Acta Kinesiologica 20 (2026) Issue.2
DOI. 10.51371/issn.1840-2976.643

Original Investigation

Influence of Motor Abilities on Throwing Performance Across Motor Learning Stages in Physically Active Female Athletes

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Purpose: The aim of this study was to determine the influence of different motor abilities on performance in shot put, discus, and javelin among women, as well as the changes in their importance across different stages of motor learning.
Methods: Participants were 21 female athletes (age 20.4 ± 1.2 years, body weight 61.6 ± 8 kg, body height 168.5 ± 5.8 cm) with recreational to developmental training backgrounds. Over five weeks, participants completed 15 training sessions. Technical performance and motor abilities (deadlift, overhead medicine ball throw, 10m sprint, standing long jump) were tested across three measurement points. Data were analyzed using repeated measures ANOVA and multiple regression.
Results: The results showed that upper-body explosive strength was the main predictor of success in all disciplines, with the strongest effect in the final stage (shot put β = .76; javelin β = .78). Maximal strength (deadlift) had a modest influence initially but became significant in the final stage, particularly in shot put (β = .10, P < .001). Sprint speed and lower-body strength had limited predictive value.
Conclusions: Motor abilities contribute differently to performance at various learning stages. In the early phases, technical instruction and movement stabilization are essential, while upper-body explosive power becomes a decisive factor once the technique is automated. These findings emphasize the importance of phased and individualized training adapted to the discipline and the level of motor development.

Keywords: power, movement stabilization, athletics, throwing technique, skill acquisition.

Introduction

One of the earliest and most intricate manifestations of human motor activity is throwing, a motor skill characterized by the precise propulsion of an object through space, achieved via the application of optimally regulated biomechanical parameters such as muscular strength, intersegmental coordination, and spatiotemporal precision.[1] While often perceived as a rudimentary action in everyday life, throwing, particularly in athletic disciplines such as shot put, javelin, and discus throw, constitutes a highly complex motor task.[2,3] This skill necessitates advanced neuromuscular synergy, encompassing sequential activation of multiple muscle groups, efficient force transmission along the kinetic chain, and elevated levels of fine motor control during the terminal phase of release.[4,5] The importance of such fine motor regulation is also confirmed by recent research in other sports requiring high technical precision, where neuromuscular factors have been shown to significantly affect stability and performance.[6]

Throwers' training involves systematically planned content to enhance maximal strength and explosive power, enabling higher release velocities, optimal release angles, and biomechanically stable execution.[7,8] Within the training process, various types of exercises are employed, which can be categorized into three primary groups: basic strength exercises (e.g., squats, deadlifts), explosive strength exercises (e.g., Olympic lifts, plyometrics), and technical-specific drills that simulate different phases of the throw. Integrating these modalities aims to improve the Rate of Force Development (RFD), a critical determinant of performance in throwing disciplines.[4,5] Despite increasing participation and achievements in throwing events for female athletes, scientific research remains predominantly focused on male populations. Given the known sex-based differences in body composition, muscle fiber structure, and neuromuscular activation,[9,10] important questions arise regarding the specificity of motor skill development in female throwers and its contribution to performance across various stages of technical learning.

Motor learning represents a fundamental component of athletic development, as it facilitates the transformation of uncertain, cognitively demanding movements into automated and biomechanically efficient executions.[11] Understanding the progression of changes that occur across each stage, from initial movement acquisition to full automation, is essential for the optimal structuring of the training process.[12,13] In the initial phase, the primary focus is on acquiring basic movement patterns. The transitional phase involves stabilizing the technique and integrating physical capacities. The final phase is characterized by performance optimization, biomechanical precision, and consistency.

Although numerous studies have examined the influence of individual motor abilities on athletic performance, the manner in which their impact evolves across different stages of motor learning remains insufficiently explored. This gap is particularly evident in the limited number of studies that integrate biomechanical performance with the development of specific motor capacities in the female throwing population. Therefore, this study aimed to identify which motor abilities most impact shot put, discus, and javelin performance in physically active female athletes across the initial, transitional, and final stages of motor learning.

