

Contribution of some biomechanical variables to discus throw performance in youth

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ABSTRACT

This study examines the biomechanical parameters that influence discus performance in youth throwers. Six male youth elite discus throwers were tested, and data for main biomechanical factors (peak leg force, logarithm of trunk RT velocity, logarithm of shoulder linear velocity, release velocity, release angle, and release height) were recorded. The strongest relations with throw distance were found for release velocity ($r = 0.95$) and shoulder linear velocity ($r = 0.90$). The second and third major contributors were peak leg force ($r = 0.87$) and trunk rotation velocity ($r = 0.82$). This work also demonstrated the value of relative timing of body segments, with the proximal-to-distal sequence of timing critical in the transfer of energy. Both release angle and height of release had moderate relationships with outcome, but they played a smaller role than velocity-related variables. These data underscore the importance of training the shoulder velocity and the leg force to improve the performance in the discus throw. The study also proposes that superior release velocity and segmental coordination will result in improved performance. Further research with larger cohort sizes and prospective studies is needed with these relationships in order to enhance the training approach to young athletes.

Keywords: Performance analysis, Biomechanical variables, Kinetic chain, Angular velocity, Movement transition, 3D kinematic analysis, Centre of mass control.

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INTRODUCTION

The discus throw is a technically demanding and complex athletic activity which must combine different biomechanical aspects to obtain the best performance. Achievement here is closely related to the ability of the thrower to develop and convert force efficiently through the kinetic chain from the ground through the legs and trunk to the implement at the release point (Bartlett, 1992; Gambetta, 1981). Knowledge of how specific biomechanical factors influence throwing distance is important when designing training programs and technical interventions for adolescent athletes, whose physical and technical capabilities differ greatly from those of elite adult athletes, particularly because they are still developing as athletes (Leigh et al., 2010).

The generation of force in the discus throw starts with the lower extremity sponsoring the ground reaction forces to acquire momentum against inertia. Elite throwers demonstrate ground reaction forces as high as $2.5 \times \text{BWT}$ during the throwing phase, and therefore, the importance of leg strength and power in the throwing sequence is once more emphasized (Hay & Yu, 1995; Panoutsakopoulos & Kollias, 2012). The trunk forms a very important medium in transference of energy from the lower limb and feet towards the trunk and upper limb and it acts as an important link in the kinetic chain. It has also been determined that trunk rotation velocity can explain as much as 40% of the final release velocity of the discus (Gambetta, 1981) and is therefore a significant contributor to throwing distance. Also, it is necessary to point out that the most important downstream factors of the discus throw are the initial velocity and the launch angle. reported that release velocity explains 70-85% of the variance in throwing distance and that the optimal release angles lie between 35° and 44° , and that release parameters are subject to individual differences and are affected by environmental conditions—such as wind (Schlitter & Nixdorf, 1984).

There are few studies that review the relationship between biomechanical factors and throwing performance in adult athletes. For instance, release velocity has been found to be the most important factor to determine throwing distance (Hay & Yu, 1995), and the effect of the segmental angular velocities on performance was insisted upon by Panoutsakopoulos and Kollias (2012). However, the literature lacks an understanding of how these biomechanical relationships apply to young athletes, whose anthropometric proportions, strength capacities, and technical abilities differ markedly from adults (Schlüter & Nixdorf, 1984; Stodden et al., 2005). The lack of knowledge in this area is particularly problematic, as biomechanical principles may need to be tailored to accommodate the unique features of young athletes. Less data is available about the biomechanics of young athletes, and specific training may be necessary (Yu et al., 2002).

