Team members underwent prior training specific to the testing procedures. All tests were recorded in a 120 frames per second video using the D5300 camera (Nikon, Japan), and the data were extrapolated using Kinovea motion analysis software (Version 2023.1.2).

A standardised 20-minute warm-up was conducted, comprising stretching exercises for gradual muscle activation, moderate-intensity running, and exercises specific to the movements involved in the explosive power tests. This warm-up aimed to optimally prepare the neuromuscular system for maximal effort.

Participants completed five field-based explosive-power tests under standardised indoor conditions. Each test was performed with maximal effort, with three attempts allowed and the best result used for analysis. Participants had adequate recovery time between attempts and sufficient rest periods between tests, following a predetermined sequence to minimise fatigue effects and allow optimal performance in each test.

For the 20 m sprint, athletes ran from a standing start on a flat indoor court. Sprint times were recorded at the start and finish lines (accuracy: ±0.01 s). For the countermovement jump (CMJ), participants stood upright with hands on hips and executed a maximal vertical jump following a rapid downward movement to approximately 90° of knee flexion. Jump height was calculated from flight time using an optical measurement system (accuracy: ±1 cm). In the standing long jump, participants performed a maximal forward jump using a double-leg take-off and natural arm swing. Horizontal distance from the take-off line to the nearest landing mark was measured with a tape measure (accuracy: ±1 cm). In the supine medicine-ball throw, participants lay on their backs with knees and hips bent at 90°, holding a 1kg ball at chest level. They performed a maximal vertical chest-pass throw while keeping their back in contact with the mat. Distance was measured from the release point to the ball's first ground contact (accuracy: ±1 cm). In the seated medicine-ball throw, participants sat against a wall with legs extended, holding a 1 kg ball at chest level. They executed a maximal horizontal chest-pass throw while maintaining contact with the wall. Throwing distance was measured from the wall to the ball's first contact point on the ground (accuracy: ±1 cm).

Statistical analysis

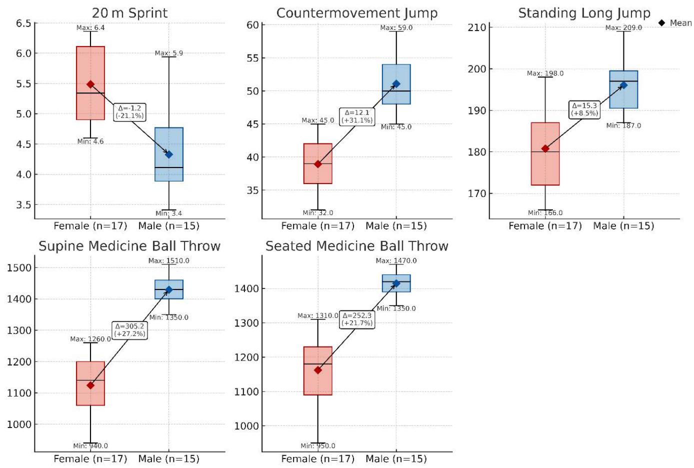
Descriptive statistics that included the minimum, maximum, and mean difference between women and men were calculated for every explosive-power test and displayed using box-and-whisker plots. A one-way multivariate analysis of variance (MANOVA) examined the combined effect of sex on all five tests, reporting Wilks' lambda (λ) and the associated p value. When the MANOVA was significant, follow-up univariate analyses of variance (ANOVAs) were carried out for each test, presenting group means ± standard deviation, conducted, reporting group means and standard deviations, percentage differences between sexes, Shapiro–Wilk normality test outcomes, two-tailed p-values, and partial eta-squared (η^2) as the effect size measure. Effect size interpretations followed Cohen's (1988) conventions: partial η^2 values of 0.01, 0.06, and 0.14 representing small, medium, and large effects, respectively. Canonical discriminant analysis was performed to identify which combination of explosive power variables best discriminated between sexes, providing standardized coefficients and structure correlations to interpret the relative contribution of each test to group separation

All analyses were performed with IBM SPSS Statistics, Version 25 (IBM Corp., Armonk, NY). Statistical significance was set at $p \leq 0.05$, with Bonferroni-adjusted $\alpha = 0.01$ applied for follow-up ANOVAs.

