



Biomechanical Parameters of Attacking Throws as a Basis for Technical Training in Judo

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Abstract

Objectives. The development of school physical education requires effective means for improving motor skills, coordination, and speed-strength qualities. Judo is one such means, and the effectiveness of teaching its technical actions depends on the objective assessment of movement biomechanics. This study aimed to determine the biomechanical parameters of the O-goshi throw in highly trained schoolchildren, develop an original biomechanical model based on tensodynamometric indicators and correlation analysis, and identify the most informative characteristics of its movement structure.

Materials and Methods. The study involved 77 male high school students aged 15–16 years. The general group (n = 63) consisted of beginners in judo, while the model group (n = 14) included advanced athletes (Candidates for Master of Sports of Ukraine and medalists of Ukrainian championships). Biomechanical parameters of O-goshi were recorded using a force plate. Force (Fzmax, Fmax, Fmax/P, GRAD, I), time (Tps, Tmax, Tmax+To, Tsum), and spatial (Hmax) parameters were analyzed. The biomechanical model was developed from the model-group data using correlation analysis and normalization of the sums of absolute correlation coefficients. Each participant performed three trials, and the mean values were analyzed.

Results. The highest relative contribution to the biomechanical model was observed for force gradient (11.13%). High informational value was also found for maximum vertical reaction force (Fzmax, 10.37%), resultant maximum force (Fmax, 10.28%), and force impulse (10.17%). Strong correlations between force and force-time parameters indicated their close interaction during O-goshi execution.

Conclusions. The developed biomechanical model identified the most informative force, time, and force-time characteristics of O-goshi in highly trained schoolchildren. The findings may be used for biomechanical monitoring and comparative assessment of performance across different training levels.

Keywords: judo, biomechanics, force-time characteristics, O-goshi, biomechanical model, schoolchildren.

Introduction

In the curriculum "Physical Education: 10–11 Grades. Standard Level," approved by the Ministry of Education and Science of Ukraine, the "Judo" elective module is designed to develop specific motor skills and abilities, as well as coordination, speed-strength motor qualities, balance, and the ability to effectively perform technical movements under varying conditions of physical activity (Ministry of Education and Science of Ukraine, 2022). The use of judo techniques in the physical education of high school students contributes to the development of specific motor skills necessary for mastering throwing techniques, as confirmed by the results of recent domestic studies (Filina, 2025).

Judo is a highly dynamic Olympic martial art in which the effectiveness of offensive techniques is largely determined by the rational spatial and temporal organization of movements, the ability to quickly generate force, and the optimal utilization of the athlete's strength during a throw.

Neuromuscular performance and lower-limb power have been identified as critically important factors in judo performance. It has been shown that improving lower-limb power and counter-movement jump (CMJ) parameters contributes to better performance on the Special Judo Fitness Test and improved throwing performance (Ho et al., 2025). Furthermore, repeated competitive bouts significantly influence the development of force impulse and indicators of bilateral strength deficit, highlighting the sensitivity of strength and strength-time characteristics to the onset of fatigue (Kons et al., 2026).

Contemporary biomechanical studies of specific judo techniques are of considerable interest. For example, a kinematic analysis of the Uchi-mata technique showed that higher-level athletes demonstrate greater center-of-mass velocity and more effective coordination of movements during the preparatory phase of the throw (Hamaguchi et al., 2024). Furthermore, it has been established that the kinematic characteristics of the lower limbs during the execution of the Uchi-mata throw differ significantly between judokas who specialize in this technique and those who do not. This confirms the existence of specific biomechanical characteristics of individual judo techniques and the need for their individual research (Brito et al., 2025). A biomechanical assessment of the Sode-tsurikomi-goshi and Tsurikomi-goshi techniques also revealed significant differences in acceleration and velocity metrics, confirming the value of using quantitative biomechanical metrics to analyze throwing techniques (Pantelidou et al., 2025).

Beyond technique-specific descriptions, recent work indicates that skill level in judo is expressed through the coordination of center-of-mass motion, segmental rotation, and momentum transfer. In seoi-nage, elite judokas demonstrate greater relative forward velocity of the whole-body center of mass than collegiate athletes (Ishii et al., 2018). More recent three-dimensional analyses combining motion capture and force platforms have identified center-of-mass control, linear and angular momentum, and rotational force generation as objective characteristics of technically proficient execution (Ishii & Koshida, 2025, 2026). These findings support the use of integrated biomechanical indicators rather than isolated variables when describing the structure of a judo throw.