Methods

Participants

The study included twenty-one females (age 20.4 ± 1.2 years, body weight 61.6 ± 8 kg, body height 168.5 ± 5.8 cm) from different sports activity backgrounds, classified as Tier 1 (Recreationally Active) to Tier 2 (Trained/Developmental) according to McKay et al.[14] Inclusion criteria to participate in this study were: (i) being in good health (absence of cardiovascular or pulmonary diseases, pain, acute or chronic illnesses, or symptoms of metabolic syndrome); and (ii) having no history of serious injuries that could impair their ability to perform physical tasks. Exclusion criteria were knowledge and prior experience in athletic throwing disciplines. All participants voluntarily agreed to participate in the research and provided written informed consent prior to their participation. They were fully informed about the purpose, procedures, and potential risks of the study, as well as their right to withdraw at any time without any consequences. A priori power analysis was conducted utilizing G*Power software (version 3.1.9.7; Universität Kiel, Germany) to determine the minimum necessary sample size with an effect size of $f = 0.25$ (medium effect, repeated-measures ANOVA, within-subjects factor), $\alpha = .05$, and power $(1-\beta)$ of .80.[15] The analysis revealed that at least 18 participants were necessary to identify significant changes across three repeated assessments (initial, transitional, and final). The final sample of twenty-one participants yielded adequate statistical power for the conducted analyses.

Study design

The methodological framework of this study is based on a longitudinal experimental design applied over five weeks to monitor changes in motor and technical performance parameters in throwing disciplines. The selected timeframe is supported by previous research indicating that significant neurological and motor adaptations can be achieved within a period of 4 to 6 weeks of continuous training.[16] Based on this, the instructional activities in this study were structured to allow the assessment of the effectiveness of different stages of motor learning, with the aim of better understanding the required frequency and dynamics of content repetition, in accordance with the participants' motor status. The research is structured based on a previously validated study conducted on a male population,[15] which analyzed the influence of different dimensions of maximal strength and explosive power on performance in shot put (SP), discus (DT), and javelin throw (JT). In this study, the same research protocol and battery of motor ability tests were applied to a female population, allowing for a reliable comparative analysis of gender differences in the predictors of success in throwing disciplines.

The participants underwent three measurement sessions: initial, transitional, and final, including evaluations of technical performance in all three disciplines and testing of selected motor abilities. The tests included an assessment of maximal strength via deadlift (DL),[17,18] upper body explosive power through an overhead 5 kg medicine ball throw (MBM5OH),[15] reaction time and acceleration through a 10-meter sprint (10m), and explosive leg power via standing long jump (SLJ).[19,20]

Learning Process

Motor learning in the throwing disciplines (shot put, discus, and javelin) was conducted within the framework of a five-week program, which included systematically structured practical sessions focused on acquiring and improving the technical elements of each discipline. The learning process was conducted under the supervision of qualified instructors with extensive experience in athletics. It encompassed fifteen sessions, divided into three developmental-functional phases of motor learning: initial, transitional, and final.

During the initial phase, participants were introduced to the biomechanical and technical fundamentals of each discipline, including starting positions, proper equipment handling, movement biomechanics, and the essential criteria for correct execution. Emphasis was placed on demonstrations and verbal instructions, with opportunities for individual correction already in the early stages. According to motor learning theory,[21] this phase corresponds to the cognitive stage, during which the basic movement schema is formed.

During the transitional phase, the focus shifted to stabilizing the acquired technical elements and integrating them into a comprehensive performance. During this phase, participants focused on proper coordination between body segments, improving rhythm, and integrating motor abilities such as strength and explosiveness into a functional performance context. This phase corresponds to the so-called associative stage of motor learning, where errors are reduced and stable movement patterns are formed.[22]

The final phase focused on automating movement, achieving biomechanical precision, and eliminating technical deficiencies. Methods such as video analysis, verbal and visual feedback, and simulation of competition conditions were employed in this stage. The training was structured according to the principles of random and variable practice, a practical approach to the long-term retention and transfer of motor skills, as outlined in the literature.[23,24] This phase aimed to establish biomechanically optimal and automated technical performance for each throwing discipline.