RESULTS

Figure 1 summarises the distribution of each explosive-power test of handball players, with individual box-and-whisker plots augmented by group means, absolute mean differences (Δ), and minimum and maximum test results. Male handball players on average outperformed females on every measure: they covered the 20 m sprint 1.16 s faster (−21.13%), achieved 12.13 cm (+31.15%) higher countermovement jump results, and recorded a 15.3 cm (+8.47%) longer standing-long-jump distance. Upper-body power showed the largest disparities, with males throwing the medicine ball 305 cm farther from supine (+27.15%) and 252 cm farther from the seated position (+21.7%).

Figure 1. Descriptive statistics for handball players' explosive-power tests by sex



A one-way MANOVA (Table 1) tested the combined effect of sex on the five explosive-power variables. The obtained λ = 0.141 means that only 14% of the variance in the combined explosive-power vector remains unexplained once sex is accounted for, leaving 86% attributable to sex differences. The associated $F(5, 26) = 31.66$, $p < 0.001$, confirms that the male and female handball players' performance profiles differ significantly when the five tests are considered simultaneously. Although Wilks' λ assumes equal covariance matrices across groups, its result here converges with the more robust Pillai statistic, reinforcing confidence in the strength and consistency of the multivariate sex effect.

Table 1. MANOVA of explosive-power tests by sex

Variable	λ	F	df_1	df_2	p
Sex	0.141	31.66	5	26	< .001

Note. λ = Wilks' lambda; F = multivariate test statistic; df_1 = numerator degrees of freedom; df_2 = denominator degrees of freedom

Follow-up univariate ANOVAs (Bonferroni-adjusted $\alpha = 0.01$) showed that males out-performed females on every test (Table 2): standing long jump ($F(1, 30) = 25.68$, $p < 0.001$, partial $\eta^2 = 0.46$); 20 m sprint ($F(1, 30) = 25.14$, $p < 0.001$, partial $\eta^2 = 0.46$); supine medicine-ball throw ($F(1, 30) = 136.21$, $p < 0.001$, partial $\eta^2 = 0.82$); seated medicine-ball throw ($F(1, 30) = 83.77$, $p < 0.001$, partial $\eta^2 = 0.74$); countermovement jump ($F(1, 30) = 73.86$, $p < 0.001$, partial $\eta^2 = 0.71$).

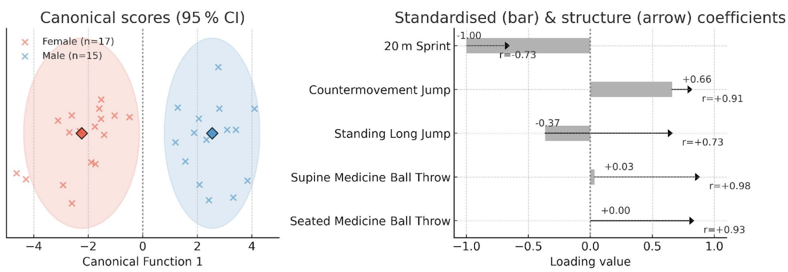
Table 2. ANOVA follow-up for each explosive-power test

Variable	Sex	M ± SD	ΔM–F %	S–W	*F*(1, 30)	*p*	partial η^2
20 m Sprint	Female	5.49 ± 0.62	−21.13	.635	25.14	< .001	.46
	Male	4.33 ± 0.69		.762			
Countermovement Jump	Female	38.94 ± 3.78	+31.14	.786	73.86	< .001	.71
	Male	51.07 ± 4.20		.680			
Standing Long Jump	Female	180.76 ± 10.02	+8.47	.438	25.68	< .001	.46
	Male	196.07 ± 6.40		.065			
Supine Medicine Ball Throw	Female	1124.12 ± 91.66	+27.15	.874	136.21	< .001	.82
	Male	1429.33 ± 45.59		.735			
Seated Medicine Ball Throw	Female	1162.35 ± 101.15	+21.7	.387	83.77	< .001	.74
	Male	1414.67 ± 35.83		.987			

Note. Values are presented as mean ± standard deviation (M ± SD). ΔM–F % = percent difference between male and female means; S–W = Shapiro–Wilk *p* value; *F*(1, 30) = degrees of freedom; *p* = significance level; partial η^2 = effect size.