Domestic studies indicate that the teaching of complex technical movements should be based on the step-by-step development of motor skills, systematic pedagogical monitoring, and objective assessment of the quality of movement execution (Krutsevich et al., 2017; Platonov, 2004). For the technical training of judokas, the use of model characteristics is of great importance, as they allow for the objectification of the process of monitoring and refining technique (Platonov, 2004). The development of biomechanical models for individual technical techniques enables a comprehensive quantitative description of their force, time, and force-time characteristics, thereby providing a scientific basis for the objective evaluation of technique and its further improvement.

An important area of contemporary research is the use of biomechanical monitoring to quantitatively assess athletes' technical readiness. The use of force-measurement methods makes it possible to determine the force and force-time characteristics of technical movements, as well as to develop model indicators of technique for athletes of various skill levels (Harkusha, 2016). At the same time, the effectiveness of mastering complex technical movements depends to a large extent on the level of development of motor coordination skills, which ensure the synchronization of movement phases and the stability of technical execution (Nosko et al., 2023).

Force-platform studies also show that interaction with the support surface is directly related to the mechanical effectiveness of throwing actions. In Harai-goshi, advanced judokas differ from novices in the horizontal force applied by the supporting leg and in sweeping-leg velocity (Pucsok et al., 2001). In osoto-gari, higher technical proficiency is associated with greater segmental angular velocities

and angular momentum transfer (Liu et al., 2024), while ground-reaction-force components and ankle-joint kinetics are related to sweeping-leg velocity at contact (Liu et al., 2025). Thus, force, temporal, and force-time characteristics can be considered complementary components of the same movement organization.

Advances in modern biomechanical analysis tools and wearable sensor systems are expanding the possibilities for objective, quantitative assessment of the kinetic and kinematic characteristics of technical movements in martial arts (Xue et al., 2025). At the same time, modern concepts of athletic training indicate that high performance in judo is achieved through the complex interaction of technical, neuromuscular, coordinative, and psychological components (Schoof et al., 2024). However, most current studies focus on specific judo techniques, physiological characteristics, or the evaluation of training program effectiveness, while the development of biomechanical models for individual throws and the comprehensive analysis of their force, time, and force-time characteristics remain under-explored.

In adolescent judo athletes, the interpretation of biomechanical and performance characteristics also requires attention to training experience and maturation. Somatic maturation, body size, and training experience contribute to variation in neuromuscular and judo-specific performance in young athletes (Detanico et al., 2020), and higher competitive level in youth judo is associated with greater training experience and superior strength- and power-related performance (Detanico et al., 2022). Accordingly, biomechanical model characteristics for school-age judokas are most informative when interpreted within comparable age and training contexts.

Thus, an analysis of current research indicates that, despite the active development of biomechanical methods for assessing the technical readiness of judo athletes, comprehensive studies aimed at developing a biomechanical model of the O-goshi throw based on an integrated analysis of its force, time, and force-time characteristics remain limited. This necessitates the research of the biomechanical parameters of this throw and the development of its biomechanical model as a basis for objectively assessing technique execution and further refining the methods of technical training for judo athletes.

The purpose of this research is to develop an original biomechanical model of the attacking throw in high-level school athletes based on tensodynamometric data and correlation analysis, and to identify the most informative biomechanical characteristics of the movement under research.

Materials and Methods

Participants

Educational research was conducted to examine the biomechanical parameters of the attacking throw in judo. The preparatory phase included selecting the sample, standardizing research procedures, and ensuring safe experimental conditions.

The research was conducted at the T. H. Shevchenko National University "Chernihiv Colehium" in a specialized biomechanical laboratory equipped with instruments for

conducting biomechanical research and high-precision measurement of force and time parameters of motor activity.

The general group (hereinafter – “GG”) consisted of 63 students aged 15–16 – pupils from general secondary schools in Chernihiv who were practicing judo at the beginner level. The model group (hereinafter – MG) included 14 high-level school students aged 15–16, among whom were candidates for the title of Master of Sports of Ukraine and medalists of Ukrainian championships.