Statistical analysis

Results are presented as means ± standard deviations (SD). The normality of data distribution was assessed using the Shapiro–Wilk test. Intraclass correlation coefficients (ICC) with 95% confidence intervals (95% CI) were calculated to evaluate the reliability of the tests assessing motor abilities. ICC values were interpreted according to standard guidelines, where values below .50 indicate poor, .50–.75 moderate, .75–.90 good, and above .90 excellent reliability.[25] The stability of measurements across three repeated trials and changes in performance across the initial, transitional, and final measurements in shot put, javelin throw, and discus throw were analyzed using repeated measures ANOVA. Partial eta squared (ηp^2) was calculated as a measure of effect size with the following thresholds: small (> .01), medium (> .06), and large (> .14). Bonferroni post-hoc testing was used to examine differences between measurement phases. The effect size was calculated using Cohen's *d* and interpreted according to the following thresholds: < .2 (trivial), .2 – .6 (small), .6 – 1.2 (moderate), 1.2 – 2.0 (large), 2.0 – 4.0 (very large), and > 4.0 (extremely large).[26] To determine the influence of selected motor variables (deadlift, 10m sprint, overhead medicine ball throw, and standing long jump) on throwing discipline performance, multiple linear regression analyses were conducted across all measurement phases. Regression models included standardized beta coefficients (β), multiple correlation coefficients (R), and coefficients of determination (R^2) to evaluate the strength and explanatory power of the predictors. Statistical significance was set at $P < .05$. Statistical analyses were performed using IBM SPSS Statistics version 26.0 (IBM Corp., Armonk, NY, USA).

Results

The Shapiro–Wilk test showed that the distribution of the variables did not significantly deviate from normality ($P > .05$). Descriptive analysis reveals that participants exhibit the greatest variability in strength (DL) and upper-body explosive power (MBM5OH), whereas performance in the 10m sprint and SLJ was more homogeneous (Table 1). The DL (40 – 110 kg) recorded the widest range of results, whereas the smallest range was observed in the 10m (1.90 – 2.11 s) and SLJ (1.74 – 2.10 m), indicating similar performance levels among participants in those tests (Table 1).

Table 1. Descriptive statistics of predictive variables.

Variable	min	max	M(SD)
DL (kg)	40	110	61.43(17.40)
10m (s)	1.90	2.11	2.00(.06)
MBM5OH (m)	5.10	11.35	7.76(1.53)
SLJ (m)	1.74	2.10	1.94(.10)

Note: DL = deadlift; 10m = 10-meter sprint; MBM5OH = overhead medicine ball throw with 5 kg; SLJ = standing long jump; Min = minimum value; Max = maximum value; M = mean; SD = standard deviation.

The results in Table 2 indicate high test reliability, with excellent ICC for the 10m and MBM5OH, and very good for the SLJ. The repeated measures ANOVA showed no statistically significant differences between the three measurements ($P > .05$), confirming the consistency of the results.

Table 2. Reliability analysis.

Variable	T1 M(SD)	T2 M(SD)	T3 M(SD)	*F*	ICC (95% CI)
10m (s)	2.04(.07)	2.02(.06)	2.03(.08)	1.13	.922 (.839 – .966)
MBM5OH (m)	7.06(1.34)	7.33(1.56)	7.50(1.64)	2.97	.945 (.886 – .976)
SLJ (m)	1.88(.11)	1.90(.10)	1.92(.09)	3.32	.883 (.757 – .949)

Note: 10m = 10-meter sprint; MBM5OH = overhead medicine ball throw with 5 kg; SLJ = standing long jump; T1, 2, 3 = consecutive trials; M = mean; SD = standard deviation; *F* = Variance ratio; ICC (95% CI) = intraclass correlation coefficient with 95% confidence interval