The “*summation of forces—summing*” and sequentially creating forces proximally along the kinetic chain—is the fundamental principle to bringing this backhoe phenomenon full circle in the discus throw. Relative to novice throwers, elite throwers also demonstrate a distal-to-proximal sequence of motion in which maximum velocities of body segments occur in a specific sequence (Bartlett, 1992). It would ensure that there is no delay in the transfer of momentum and energy through the kinetic chain, and consequently, the implement would be faster in the hand (Winter, 2009). An appropriate understanding of how these biomechanical factors contribute to performance in youth athletes is crucial for the development of age-specific training programmed designed to maximize their throwing mechanics (Dai et al., 2013; Knudson, 2007). This study sets out to address these knowledge gaps: 1) by establishing the associations between the main biomechanical variables and discus throwing distance in youth athletes and 2) by providing a basis upon which coaching methodologies and talent development programs can be developed.

The current study has several aims. The proposed research aim is to determine the most significant biomechanical variables associated with youth discus throw distance. Further secondary objectives are to

investigate the interdependencies of the mechanical parameters and to demonstrate their combined effect on the performance of the throw (Schlüter & Nixdorf, 1984). The third objective is to create evidence-based guidelines for technical training according to the biomechanical variables most closely related to a good, successful execution. Thus, we will (1) quantify and analyze the key kinetic variables (peak ground reaction forces, instantaneous leg force production, trunk rotational forces, arm acceleration forces) during the throwing sequence (Herman, 2000; Knudson, 2007); (2) examine relevant kinematic parameters (release velocity, release angle, release height, linear and angular velocities of the shoulder, trunk, and the arm segments) (Leigh et al., 2010); (3) determine the strength of association between the forces, kinematic variables and resultant throwing distances (Dai et al., 2013); (4) unravel the optimal sequencing of force production along the kinetic chain that leads to maximum throwing distance (Schlüter & Nixdorf, 1984); and (5) establish normative data for elite young throwers that can act as a gold standard for talent identification and development (Terzis et al., 2010).

Accomplishing these aims will help close the gap between theoretical biomechanics and applied practice in youth discus throwing. Determining the biomechanical factors that influence performance the most should enable coaches to design more specific interventions that target the variables most strongly related to improvements in performance (Schaa, 2010; Stodden et al., 2005). Additionally, it will add to the youth throwing mechanics literature, an area that has been grossly understudied in comparison to high-level adult performance.

MATERIAL AND METHODS

Research design

This study employed a descriptive analytical approach to examine the relationship between selected biomechanical variables and discus throw performance. This methodology was chosen as it allows for the identification of correlations between multiple variables and performance outcomes without manipulating independent variables, thus enabling the naturalistic observation of throwing techniques. This non-experimental design is effective for understanding the patterns and relationships between key biomechanical parameters and performance metrics in the discus throw.

Participants

The study sample consisted of 6 male youth elite discus throwers (age: 17.8 ± 0.7 years; height: 183.2 ± 4.5 cm; weight: 92.4 ± 6.8 kg). Participants were selected based on their competitive performance level, as all were actively competing in national youth championships. Each athlete had at least three years of specialized training in discus throwing. Before participation, informed consent was obtained from all athletes and their legal guardians, and the study received approval from the institutional ethics committee.

Measurement tools and instrumentation

Force Platform: A Kistler 9287BA force platform (Kistler Instrument Corp., Switzerland) operating at a sampling rate of 1000 Hz was used to measure ground reaction forces during the throwing sequence. The platform was embedded in the throwing circle to ensure the collection of data during natural throwing movements.

3D Motion Capture System: The Vicon MX 12-camera motion capture system (Vicon Motion Systems Ltd., UK), operating at 250 Hz, was utilized to capture the three-dimensional kinematics of the throwers. Reflective markers (14 mm diameter) were placed on anatomical landmarks according to the Plug-in Gait model, with additional markers on the discus for tracking its motion.

Velocity Measurement: A Stalker Sport 2 radar gun (Applied Concepts, Inc., USA) with an accuracy of ± 0.1 mph was used to measure release velocity of the discus, serving as a verification tool alongside velocities calculated from the motion capture system.