Canonical discriminant analysis (Figure 2) yielded a single function that completely separated the groups; standardised coefficients showed that sprint time (−1.00) and countermovement jump (+0.66) contributed most uniquely, while both medicine-ball throws displayed the strongest structure correlations ($r \approx 0.95$) but minimal unique contribution, illustrating shared upper-body power. Together, these results confirm a large, multidimensional sex effect across speed, lower-body power, and throwing strength in professional handball players.

Figure 2. Canonical discriminant analysis of explosive-power tests



Note. CI = confidence intervals; r = structure coefficient.

DISCUSSION

The present study aimed to examine sex-based differences in explosive power among second-division Serbian handball players. Multivariate analysis revealed that sex explained 86% of the combined variance in the five explosive-power tests, and every univariate comparison showed large effects (partial $\eta^2 \geq 0.46$). Men out-performed women in all tasks, with the largest relative gaps observed in countermovement-jump height (31%), followed by the supine (27%) and seated (22%) medicine-ball throws, the 20-m sprint (21%) and standing long jumps (8.47%). These findings align with previous reports in invasion sports, where upper-body power and explosive leg actions consistently show the greatest sex disparities (Granacher et al., 2016). Specifically, our results are consistent with handball-specific studies showing 20–30% sex differences in jumping and throwing performance (Hermassi et al., 2011; Massuca et al., 2015), though our sample demonstrated somewhat larger gaps, possibly reflecting the sub-elite competitive level. The canonical discriminant function confirmed that sprint time and countermovement jump height carry the strongest unique weights, whereas the medicine-ball throws, although highly correlated with the function, share variance attributable to general upper-body strength. The consistently higher male medians and non-overlapping inter-quartile ranges, together with visibly higher maxima, support the large effect sizes reported in the univariate ANOVAs and confirm that sex differences span the entire performance spectrum rather than being driven by a few extreme values.

The magnitude of sex differences observed in our study compares favourably with existing handball literature. Michalsik and Aagaard (2015) reported similar patterns in elite players, with men demonstrating 25–35% advantages in upper-body power tasks and 15–25% in lower-body explosive actions. However, the countermovement jump difference that we recorded (31%) is lower than those typically reported in elite samples (20–25%), which may reflect training differences at the sub-elite level where strength and conditioning programs are less systematised (Wagner et al., 2019). Conversely, our sprint time difference (21%) aligns closely with meta-analytic data from team sports (Lidor & Ziv, 2010), suggesting that linear speed differences are relatively consistent across competitive levels. This pattern is further supported by recent findings demonstrating that explosive power variables (squat strength, vertical jump) are more discriminative than sprint speed in determining team ranking among elite handball players, with speed showing weaker correlations with competitive success (Wei et al., 2024). These results align with our observation that the smallest sex difference occurred in sprint performance (21%) compared to explosive power tasks (22–27%).

Several factors probably underlie the magnitude of the differences. Men in our sample were four years older on average than the women, implying more years of training and greater hormonal exposure, both of which favour muscle-mass accretion and neural efficiency (Kraemer & Ratamess, 2005). Testosterone concentrations, which are 10–15 times higher in men, directly influence protein synthesis, muscle fibre hypertrophy, and the proportion of fast-twitch fibres crucial for explosive actions (Horwath et al., 2020). Furthermore, sex-related anthropometric traits, such as greater stature, muscle cross-section, and limb length in men, directly benefit jump distance, throwing distance, and stride length (Srinivas-Shankar et al., 2010; Hunter, 2014). These morphological advantages likely contribute to the large sex gaps observed, particularly in countermovement jump (31%) and the medicine-ball throws (22–27%), alongside a substantial difference in short-sprint time (21%) and a smaller gap in standing long jump (8.5%).