Mauchly's test revealed that there was no violation of sphericity for shot put ($W = .91$, $P = .405$), javelin ($W = .79$, $P = .108$), and discus ($W = .79$, $P = .108$). The repeated measures ANOVA showed a significant main effect of time for shot put (SP; Figure 1A: $F = 21.22$, $P < .001$), javelin throw (JT; Figure 1B: $F = 38.30$, $P < .001$), and discus throw (DT; Figure 1C: $F = 46.39$, $P < .001$). Effect sizes indicated large effects: SP $\eta p^2 = .52$, JT $\eta p^2 = .66$, DT $\eta p^2 = .70$. Pairwise comparisons in SP showed statistically significant improvements from initial to transitive measurements ($P = .031$, Cohen's $d = .76$ [moderate]), transitive to final ($P = .001$, Cohen's $d = .45$ [small]), and from initial to final measurements ($P < .001$, Cohen's $d = 1.52$ [large]). In the JT, significant improvements were observed from initial to transitive measurements ($P = .009$, Cohen's $d = .88$ [moderate]), transitive to final ($P < .001$, Cohen's $d = 1.33$ [large]), and initial to final measurements ($P < .001$, Cohen's $d = 2.01$ [very large]).

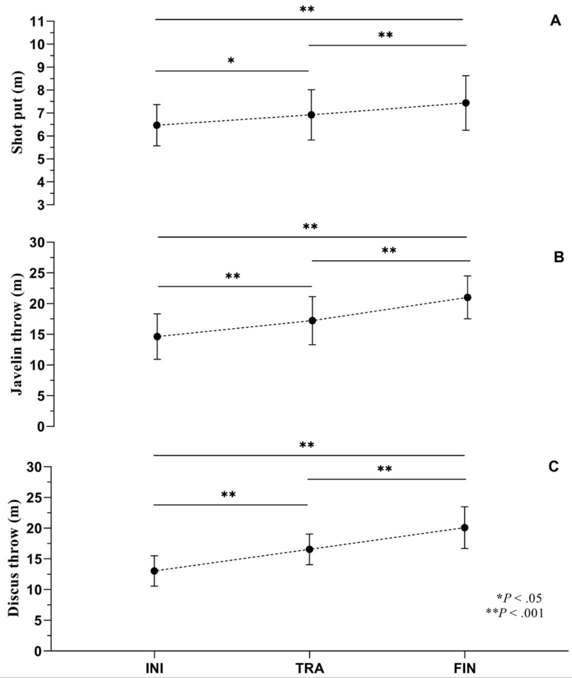

Figure 1. Throwing distance across three measurement points for (A) shot put, (B) javelin, and (C) discus throws. Circles show mean distance; error bars = standard deviation. Horizontal lines with asterisks indicate significant pairwise differences from the repeated measures ANOVA.; INI - Initial measurement; TRA = Transitive measurement; FIN = Final measurement.

Likewise, in the DT, significant changes were recorded across all phases: initial–transitive ($P < .001$, Cohen's $d = 1.14$ [large]), transitive–final ($P < .001$, Cohen's $d = 1.15$ [large]), and initial–final ($P < .001$, Cohen's $d = 2.08$ [very large]).

As shown in Table 3, regression analysis revealed a progressive strengthening of the relationship between predictor variables and performance outcomes across all disciplines throughout the measurement phases. The highest multiple correlation coefficients and coefficients of determination were recorded in the final measurement for all athletic disciplines (SP: $R = .85$, $R^2 = .72$; JT: $R = .69$, $R^2 = .47$; DT: $R = .57$, $R^2 = .33$), while these values were the lowest in the initial measurement (SP: $R = .77$, $R^2 = .59$; JT: $R = .40$, $R^2 = .16$; DT: $R = .25$, $R^2 = .06$). The MBM5OH was the only significant predictor for SP in all phases, whereas in TRA and FINAL for JT. There were no significant predictors for DT across all phases.

Table 3. The influence of motor abilities on throwing performance (initial, transitive, and final).