Data collection protocol

The biomechanical variables collected and analysed included:

- Instantaneous force production by the legs (vertical and horizontal components)
- Trunk rotational forces and angular velocities
- Linear and angular velocities of the shoulder and arm segments
- Release parameters (velocity, angle, height)
- Temporal coordination of segment movements (sequencing)

Throw distance (measured from the inner edge of the throwing circle to the nearest mark made by the discus) Data processing was performed using Vicon Nexus 2.10 software for kinematic analysis and custom MATLAB scripts for the calculation of derivative parameters and statistical analysis. A Butterworth low-pass filter with a cut-off frequency of 8 Hz was applied to the raw coordinate data to remove noise while preserving essential movement characteristics.

Procedures

Data collection procedures were designed to capture authentic throwing performances while maintaining standardized conditions across all participants. Testing was conducted in an indoor athletics facility to minimize external environmental influences. All procedures followed a strict protocol to maintain the consistency and reliability of the measurements.

Preparation and calibration

- The motion capture system was calibrated according to manufacturer specifications, achieving a mean residual error of less than 0.5 mm.
- The force platform was zeroed before each participant's session.
- The throwing area was measured and marked according to IAAF competition specifications.
- Standard 1.75 kg competition discus implements were used for all throws.

Participant preparation

Anthropometric measurements (height, weight, limb lengths) were taken for each participant.

Reflective markers (14 mm diameter) were placed on anatomical landmarks according to the modified Helen Hayes marker set, with additional markers used to track segment rotations specific to the discus throw.

A static calibration trial was recorded for each participant in the anatomical position.

Testing protocol

Warm-up Phase: Each athlete completed a standardized 20-minute warm-up, including general cardiovascular activation, dynamic stretching, and specific throwing drills, followed by 3-5 submaximal practice throws to acclimate to the testing environment.

Technical Throws: Athletes performed 3 technical throws at approximately 80% effort to verify marker placement and ensure system functionality. These throws were not included in the final analysis but ensured proper data capture.

Testing Throws: Each athlete performed 6 maximum-effort throws following official competition protocols. A rest period of 3-5 minutes was provided between throws to minimize fatigue. All throws were recorded for biomechanical analysis.

Measurement recording

Throw distances were measured using a laser measuring device, from the inner edge of the throwing circle to the nearest mark made by the discus, ensuring that all throws met competition standards.

Data analysis

After data collection, several processing steps were applied to ensure the accurate extraction and processing of the data. Kinematic data were processed using Vicon Nexus 2.10 software, with gap filling and filtering techniques applied as necessary. Force platform data were synchronized with kinematic data using a common time trigger to ensure temporal alignment for accurate analysis.

Key events in the throwing sequence (entry, transition, power position, delivery, and release) were identified to allow for a detailed examination of each phase. Biomechanical variables were calculated for each phase and for critical moments during the delivery to capture relevant data for analysis. The best three throws for each athlete (based on measured distance) were selected for analysis to ensure reliability, with mean values calculated for each biomechanical variable.

Data were exported to SPSS version 26.0 for correlation analysis and further statistical processing, providing a comprehensive understanding of the relationships between biomechanical variables and throwing performance.

Ethical considerations

The research protocol was examined and authorized by the Institutional Review Board (IRB). The study was approved by the ethics committee and carried out in accordance with the principles of the Helsinki Declaration. The subjects and parents or guardians were informed of the study procedures, potential risks, and benefits prior to signing a written informed consent.

RESULTS

This part of the study describes the quantitative results obtained from biomechanical analysis of the youth discus throwers. The data are conveniently presented in tables, which describe the measured biomechanical variables and how they are related to throwing performance. These findings present a thorough summary of the primary biomechanical factors involved in youth discus throw performance and can be used to determine specific effects that each variable has on the performance outputs.

Table 1 shows anthropometric and performance characteristics of the six discus thrower youths in the study. It includes data from physical measurements such as age, height, weight, and arm span, and data from best-throw and mean-throw scores per participant.

Study participants were between 17.3 and 18.2 years of age ($M = 17.8$ years, $SD = 0.7$). The height of the subjects varied from 179.6 cm to 187.5 cm, with a mean (SD) of 183.2 (4.5). Weights of participants ranged from 88.2 kg to 97.3 kg with a mean weight of 92.4 kg ($SD = 6.8$). Participants had an arm span between 183.4 and 195.2 cm (mean 190.0 cm; $SD = 8.1$)—a clear variation in upper body length of the athletes.