The model group consisted of 10th-grade students from general secondary schools in Chernihiv and Kyiv, aged 15–16, who regularly practice judo and train at leading sports schools and clubs, including: the Chernihiv City Council Sports Wrestling Center, the “Fortuna” Children’s and Youth Sports School, Children’s and Youth Sports School No. 2, the “Yavara” Sports Club, the “JC Ippon Kyiv” Sports Club, and the “Young Spartak” Sports Club. The model group consisted of schoolchildren with a high level of training (Candidate Masters of Sports, prize winners of Ukrainian championships), which made it possible to determine the model biomechanical parameters for performing an attacking throw and to use them to construct an original biomechanical model of the technical action under research and for further comparative analysis.

All participants were informed of the research’s purpose, objectives, and procedures and provided written informed consent to participate. Since all participants were minors at the time of the research, written informed consent was also obtained from their parents or legal guardians. The research included schoolchildren of the same age and weight categories, which ensured the homogeneity of the sample and minimized the impact of anthropometric differences on the research results. The research was conducted in accordance with generally accepted ethical principles for educational research involving schoolchildren. Before the experiment began, all participants underwent a preliminary medical examination and received detailed instructions on how to perform the research procedures.

Research Design

The research procedure consisted of a preparatory phase and an experimental phase, each of which had clearly defined objectives and was designed to ensure the reliability and reproducibility of the results obtained.

All participants performed the same technical movement – the throw over the hip (O-goshi).



Fig. 1. Execution of the throw over the hip (O-goshi): a – starting position and grip; b – the initial phase of the throw, involving a step-in and bringing the hip under the opponent’s center of gravity

All participants performed a throw over the hip (O-goshi) on a standard training dummy, whose weight corresponded to that of the schoolchild performing the technique. Each participant performed three trials under identical experimental conditions following a standard warm-up. To minimize the impact of random variations and increase the reliability of the results, the subsequent statistical analysis used the average values of the biomechanical parameters obtained from the three trials of each participant.



Fig. 2. Experimental setup for researching the biomechanical characteristics of the O-goshi throw on a training dummy using a force plate

Force and time parameters were recorded using a calibrated force plate, which ensured highly accurate measurement of the reaction force during the execution of the movement. The force plate automatically recorded the “force-time” curves during each throw.

For further analysis, all recorded parameters were grouped into three categories: force parameters, time parameters, and combined force-time parameters.

Specifically, the maximum thrust force relative to the vertical axis (F_{zmax}) was $1,544.48 \pm 123.41$ N, and the maximum resultant force (F_{max}) was $1,549.53 \pm 129.37$ N. The relative force ratio (F_{max}/P) was 2.66 ± 0.21 . The force gradient (GRAD), which characterizes the rate of increase in muscle effort, was $5,945.82 \pm 442.18$ N/s. The force impulse (I) was 208.71 ± 17.86 N·s. The temporal characteristics of the movement were as follows: takeoff time (T_{ps}) – 0.09 ± 0.01 s; time to reach maximum force (T_{max}) – 0.16 ± 0.02 s. The total time of the push-off phase ($T_{max}+T_o$) was 0.21 ± 0.02 s, and the total time of the movement (T_{sum}) was 0.43 ± 0.04 s.

The maximum height of the center of mass (H_{max}) was 0.08 ± 0.01 m, which characterizes the vertical displacement of the body during the performance of the movement under research.

Based on the obtained data, a graphical biomechanical model was constructed (Fig. 3), which reflects the relative contribution of biomechanical characteristics to the structure of the throw under research, expressed as a percentage.

The author’s graphical biomechanical model demonstrates the relative contribution of individual parameters to the structure of the throw under research. The highest values of relative contribution were found for the force gradient (GRAD), relative maximum force (F_{max}/P), takeoff time (T_{ps}), and maximum force characteristics (F_{zmax} , F_{max}). Other indicators are also represented in

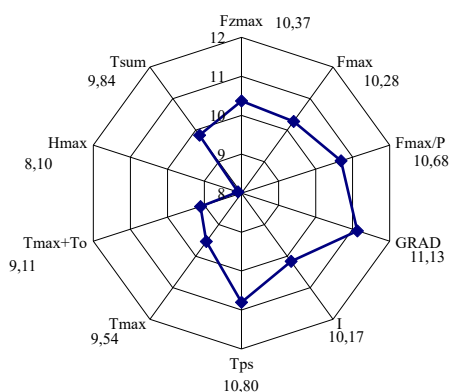


Fig. 3. The author's graphical model of the biomechanical parameters of throws over the hip in highly trained schoolchildren

the model's structure and characterize the temporal, spatial, and force-time characteristics of the movement's execution. The resulting distribution indicates the complex nature of the interrelationships among the biomechanical parameters under research during the execution of the throw over the hip (O-goshi).