	Variable	INI		TRA		FIN	
		β	***P***	***β***	***P***	***β***	***P***
SP	**DL (kg)**	- .04	.005	.07	.03	.10	< .001
	10m (s)	- .128		- .07		- .14	
	MBM5OH (m)	.73**		.62*		.76***	
	SLJ (m)	.13		.15		.01	
JT	**DL (kg)**	- .14	.56	- .10	.04	- .13	.03
	10m (s)	- .20		.02		.31	
	MBM5OH (m)	.34		.66**		.78**	
	SLJ (m)	- .01		.34		.32	
DT	**DL (kg)**	.05	.90	.11	.43	.24	.15
	10m (s)	- .07		- .21		.25	
	MBM5OH (m)	.01		.31		.47	
	SLJ (m)	- .29		- .16		.08	

Note: 10m = 10-meter sprint; MBM5OH = overhead medicine ball throw with 5 kg; SLJ = standing long jump; SP = Shot put; JT – Javelin throw; DT = Discus throw; INI - Initial measurement; TRA = Transitive measurement; FIN = Final measurement; β (beta) = Strength of predictor; Significance level: * - $P < .05$; ** - $P < .01$; *** - $P < .001$

Discussion

Findings from the present study demonstrate that motor abilities significantly influence performance in shot put, javelin, and discus throw among female athletes, with their predictive value varying across different stages of motor learning. This longitudinal analysis offers a comprehensive perspective on the dynamic changes that occur in both technical execution and the relative contribution of individual motor variables throughout the learning process. Consistent with these observations, Takanashi et al,[27] highlighted that training programs for female throwers are frequently based on models developed for male athletes, which fail to account for sex-specific adaptive patterns in female motor development.

When each discipline is analyzed individually, different patterns of association between motor variables and performance become evident. In the initial phase, the results indicate weaker associations between motor variables and performance, particularly in the discus throw ($R^2 = .06$), which aligns with the cognitive stage of learning theory,[28] where movement execution is primarily dominated by conscious processing, and physical capacities are not yet fully integrated. It is important to emphasize that the discus throw stands out as the most complex of the throwing disciplines, primarily due to its high technical demands, which involve the integration of rotational movement patterns, postural stability, and precise temporal coordination of body segments. As a result, mastering this discipline requires a longer period of time, particularly during the early stages of learning, when technical instability may reduce the impact of motor abilities on performance. This highlights the need for early training phases to emphasize technical education, visual correction, and the automation of fundamental movement patterns rather than the intensive development of strength capacities. Conversely, in the later stages, characterized by highly automated and biomechanically optimized movements, a significantly stronger correlation emerges between upper-body explosive strength and performance across all three disciplines, underlining the critical role of these motor abilities in enabling optimal force transfer during the release phase. These findings are consistent with previous research,[29] which has identified the rate of force development as a decisive factor in throwing performance.

Explosive strength showed a significant association with shot put performance already in the early stages of motor learning, whereas in the javelin throw, its contribution became evident only after achieving technical stability and biomechanical efficiency, which is acquired following the approach phase that enables optimal force transfer into the release. This pattern, consistent with previous research on male populations, indicates that the integration of motor abilities into performance depends on the specific biomechanical demands of each discipline.[15] In technically simpler movements, such as the shot put, explosive strength can be effectively applied even in the early stages of learning, while in more complex disciplines like the javelin throw, its full effect becomes apparent only once the kinematic chain is stabilized. These findings underscore the importance of tailoring strength training to the unique demands of each discipline and the athlete's stage of motor learning.

The findings of this study indicate that sprint speed (10m sprint) and lower-limb explosive power have limited predictive value for performance in this specific female population and throwing disciplines. This phenomenon can be attributed to the biomechanical characteristics of the throwing technique, which rely more heavily on trunk translation and rotation, as well as upper-body strength, rather than linear running speed. In contrast, previous research[30] has identified a significant association between lower-limb explosive strength, assessed through sprint performance and various jump tests, and javelin throw outcomes in male athletes. Sex-based differences in body composition further reinforce these findings. On average, women have a lower proportion of muscle mass in the lower extremities, which limits their capacity to generate high levels of explosive force and consequently reduces the contribution of the lower body to the overall transfer of kinetic energy to the projectile.[9] In throwing disciplines such as shot put, discus, and javelin, lower-limb muscle groups, mainly the ankle plantar flexors and hip extensors, are critical for force generation during the final acceleration phase.[31] Given that women possess proportionally less muscle mass in these regions, their ability to generate equivalent explosive force is reduced, which affects the biomechanical efficiency of energy transfer during the release phase of the throw.[32] Despite these limitations, other studies indicate that lower-limb strength can still contribute to performance in specific contexts, such as plyometric pre-conditioning, which acutely enhances explosive abilities and performance.[33]