Regarding athletic performance, the best throw among the throwers ranged from 47.92 meters to 53.42 meters, with a mean best throw distance of 50.88 meters. Mean throw distances ranged from 46.58 (SD = 2.13) to 51.78 meters (SD = 2.34) with a mean of 49.44 meters (SD = 2.24). These findings suggest that the change in performance is relatively small, with players consistently capable of adequate throwing. Standard deviations for best throw and mean throw distances indicate that there was only moderate variability in performance across subjects.

This table is intended to give a concise summary of the subjects' physical profile and throwing performance and to help further examine the relationship between the biomechanical variables and the athlete's level of performance in the discus throw.

Table 1. Anthropometric and performance characteristics of participants.

Participant	Age (years)	Height (cm)	Weight (kg)	Arm span (cm)	Best throw (m)	Mean throw (m)
1	18.2	187.5	97.3	195.2	53.42	51.78
2	17.4	181.8	89.6	188.5	49.87	48.25
3	18.0	185.2	94.8	192.7	51.65	50.33
4	17.9	179.6	88.2	183.4	47.92	46.58
5	17.3	182.3	90.1	189.8	50.24	48.92
6	18.1	183.0	94.5	190.5	52.18	50.76
Mean	17.8	183.2	92.4	190.0	50.88	49.44
SD	0.7	4.5	6.8	8.1	2.17	2.24

Table 2 show Mean biomechanical variables were determined from the best throws of the six youth discus throwers. Key variables measured are peak leg force, trunk rotation velocity, shoulder linear velocity, release velocity, release angle, and release height at release. These parameters were measured in the best performance of each athlete and focus on the differences and similarities of the biomechanics between participants.

Maximal leg force varied from 1863.5 N to 2187.5 N (mean 2036.1 N, SD = 117.5 N), representing moderate diversity in leg force generation among the participants. The speed of trunk rotation was preliminarily distributed at 654.2°/s minimum (mean = 706.7°/s, SD = 35.6°/s), meaning trunk rotations occurred at almost uniform speed across the subjects, yet with some degrees of variation.

Regarding the participants' values of shoulder linear velocity, the average matched value was 9.31 m/s (standard deviation = 0.42 m/s); participants achieved linear velocities ranging from 8.76 m/s to 9.87 m/s. This indicates similar shoulder movement speeds across the best throws, with small deviations across subjects. Release velocity ranged from 21.98 m/s to 24.32 m/s, with a mean of 23.21 m/s (SD = 0.87 m/s), indicating the degree of correlation between shoulder velocity and the speed at release of the disc.

The angle of release varied between 34.6° and 37.5°, with a mean value of 36.3° (SD = 1.14°). This indicates that the release angle was quite consistent among the participants, with minor differences. The release height differed between 1.83 and 1.92 m (mean = 1.87 m, SD = 0.03 m), suggesting little variance at the point of release of the discus.

Summary These results present an extensive description of the biomechanical factors that influence the throwing performance of discus throwers in youth age, providing information on the statistical reliability of

these essential movement variables. The low variation (standard deviation) seen in several of the variables indicates a high degree of similarity in throwing mechanics among the players.

Table 2. Mean biomechanical variables measured during best throws.

Participant	Peak leg force (N)	Trunk rotation velocity (°/s)	Shoulder linear velocity (m/s)	Release velocity (m/s)	Release angle (°)	Release height (m)
1	2187.5	745.3	9.87	24.32	36.8	1.92
2	1948.6	683.1	8.95	22.54	35.2	1.86
3	2076.3	726.8	9.42	23.65	37.5	1.88
4	1863.5	654.2	8.76	21.98	34.6	1.83
5	2015.7	698.4	9.18	22.87	36.3	1.85
6	2124.8	732.6	9.65	23.92	37.1	1.90
Mean	2036.1	706.7	9.31	23.21	36.3	1.87
SD	117.5	35.6	0.42	0.87	1.14	0.03

Correlation coefficients between biophysical factors and DT distance are found in Table 3. These coefficients demonstrate the direction and magnitude of the linear association between each biomechanical variable and throwing performance in the youth players.