Statistical Analysis

Statistical analysis of the obtained data was performed using SPSS software (IBM Corp., USA).

Descriptive statistics (mean and standard deviation) were calculated for all biomechanical parameters, which allowed us to characterize the central tendency and variability of the studied parameters.

To determine the relationships between biomechanical parameters, correlation analysis was performed using Pearson's correlation coefficient (r). The strength of the correlations was interpreted in accordance with generally accepted statistical approaches.

A comparative analysis of the indicators for the general and model groups was performed using Student's t -test for independent samples.

To construct the author's biomechanical model, a data normalization method was used. In the first stage, for each indicator, the sum of the absolute values of the correlation coefficients (Σr) was calculated, which characterized the degree of its integration into the system of interrelationships among the studied parameters. In the second stage, the obtained values were normalized relative to the total sum of the correlation coefficients of all indicators, followed by the determination of their percentage contribution to the structure of the author's biomechanical model.

The level of statistical significance was set at $p < 0.05$.

Results

Descriptive characteristics of biomechanical parameters.

Analysis of the tensodynamometric data and the results of the correlation analysis made it possible to determine the relative contribution of individual biomechanical parameters to the structure of the authors' model of the throw over the hip (O-goshi) in highly trained schoolchildren (Fig. 4).

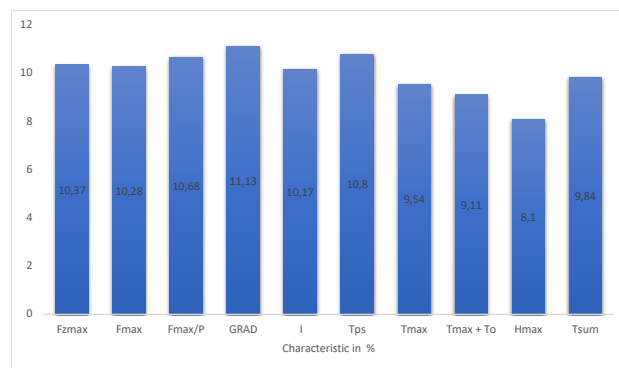


Fig. 4. Biomechanical parameters of attacking throws among highly trained schoolchildren (%)

The obtained values ranged from 8.10 % to 11.13 %, indicating a relatively uniform distribution of the contributions of the studied biomechanical parameters to the structure of the authors' model.

The highest relative contribution was demonstrated by the force gradient (GRAD), which amounted to 11.13 %. High values were also characteristic of relative maximum force (Fmax/P) – 10.68 %, preparatory phase time (Tps) – 10.80 %, maximum vertical ground reaction force (Fzmax) – 10.37 %, and resultant maximum force (Fmax) – 10.28 %.

The force impulse index (I) was 10.17 %. The time characteristics had the following contribution values: time to reach maximum force (Tmax) – 9.54 %, total duration of the push-off phase (Tmax+To) – 9.11 %, and total duration of the movement (Tsum) – 9.84 %. The smallest relative contribution was found for the maximum vertical displacement of the center of mass (Hmax), which was 8.10 %.

The resulting distribution indicates the comprehensive nature of the biomechanical model developed, within which all studied parameters are characterized by relatively similar values of relative contribution and reflect various aspects of the force, time, and force-time structures of the throw over the hip (O-goshi).

Comparative Analysis of Biomechanical Parameters in Schoolchildren of Different Fitness Levels

To verify the validity of the author's biomechanical model, a comparative analysis was conducted of the performance metrics of highly trained students in the model group (MG, $n = 14$) and students who were at the initial stage of judo training (CG, $n = 63$). The results of the comparison are presented in Table 4 and Figure 4.

The analysis revealed statistically significant differences in all biomechanical parameters studied ($p < 0.05$). The greatest intergroup differences were observed in the force gradient (GRAD) parameter, which was 47.56 % higher in the model group than in the general group. Significant differences were also found in the indicators of maximum center-of-mass displacement (Hmax) – 41.82 %, force impulse (I) – 38.99 %, relative maximum force (Fmax/P) – 38.54 %, and time to reach maximum force (Tmax) – 38.46 %.