Based on our findings, we recommend a three-pronged training approach for female handball players. First, upper-body power development should be prioritised given the largest deficits observed in medicine ball throws (22–27%). This could include twice-weekly sessions featuring explosive medicine ball exercises (chest passes, overhead throws, rotational throws), plyometric push-ups, and weighted ball throws with 3–5 sets of 6–8 repetitions at maximum velocity (Hermassi et al., 2011; Chelly et al., 2014). Second, vertical power training should address the 31% countermovement jump deficit through depth jumps (40–60 cm), reactive jumps, and handball-specific jumping drills performed 2–3 times weekly during the preparatory period (Granacher et al., 2016). Third, sprint acceleration should be enhanced through short-distance sprints (10–30 m), resisted sprint training, and acceleration mechanics, given the 21% speed disadvantage observed. Meta-analytic evidence confirms that female handball players demonstrate superior sprint training adaptability compared to males, supporting the effectiveness of targeted speed interventions in this population (Wang et al., 2024). Periodization should prioritise these interventions during the preparatory phase (8–12 weeks), with maintenance training (1–2 sessions weekly) during the competitive season to preserve adaptations while managing fatigue (Marques & González-Badillo, 2006). Coaches should track progress using the same field tests employed in this study, with realistic targets of 10–15% improvement in the first training year. Given the substantial sex differences observed, female-specific training groups may be warranted to ensure appropriate training loads and technical progressions are applied. This approach is supported by systematic reviews confirming that exercise training interventions are most effective when targeting specific performance components such as jumping, speed, and agility, the exact domains showing the largest sex differences in our study (Akbar et al., 2024)

Several study limitations warrant caution when interpreting these findings. The cross-sectional design precludes causal inference about the origins of observed sex differences, limiting conclusions about whether gaps are primarily biological, training-related, or developmental in nature. The significant age mismatch between groups (men: 26.0 ± 2.9 years vs women: 21.9 ± 0.9 years) represents a potential confounding factor, as the additional 4.1 years of training exposure and physiological maturation in males may artificially inflate the magnitude of sex differences beyond pure biological effects. The relatively small sample size (n = 32; 17 women, 15 men) limits statistical power for detecting smaller effects and prevents more sophisticated analyses such as age-adjusted comparisons or subgroup analyses by playing position. Although all tests showed acceptable Shapiro-Wilk values ($p > 0.05$), larger samples would strengthen normality assumptions and enable more robust multivariate covariance testing (Cohen, 1988). The exclusive reliance on field-based assessments, while practically relevant, limits mechanistic understanding of the observed differences. Laboratory measures, including force-plate kinetics, muscle architecture analysis, hormonal profiling, or isokinetic strength testing, would provide deeper insight into the physiological bases of performance gaps. Training history and current training loads were self-reported rather than objectively quantified, potentially introducing recall bias and limiting our ability to account for training-related confounders.

CONCLUSION

This study offers a comprehensive assessment of how sex influences explosive power in competitive handball. Analysing sprint speed, vertical and horizontal jump capacity, and upper-body throwing distance results, we found that sex explained nearly nine-tenths of the multivariate variance, with men outperforming women across all tests. The magnitude of the gaps, particularly in medicine-ball throws, countermovement-jump height, and short-sprint time, highlights these capacities as priority targets for performance enhancement in women's training programmes. Conditioning plans that emphasise high-velocity strength work, plyometric drills, and upper-body power exercises are therefore recommended. Future research should verify these outcomes with larger, age-matched samples and longitudinal a that track how targeted power training narrows sex-based disparities over a full season. Also, the inclusion of objective training load monitoring (GPS, heart rate, session RPE) and detailed strength training histories will facilitate better distinction between biological from environmental factors. Incorporating everything that we talked about in women's conditioning programmes may yield significant performance gains and provide evidence-based benchmarks for talent development. Integrating these findings into women's conditioning programmes may yield significant performance gains and provide evidence-based benchmarks for talent development.

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