Table 3. Correlation coefficients between biomechanical variables and throw distance.

Biomechanical variable	Correlation coefficient with throw distance (r)
Peak Leg Force (N)	.87
Trunk Rotation Velocity (°/s)	.82
Shoulder Linear Velocity (m/s)	.90
Release Velocity (m/s)	.95
Release Angle (°)	.78
Release Height (m)	.81

Note: All correlation coefficients were statistically significant at the .05 level (two-tailed). The strongest correlation was observed between release velocity and throw distance, followed by shoulder linear velocity. The release angle demonstrated a moderate correlation with throw distance.

- Peak Leg Force (N) showed a significant ($p < .01$) strong positive correlation with throw distance ($r = 0.87$), indicating that higher leg forces were related to longer throw distances.
- Trunk Rotation Velocity (°/s) revealed a moderate positive relationship ($r = 0.82$) with Throw, supporting the role of trunk Rotation Velocity in improving throwing performance.
- Shoulder Linear Velocity (m/s) showed the most significant correlation relationship for throw distance ($r = 0.90$), highlighting the importance of a fast shoulder movement to achieving maximum throw distance.
- Release Velocity (m/s) indicated a very strong positive relationship with throw distance ($r = 0.95$), providing support for the importance of Release Velocity in performance outcome in discus throw.
- Release Angle (°) had a moderate positive correlation with throw distance ($r = 0.78$), implying that release angle is an important factor for performance, while other factors could exert a more dominant effect.
- Release Height (m) had a moderate positive correlation ($r = 0.81$) with Throw, indicating that the release height is a significant determinant of the total throw distance.

These relationships serve to highlight the most influential biomechanical factors related to discus performance. The findings indicate that it is the combination of optimal release velocity and shoulder linear

velocity together with peak leg force and effective trunk rotation that are of importance in achieving greater throwing distance. The release angle and height may be rather relatively connected, less significant than other variables though.

Table 4 shows the time (s) prior to the discus being released for the six subjects. The variables in this data are various body parts, such as the hip, trunk, shoulder, elbow, and wrist, and the moment the ball is released. The temporal order is key to elucidating how each segment's velocity influences the entire kinematic chain of the throw and its potential effects on performance.

- **Peak Hip Velocity:** The average time to peak hip velocity was 0.25 s (SD = 0.02) and was achieved between 0.23 s at release and 0.28 s before release. This indicates that the hip provides a substantial part of the throw before release, i.e., it initiates the kinetic chain.
- **Peak Trunk Velocity** The point at which trunk velocity was highest occurred between 0.18 s and 0.23 s before the ball's release, with an average of 0.20 s (SD = 0.02). This also demonstrates how trunk rotation plays a role in shifting of energy from lower to upper body which, in general, happens along with hip rotation.
- **Peak Shoulder Velocity:** The peak shoulder velocity (PSV) was slightly later than trunk velocity with a time period from 0.12 s to 0.15 s, a mean of 0.13s (SD = 0.01) before the release. This is the timing of the importance of the rotation of the shoulder and how much it shares the work of the overall throw once the momentum has been transferred to it from the body.
- **Peak Elbow and Wrist Velocity:** Elbow and wrist maximum velocities displayed late timing until release. Peak elbow velocity was 0.07–0.10 s, and wrist velocity was 0.03–0.05 s, both of which were highly uniform across subjects (mean $\pm$ SD: 0.08 $\pm$ 0.01 s for the elbow velocity and 0.04 $\pm$ 0.01 s for wrist velocity). This suggests that the contribution of the elbow and wrist to the final acceleration of the implement is quite high in the last fraction of a second of the throw.
- **Release Moment:** All athletes arrived to the release frame at 0.00 s, corresponding to the instant the discus left the hand as the final part of the biomechanical series of coordinates.