The values for maximum vertical reaction force (Fzmax) and maximum resultant force (Fmax) among students in the model group were 35.49 % and 35.19 % higher, respectively,

Table 1. Biomechanical parameters of attacking throws in beginner at beginner and highly trained schoolchildren

No.	Characteristics	Unit of measur.	GG (n = 63)	MG (n = 14)	Diff. in %	P (темп.)
1	Fzmax	N	1139.94 ± 98.56	1544.48 ± 123.41	35.49	< 0.05 (15.634)
2	Fmax	N	1146.15 ± 103.16	1549.53 ± 129.37	35.19	< 0.05 (14.876)
3	Fmax/P	-	1.92 ± 0.17	2.66 ± 0.21	38.54	< 0.05 (16.751)
4	GRAD	N/s	4029.43 ± 321.59	5945.82 ± 442.18	47.56	< 0.05 (21.110)
5	I	Ns	150.16 ± 12.76	208.71 ± 17.86	38.99	< 0.05 (16.027)
6	Tps	s	0.14 ± 0.01	0.09 ± 0.01	35.71	< 0.05 (22.361)
7	Tmax	s	0.26 ± 0.02	0.16 ± 0.02	38.46	< 0.05 (22.361)
8	Tmax+To	s	0.32 ± 0.02	0.21 ± 0.02	34.38	< 0.05 (24.597)
9	Hmax	m	0.06 ± 0.01	0.08 ± 0.01	41.82	< 0.05 (10.286)
10	Tsum	s	0.67 ± 0.05	0.43 ± 0.04	35.82	< 0.05 (24.623)

compared to students at the beginner level of training. At the same time, students with a high level of training exhibited lower values for the time parameters Tps, Tmax, Tmax+To, and Tsum, indicating a faster realization of force potential during the execution of attacking technical actions.

A visual analysis of the profiles presented in Table 1 reveals significant differences in the structure of force-time characteristics between the groups. The profile of the model group is characterized by higher values of force indicators (Fzmax, Fmax, Fmax/P, GRAD, I) and lower values of time parameters (Tps, Tmax, Tmax+To, Tsum), reflecting a more efficient organization of the movement and a higher level of utilization of speed-strength capabilities during the execution of attacking throws.

The results obtained indicate significant differences in the biomechanical organization of attacking throws among schoolchildren of varying fitness levels. The indicators of the model group can be considered as indicative model characteristics of the biomechanical profile of attacking throws in schoolchildren with a high level of fitness and can be used for biomechanical monitoring and comparative analysis of schoolchildren's fitness levels.

A comprehensive analysis of the results showed that the average magnitude of intergroup differences across all biomechanical parameters studied was 38.20 %, in favor of the students in the model group. This indicates significant differences in the structure of the force-time characteristics of attacking throws between students with a high level of training and those with a beginner level of training. The greatest differences were recorded for the force gradient (47.56 %), while the smallest were for the resultant maximum force (35.19 %). The data confirm that the level of training is accompanied by complex changes in both the force and time components of the motor action.

Correlation Analysis

Correlation analysis made it possible to determine the nature of the relationships between the biomechanical parameters of attacking throws studied in highly trained schoolchildren (Table 1).

Numerous statistically significant, strong correlations were found between the force, time, and force-time characteristics of the motor action. The strongest positive

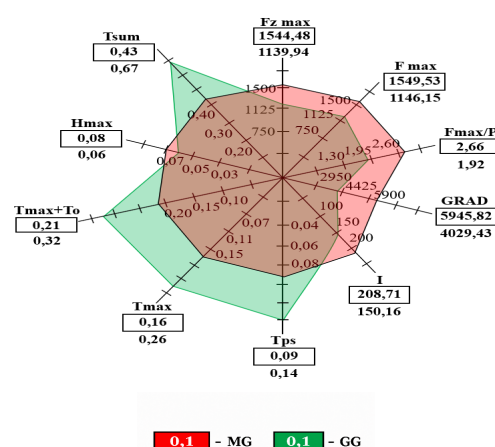


Fig. 5. Biomechanical profile of the throws over the hip in elementary school students (GG) and highly trained schoolchildren (MG)

correlations were found between the force gradient (GRAD) and the maximum vertical ground reaction force (Fzmax; $r = 0.998$), as well as between the force gradient and the force impulse (I ; $r = 0.998$). A very strong positive correlation was found between the maximum vertical ground reaction force and the resulting maximum force ($r = 0.938$), between force impulse and relative maximum force ($F_{\max}/P$; $r = 0.926$), as well as between force impulse and maximum vertical ground reaction force ($r = 0.925$).