The observed differences in levels of statistical significance and effect sizes across disciplines suggest that each throwing event is characterized by distinct biomechanical and motor demands. The discus throw demonstrated a more significant progression in performance (Cohen's d = 2.08) compared to the shot put (Cohen's d = 1.52), which may indicate that the discus's technical component requires a longer acquisition period yet allows for more substantial improvement once it is adequately mastered. This underscores the importance of discipline-specific training approaches that account for the varying complexity and motor learning trajectories of each throwing modality.

Despite its valuable contributions, this study has several limitations that should be acknowledged. First, the sample consisted exclusively of physically active females, which may limit the external validity and generalizability of the findings to elite female athletes. Furthermore, although the achieved sample size met the a priori power requirements, its relatively small size reduces the statistical power of the analysis. It may limit the detection of more subtle effects and the stability of the applied regression models. Future research should include larger and more diverse samples to enhance the robustness and applicability of the findings to broader athletic populations. Lastly, although the selected timeframe was based on previous scientific findings, the acquisition of technically demanding throwing disciplines in women likely requires a longer intervention period to more reliably assess the impact of motor abilities on throwing performance.

These findings have important implications for training design, highlighting the need for a phased approach that integrates the development of specific motor abilities by the level of technical proficiency. In the early stages of learning, coaches should prioritize technical instruction and coordination while progressively incorporating elements of strength and explosive power as technical execution advances to maximize performance outcomes. These results go beyond the immediate context of the training process, as they clearly indicate that female throwers require developmental models that differ from those applied in men's sport. Systematic consideration of sex-specific differences in strength, explosiveness, and adaptive patterns is crucial for developing sustainable programs that promote long-term performance progression and minimize the risk of injury.

Practical Applications

The obtained results have significant practical implications for the planning and programming of the training process in throwing disciplines among female athletes. In the initial phases of motor learning, priority should be directed toward technical instruction, stabilization of fundamental movement patterns, and correction of biomechanical deficiencies, as physical abilities at this stage contribute only a limited amount to performance outcomes. As the learning process progresses toward the final phase, upper-body explosive strength assumes a key role, underscoring the need to incorporate specific training content aimed at developing this capacity. Furthermore, although maximal strength exerts a smaller effect in the early phases, it becomes an important determinant of success in the later stages, particularly in shot put, which suggests the need for its gradual and long-term development in parallel with technical improvement. These findings underscore the importance of an individualized and phase-structured approach to training, taking into account the specific demands of each discipline.

Conclusions

This study provides new insights into the dynamic relationship between motor abilities and performance in throwing disciplines across different stages of motor learning in the female athletic population. The results indicate that motor abilities, particularly upper-body explosive power, do not contribute equally across all phases of learning. Instead, their importance progressively increases as technical execution transitions from the cognitive to the associative and finally to the autonomous stage. In the early phase, biomechanical instability and high levels of cognitive involvement in learning limit the contribution of physical capacities. In contrast, when motor patterns are stabilized in later stages, explosive strength becomes a critical determinant of effective force transmission along the kinetic chain. These findings further support the notion that physical capacities reach their full functional value only when integrated with biomechanical precision and technical stability. In technically complex events such as the discus and javelin throw, performance effectiveness strongly depends on the optimal synergy between acquired technical skills and the explosive potential of the upper limbs. This highlights the necessity for individualized training approaches that consider both the athlete's stage of motor development and the unique biomechanical demands of each discipline.

Acknowledgments

The authors would like to thank the students who participated in this study for their time, effort, and commitment.

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

Ethical Committee Approval

Ethical Committee of the Faculty of Kinesiology, University of Split, Split, Croatia (approval No.: 2181-205-02-05-25-035).

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Topic

Sport science

Conflicts of interest

The authors have no conflicts of interest to declare.

Funding

No funding was received for this investigation.