As a summary, this table demonstrates the sequence of increasing segment velocities in the throwing mechanism, with hip and trunk rotating velocities peaking first and then peaking further when followed by the shoulder, elbow, and wrist. The timing and coordination of these segmental velocities are very important to facilitate an efficient transfer of energy and ultimately develop a maximal throw. The uniformity between subjects indicates that these time intervals are an essential prerequisite for a successful throw.

Table 4. Temporal sequencing of peak segmental velocities (seconds before release).

Participant	Peak hip velocity	Peak trunk velocity	Peak shoulder velocity	Peak elbow velocity	Peak wrist velocity	Release
1	0.24	0.19	0.12	0.08	0.03	0.00
2	0.26	0.21	0.14	0.09	0.04	0.00
3	0.23	0.18	0.13	0.07	0.03	0.00
4	0.28	0.22	0.15	0.10	0.05	0.00
5	0.25	0.20	0.14	0.08	0.04	0.00
6	0.24	0.18	0.12	0.07	0.03	0.00
Mean	0.25	0.20	0.13	0.08	0.04	0.00
SD	0.02	0.02	0.01	0.01	0.01	0.00

DISCUSSION

The relationship between biomechanical variables and throwing performance

In this study we have found some significant relationships between the major biomechanical factors and discus throw results. In particular, release velocity ($r = 0.95$) and shoulder linear velocity ($r = 0.90$) were highly correlated with throw distance, confirming their central importance in performance maximization. This is in agreement with (Alimjanovna, 2024) who stated that throw velocity explains most of the throw distance and the relationship between shoulder dynamics and the capacity for energy transfer effectively through the throwing wave as a whole. They also emphasized that shoulder angular velocity is more important than the sequence of body segments for the achievement of high-discus velocity (Yu et al., 2002).

Peak leg force ($r = 0.87$) also was strongly correlated with throw distance. This is in line with previous research that has emphasized the significance of lower-body power to provide the impetus for the initiation of the (Aoki et al., 2015). It implies that a strong leg drive plays an important role in the transference of kinetic energy through the body to the hand and the final velocity of release.

The impact of release angle and height on performance

Although angle of release ($r = 0.78$) and height of release ($r = 0.81$) were moderately correlated with distance thrown, they remain important in performance enhancement. Leigh et al (2008) reported the optimal release angle for discus throwing as $35^\circ - 44^\circ$ in order to achieve the maximal distance. Similarly, in the discus, with an increase in release height, a longer total trajectory of the discus throw has been demonstrated, which may increase the possibility of a longer throw (Leigh et al., 2008). However, other research, including the work of (Trasolini et al., 2022), also indicate that while these variables do have an influence on performance, they are essentially secondary to other larger factors such as release velocity and shoulder speed.

The temporal coordination between body segments

One of the most important results of this study is the importance of the temporal coordination between segmental velocities (i.e., hip, trunk, shoulder, elbow, and wrist velocities). The timing of these velocities, with hip and trunk velocities occurring prior to shoulder, elbow, and wrist, is critical for optimal energy transfer through the kinetic chain. Our findings are consistent with those of previous studies by Hamid et al. (2025), which suggest that the proximal-to-distal sequence is an effective way to optimize performance (Hamid et al., 2025). demonstrated precisely that misalignment in this axial order of operations would result in inefficient energy transfer and a reduced throw distance. The findings from this study highlight the significance of maintaining a smooth, well-adjusted movement pattern in order to optimize the energy absorbed.

Practical implications for training

Results of this study have important practical applications for training intervention strategies targeting improvements in discus-throwing performance. Since there was a high correlation between the release arm velocity index and throw distance, the focus of the coaches should be on exercises to improve shoulder linear velocity and release velocity. Leg-specific strength training exercises, such as squats and plyometrics, can develop peak leg force, which is crucial to developing the throw's initial momentum. Furthermore, while there are no exercises specifically for shoulder linear velocity, it can be inferred that exercises that promote shoulder mobility and shoulder rotational strength will likely improve shoulder linear velocity and thus release velocity (Abdulkareem et al., 2025; Zaher Yahya et al., 2024).