An analysis of the time parameters revealed strong positive correlations between the preparatory phase time (Tps) and the total movement duration (Tsum; $r = 0.992$), between the preparatory phase time and the time to reach maximum force (Tmax; $r = 0.916$), as well as between the preparatory phase duration and the total duration of the push-off phase (Tmax+To; $r = 0.914$). This indicates a high level of coordination in the temporal structure of attacking technical actions.

Strong inverse correlations prevailed between force and time measures. Specifically, a correlation of $r = -0.988$ was found between the force gradient and the duration of the preparatory phase; $r = -0.967$ between the force gradient and the time to reach maximum force; and $r = -0.876$ between the force impulse and the duration of the preparatory phase. The

Table 2. Correlation matrix of biomechanical parameters of attacking throws in highly trained schoolchildren, with the specified level of statistical significance ($p < 0.05$)

Throw	Fzmax	Fmax	Fmax/P	GRAD	I	Tps	Tmax	Tmax+To	Hmax	Tsum
Fzmax	1									
Fmax	0.938	1								
Fmax/P	0.918	0.893	1							
GRAD	0.998	0.925	0.864	1						
I	0.925	0.922	0.926	0.998	1					
Tps	-0.918	-0.916	-0.926	-0.988	-0.876	1				
Tmax	-0.907	-0.905	-0.926	-0.967	-0.874	0.916	1			
Tmax+To	-0.736	-0.758	-0.924	-0.951	-0.731	0.914	0.634	1		
Hmax	-0.698	-0.695	-0.783	-0.797	-0.634	0.792	0.532	0.628	1	
Tsum	-0.869	-0.886	-0.989	-0.998	-0.867	0.992	0.615	0.672	0.615	1
Sum r	7.91	7.84	8.15	8.49	7.75	8.24	7.27	6.95	6.17	7.50
%	10.37	10.28	10.68	11.13	10.17	10.80	9.54	9.11	8.10	9.84
Rank	4	5	3	1	6	2	8	9	10	7

results indicate that higher indicators of strength potential are accompanied by a reduction in the duration of individual phases of the movement.

The sum of the correlation coefficients for each indicator was used to determine its integral informativeness within the structure of the author's biomechanical model.

The highest integral values were found for the force gradient ($\Sigma r = 8.49$), the duration of the preparatory phase ($\Sigma r = 8.24$), and relative maximum force ($\Sigma r = 8.15$). Based on the normalized values of the sums of correlation coefficients, the relative contribution of each indicator to the overall structure of the author's biomechanical model was determined, which made it possible to rank the studied parameters according to their degree of integration into the system of attacking technical actions.

The resulting correlation structure confirms the integrated nature of the biomechanical organization of attacking throws and indicates a close interrelationship between force, time, and force-time characteristics in highly trained schoolchildren.

Discussion

The purpose of this research was to develop an original biomechanical model of the throw over the hip (O-goshi) in highly trained schoolchildren based on tensodynamometric measurements and correlation analysis.

The force gradient index (11.13 %) demonstrated the highest relative contribution to the model's structure. The results obtained are consistent with data from recent biomechanical studies, which emphasize the importance of rapid muscle force development during the execution of judo techniques. For example, Hamaguchi et al. (2024) note that the characteristics of the preparatory phases (kuzushi and tsukuri) are associated with the acceleration characteristics of movement and the transfer of force impulse. The results of the present research complement these findings, demonstrating the high integration of the force rise rate indicator within the model structure.

Maximum force values (Fzmax – 10.37 %; Fmax – 10.28 %; Fmax/P – 10.68 %) were also characterized by high relative contribution values. Similar conclusions have been reported in biomechanical studies of the Sode-tsurikomi-goshi and Tsurikomi-goshi techniques, where peak accelerations and kinematic parameters of movement were associated with a high level of athletic proficiency (Pantelidou et al., 2025). In contrast to these studies, which focused primarily on segmental kinematics, the results of this research complement them with data on the role of support reaction parameters in the structure of the biomechanical model.