Authors contribution

Conceptualization, F.Ž..; methodology, G.K. and P.M.; software, F.Ž.; validation, G.K.; formal analysis, F.Ž.; data curation, F.Ž., P.M. and G.K.; writing—original draft preparation, F.Ž., P.M. and G.K.; writing—review and editing, G.K. and P.M.; visualization, G.K.

References

1. Haywood KM, Getchell N. *Life Span Motor Development.* 6th ed. Human kinetics; 2024.
2. Hansen C, Rezzoug N, Gorce P, Venture G, Isableu B. Rotation axes in overarm throwing. *Comput Methods Biomech Biomed Engin*. 2013;16(sup1):70-71. doi:10.1080/10255842.2013.815963
3. Błażkiewicz M, Łysoń B, Wit A. Mechanical energy flows between body segments in ballistic track-and-field movements (shot put, discus, javelin) as a performance evaluation method. *Acta Bioeng Biomech*. 2019;21(1):31-36.
4. Terzis G, Georgiadis G, Vassiliadou E, Manta P. Relationship between shot put performance and triceps brachii fiber type composition and power production. *Eur J Appl Physiol*. 2003;90(1-2):10-15. doi:10.1007/s00421-003-0847-x
5. Zaras N, Stasinaki AN, Terzis G. Biological Determinants of Track and Field Throwing Performance. *J Funct Morphol Kinesiol*. 2021;6(2):40. doi:10.3390/jfmk6020040
6. Kuliś S, Kłobuchowski W, Skorulski M, Pietraszewski P, Callegari B. Upper limb tremor variability in elite sport dancers: The influence of competitive simulation. *Biomed Hum Kinet*. 2025;17(1):219-228. doi:10.2478/bhk-2025-0021
7. Palmer T, Uhl TL, Howell D, Hewett TE, Viele K, Mattacola CG. Sport-Specific Training Targeting the Proximal Segments and Throwing Velocity in Collegiate Throwing Athletes. *J Athl Train*. 2015;50(6):567-577. doi:10.4085/1062-6040-50.1.05
8. Terzis G, Spengos K, Kavouras S, Manta P, Georgiadis G. Muscle fibre type composition and body composition in hammer throwers. *J Sports Sci Med*. 2010;9(1):104-109.
9. Wells JCK. Sexual dimorphism of body composition. *Best Pract Res Clin Endocrinol Metab*. 2007;21(3):415-430. doi:10.1016/j.beem.2007.04.007
10. Ansdell P, Thomas K, Hicks KM, Hunter SK, Howatson G, Goodall S. Physiological sex differences affect the integrative response to exercise: acute and chronic implications. *Exp Physiol*. 2020;105(12):2007-2021. doi:10.1113/EP088548
11. De Giorgio A, Sellami M, Kuvacic G, et al. Enhancing motor learning of young soccer players through preventing an internal focus of attention: The effect of shoes colour. *PLoS One*. 2018;13(8):e0200689. doi:10.1371/journal.pone.0200689
12. Christiansen L, Larsen MN, Madsen MJ, Grey MJ, Nielsen JB, Lundbye-Jensen J. Long-term motor skill training with individually adjusted progressive difficulty enhances learning and promotes corticospinal plasticity. *Sci Rep*. 2020;10(1):15588. doi:10.1038/s41598-020-72139-8
13. Gupta A, Vig L, Noelle DC. A neurocomputational approach to automaticity in motor skill learning. *Biol. Inspired Cogn. Archit*. 2012;2:1-12. doi:10.1016/j.bica.2012.07.009
14. McKay AKA, Stellingwerff T, Smith ES, et al. Defining Training and Performance Caliber: A Participant Classification Framework. *Int J Sports Physiol Perform*. 2022;17(2):317-331. doi:10.1123/ijspp.2021-0451
15. Žuvela F, Škorić J, Matijašević P. Influence of different strength and power dimensions on success in throwing disciplines. *Hum. Mov*. 2025:79-88. doi:10.5114/hm/203540
16. Adkins DL, Boychuk J, Remple MS, Kleim JA. Motor training induces experience-specific patterns of plasticity across motor cortex and spinal cord. *J Appl Physiol*. 2006;101(6):1776-1782. doi:10.1152/japplphysiol.00515.2006
17. Thompson BJ, Stock MS, Shields JE, et al. Barbell Deadlift Training Increases the Rate of Torque Development and Vertical Jump Performance in Novices. *J Strength Cond Res*. 2015;29(1):1-10. doi:10.1519/JSC.0000000000000691
18. Grgic J, Lazinica B, Schoenfeld BJ, Pedisic Z. Test–Retest Reliability of the One-Repetition Maximum (1RM) Strength Assessment: a Systematic Review. *Sports Med Open*. 2020;6(1):31. doi:10.1186/s40798-020-00260-z
19. Marin-Jimenez N, Perez-Bey A, Cruz-Leon C, et al. Criterion-related validity and reliability of the standing long jump test in adults: The Adult-Fit project. *Eur J Sport Sci*. 2024;24(9):1379-1392. doi:10.1002/ejsc.12182
20. Castro-Piñero J, Ortega FB, Artero EG, et al. Assessing Muscular Strength in Youth: Usefulness of Standing Long Jump as a General Index of Muscular Fitness. *J Strength Cond Res*. 2010;24(7):1810-1817. doi:10.1519/JSC.0b013e3181ddb03d
21. Schmidt R, Lee T. *Motor Control and Learning: A Behavioral Emphasis*. 5th ed. Champaign, IL: Human kinetics; 2005.
22. Magill RA, Anderson DI. *Motor Learning and Control: Concepts and Applications*. McGraw-Hill Education; 2017.
23. Memmert D. Long-Term Effects of Type of Practice on the Learning and Transfer of a Complex Motor Skill. *Percept Mot Skills*. 2006;103(3):912-916. doi:10.2466/pms.103.3.912-916
24. Krstulović S, De Giorgio A, DelCastillo Andrés Ó, Franchini E, Kuvačić G. Effects of Contextual Interference on Learning of Falling Techniques. *Motor Control*.