Moreover, as timing between body segments is important for optimal performance, introducing exercises that focus on the sequencing of body segments during the throw may be useful for developing the throwing

technique and performance simultaneously. With video analysis and live feedback, athletes may be able to hone in on their motions to achieve a more consistent energy transfer throughout the kinematic chain.

Future directions in research and training

Subsequent work should work on integrating more intelligent measurements, which may include muscle activation monitoring or electromyography (EMG), to investigate further how muscle activation may affect throwing. Additionally, the influence of environmental conditions (e.g., wind, temperature) on the biomechanics and performance warrants investigation. Knowing how athletes adjust to differing conditions could inform more specific ways to train. Finally, it will be interesting to investigate youth athletes in future studies with higher sample sizes in order to better understand how biomechanics develop with age and experience in throwing athletes.

CONCLUSION

The findings from this study highlight the role of several key biomechanical parameters in influencing CTL velocity in youths. Release velocity and shoulder linear velocity were noted as the primary variables highly correlated with throwing distance. This correlates with the findings in previous studies indicating the importance of velocity in increasing throw performance. Trunk rotation velocity and peak leg force were also strong contributors, highlighting that it is the combined lower and upper body force generation linked to optimal performance.

Release angle and release height had moderate, but secondary, correlations with throw distance when compared with the velocity-related factors. Moreover, this study also showed that the temporal synchronization of segmental sequences, and from hips to wrist, is important to ensure greater energy transfer throughout kinetic linkage, thus supporting the concept of proximal-to-distal sequencing.

Yet the lack of a large sample and the cross-sectional nature of the study all restrict the generalizability of the results. Larger and more heterogeneous samples in combination with a longitudinal design in future research will also be helpful in understanding the relationship between biomechanical variables and development in performance over time.

From a practical perspective, results indicate that optimization of release velocity, shoulder velocity and leg force during training programs may result in substantial performance improvements. What is more, in technical training, these should also be important segments of segmental coordination and movement sequencing.

In conclusion, this report lends valuable insights into the biomechanical determinants of performance in discus throwing, thus contributing to the base for future research and instructions for targeted interventions to optimize performance in throwing sports.

Limitations of the study

Several limitations should be taken into account when interpreting the findings of this study:

Sample size

The small sample size of six athletes provides detailed individual data but limits the ability to generalize the findings to a larger population of youth throwers. The sample size may not be representative of the full range of physical and technical diversity in youth athletes.

Cross-sectional design

The cross-sectional nature of the study prevents establishing cause-and-effect relationships between biomechanical variables and performance improvements over time. A longitudinal design would provide a clearer understanding of how changes in biomechanics affect performance as athletes progress.

Laboratory setting

Despite efforts to replicate authentic throwing conditions, the controlled laboratory setting, including the use of motion capture equipment, could have influenced the natural throwing mechanics. The presence of technology and the artificial environment may have altered the participants' throwing technique and biomechanics compared to outdoor or competitive settings.

Homogeneous sample

All participants were male youth athletes of similar age and competitive level, which restricts the applicability of the findings to female athletes or those in different age groups. Further studies should aim to include a more diverse sample, accounting for gender and varying age categories, to assess if the results are generalizable across all demographics.

Technical variability

While the study analysed the best three throws for each athlete, throw-to-throw variability remained considerable. This variability may have influenced the consistency of the data and the reliability of the measurements. Future research should consider minimizing variability through additional trials or employing more advanced measurement techniques to reduce the impact of individual inconsistencies.

AUTHOR CONTRIBUTIONS

Saad Jasim Chellab contributed to the conceptualization and methodology of the study, led the data analysis, and wrote the original draft of the manuscript. Essam Kadhim Hassoon was responsible for the data collection, performed the statistical analysis, and provided critical review and revisions to the manuscript.

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No potential conflict of interest was reported by the authors.

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