The high contribution of maximum force variables is also consistent with findings from other judo throwing techniques. Pucsok et al. (2001) showed that advanced performers of Harai-goshi differed from novices in support-leg force application, whereas Liu et al. (2025) reported significant relationships between ground-reaction-force components and sweeping-leg velocity in osoto-gari. Although the mechanical structure of these techniques is not identical to O-goshi, the common pattern is that proficient throwing requires effective conversion of support forces into rapid whole-body and segmental motion. In the present research, the higher Fzmax, Fmax, Fmax/P, and GRAD values in the model group are consistent with this broader biomechanical pattern.

Force impulse (10.17 %) also demonstrated a high level of integration within the system of parameters under research. Previous studies have established a link between impulse characteristics and indicators of sport-specific performance in judo (Ho et al., 2025). The results of this research complement these findings, demonstrating the relationship between force impulse and the force and force-time characteristics of the throw over the hip.

The time parameters (Tps, Tmax, Tmax+To, Tsum) were characterized by relative contribution values ranging from 9.11 % to 10.80 %. The results obtained are consistent with multidimensional concepts of athletic performance in judo, which emphasize the integration of neuromuscular, technical, and coordinative components (Schoof et al., 2024).

The temporal differences observed between the groups should therefore be interpreted together with the spatial and rotational organization of the movement. Ishii et al. (2018) found that elite seoi-nage performers generated greater relative forward center-of-mass velocity, while Liu et al. (2024) reported larger angular momentum and segmental angular velocities in black-belt than in white-belt judokas. Recent studies of seoi-nage further identify center-of-mass control, propulsion, and angular momentum transfer as objective markers of proficient throwing performance (Ishii & Koshida, 2025, 2026). From this perspective, the inverse correlations between force and time parameters in the present research may reflect a more compact and coordinated realization of force during the throw rather than an isolated reduction in movement duration.

The use of force plate analysis is in line with the current trend toward objective, quantitative assessment of biomechanical parameters (Xue, Han & Zhu, 2025). Unlike wearable sensor systems, the force platform provides highly accurate measurements of ground reaction forces and temporal characteristics of movement, which enables the development of integrated biomechanical models.

It is important to note that the relatively narrow range of normalized contributions (8.10–11.13 %) indicates the systemic nature of the biomechanical organization of the throw over the hip.

The practical significance of the author's model lies in the ability to use the obtained biomechanical indicators for biomechanical monitoring, comparative analysis of the characteristics of the throw over the hip (O-goshi) among schoolchildren of different fitness levels, further research of the biomechanical structure of technical movements in judo, and the development of the author's technical training methodology. The obtained values of force gradient, maximum force indicators, and force impulse can be used as indicative model characteristics.

For application in school-age athletes, the proposed values should be treated as reference characteristics for comparable age and training groups rather than as universal normative thresholds. Research in youth judo has shown that maturation, growth, and training experience contribute to neuromuscular and judo-specific performance (Detanico et al., 2020, 2022). Moreover, competitive level in judo can be differentiated by a combination of biomechanical, anthropometric, and sport-specific performance variables rather than by a single indicator (Teixeira et al., 2022). This supports using the proposed O-goshi profile as a multidimensional monitoring tool and interpreting changes in relation to the athlete's developmental and training context.

The limitations of the research include the relatively small sample size ($n = 14$), the analysis of only one technical movement (O-goshi), the use of force-measurement data without simultaneous assessment of the kinematic characteristics of the movement, and the inclusion of only male schoolchildren aged 15–16 years.

A separate limitation is the absence of a direct assessment of the technical effectiveness of the throw using expert evaluation, performance indicators, or other objective criteria of technical proficiency. Therefore, the results obtained characterize only the biomechanical features of the O-goshi throw and do not provide a basis for a direct assessment of the technical preparedness of school-age judo athletes.

The proposed biomechanical model can be used as a tool for the quantitative description and comparative analysis of the biomechanical characteristics of the movement, whereas establishing their relationship with technical effectiveness requires further research using additional evaluation criteria and the development of technical training methods based on the identified biomechanical patterns.