2021;25(1):117-135. doi:10.1123/mc.2020-0066
25. Koo TK, Li MY. A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. *J Chiropr Med*. 2016;15(2):155-163. doi:10.1016/j.jcm.2016.02.012
26. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive Statistics for Studies in Sports Medicine and Exercise Science. *Med Sci Sports Exerc*. 2009;41(1):3-12. doi:10.1249/MSS.0b013e31818cb278
27. Takanashi Y, Fujimori N, Koikawa N. An investigation into the relationship between throw performance and maximum weight in weight training of female discus throwers. *J. Hum. Sport Exerc*. 2021;16(1):226-234. doi:10.14198/jhse.2021.161.20
28. Wulf G, Lewthwaite R. Optimizing performance through intrinsic motivation and attention for learning: The OPTIMAL theory of motor learning. *Psychon Bull Rev*. 2016;23(5):1382-1414. doi:10.3758/s13423-015-0999-9
29. Zaras N, Spengos K, Methenitis S, et al. Effects of Strength vs. Ballistic-Power Training on Throwing Performance. *J Sports Sci Med*. 2013;12(1):130-137.
30. Maeda K, Yamamoto K, Hirose K, Ohyama-Byun K. Identifying standard values for the strength of male javelin throwers. *Res J Sports Perf*. 2019;11:446-458.
31. Łysoń-Uklańska B, Błażkiewicz M, Kwacz M, Wit A. Muscle Force Patterns in Lower Extremity Muscles for Elite Discus Throwers, Javelin Throwers and Shot-Putters – A Case Study. *J Hum Kinet*. 2021;78:5-14. doi:10.2478/hukin-2021-0026
32. Bartolomei S, Grillone G, Di Michele R, Cortesi M. A Comparison between Male and Female Athletes in Relative Strength and Power Performances. *J Funct Morphol Kinesiol*. 2021;6(1):17. doi:10.3390/jfmk6010017
33. Kale M, Yol Y, Tolali AB, Ayaz E. Effects of repetitive different jump pre-conditioning activities on post activity performance enhancement. *Acta Kinesiol*. 2023;(N2 2023). doi:10.51371/issn.1840-2976.2023.17.2.9

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Received: 01.10.2025.
Accepted: 15.12.2025.
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