Conclusions

The research developed an original authors' biomechanical model of the throw over the hip (O-goshi) in highly trained schoolchildren based on tensodynamometric and correlation analysis. It was found that the greatest relative contribution to the structure of the developed model comes from the indicators of force rate of increase, maximum ground reaction force, and force impulse, which are characterized by a high degree of correlation with other biomechanical parameters of the movement under study.

An analysis of normalized contributions showed that the highest values of relative contribution are characteristic of the indicators of force rise rate, relative maximum force, maximum ground reaction force, and force impulse. The obtained results reflect the characteristics of the distribution of force, time, and force-time characteristics within the structure of the authors' biomechanical model.

The model group's measurements differed statistically significantly from those of schoolchildren at the initial stage of judo training across all biomechanical parameters studied ($p < 0.05$). The model characteristics obtained by the authors can be used for a comparative analysis of the biomechanical parameters of the throw over the hip (O-goshi) in schoolchildren of varying levels of training and for further research into the biomechanical structure of movement actions in judo.

Informed Consent

All participants were informed about the purpose, procedures, and conditions of the study before participation. Written informed consent was obtained from all participants. For participants under 18 years of age, additional written informed consent was obtained from their parents or legal guardians.

AI Transparency Statement

The authors declare that artificial intelligence tools were not used in the design of the study, data collection, data analysis, statistical processing, interpretation of the results, or formulation of scientific conclusions. ChatGPT (OpenAI, USA) was used exclusively for linguistic editing and grammatical improvement of the manuscript. The authors reviewed and approved all AI-assisted revisions and take full responsibility for the accuracy, integrity, and scientific content of the final manuscript.

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Conflict of Interest

The authors declare no conflict of interest.

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Біомеханічні параметри атакуючих кидків як основа технічної підготовки в дзюдо

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Авторський вклад: А – дизайн дослідження; В – збір даних; С – статаналіз; D – підготовка рукопису; Е – збір коштів

Реферат. Стаття: 9 с., 2 табл., 5 рис., 22 джерела.

Мета дослідження. Сучасний розвиток фізичного виховання школярів потребує ефективних засобів удосконалення рухових навичок, координаційних і швидко-силових здібностей. Одним із таких засобів є дзюдо, ефективність навчання технічних дій якого значною мірою залежить від об'єктивного оцінювання біомеханіки рухів. Метою дослідження було визначити біомеханічні параметри кидка O-goshi у школярів високої спортивної кваліфікації, розробити оригінальну біомеханічну модель на основі тензодинамометричних показників і кореляційного аналізу та визначити найбільш інформативні характеристики структури руху.

Матеріали та методи. У дослідженні взяли участь 77 учнів старшого шкільного віку чоловічої статі 15–16 років. Загальну групу (n = 63) становили початківці в дзюдо, тоді як модельну групу (n = 14) — спортсмени високої кваліфікації (кандидати у майстри спорту України та призери чемпіонатів України). Біомеханічні параметри кидка O-goshi реєстрували за допомогою тензодинамометричної платформи. Аналізували силові (Fzmax, Fmax, Fmax/P, GRAD, I), часові (Trp, Tmax, Tmax+To, Tsum) та просторові (Hmax) параметри. Біомеханічну модель розроблено на основі даних модельної групи із застосуванням кореляційного аналізу та нормування сум абсолютних значень коефіцієнтів кореляції. Кожен учасник виконував три спроби; для аналізу використовували середні значення показників.

Результати. Найбільший відносний внесок у біомеханічну модель мав градієнт сили (11,13%). Високу інформативність також встановлено для максимальної вертикальної сили реакції опори (Fzmax — 10,37%), результуючої максимальної сили (Fmax — 10,28%) та імпульсу сили (10,17%). Сильні кореляційні зв'язки між силовими та силово-часовими параметрами свідчать про їх тісну взаємодію під час виконання кидка O-goshi.

Висновки. Розроблена біомеханічна модель дала змогу визначити найбільш інформативні силові, часові та силово-часові характеристики кидка O-goshi у школярів високої спортивної кваліфікації. Отримані результати можуть бути використані для біомеханічного контролю та порівняльного оцінювання техніки виконання кидка спортсменами різного рівня підготовленості.

Ключові слова: дзюдо, біомеханіка, силово-часові характеристики, O-гоші, біомеханічна модель, школярі.

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