**INTERDISCIPLINARY DOCTORAL SCHOOL**

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# Study on the Biomechanics of the Throw and Kinematic Transfer in the Javelin Throw Event among Junior Athletes

SUMMARY

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# PART I

## 1. CONCEPTUAL AND METHODOLOGICAL ASPECTS IN ATHLETICS

### 1.1 General Aspects of the Evolution of Athletics and the Javelin Throw Event

Athletics, one of the oldest and most renowned sports disciplines in the world, comprises, in the form we know it today, three major categories of events: track, jumps, and throws. These are conducted inside the stadium, whereas out-of-stadium competitions include race walking and the marathon, alongside the more recently introduced disciplines of ultramarathon and trail running.

Within the framework of the modern Olympic Games, the javelin throw was introduced for men in 1906, and for women in 1932. Athletes from the Scandinavian Peninsula heavily dominated the first three decades of international competitions to such an extent that they secured six Olympic gold, four silver, and four bronze medals between 1908 and 1932. Furthermore, they retained ownership of the world record until 1953[1]. Possessing three Olympic titles—Athens 1906, London 1908, Stockholm 1912—Eric Lemming (Sweden) remains historically recognized as the first athlete to win this event three consecutive times. His achievement was later matched by the famous Jan Zelezny (Czech Republic), the current world record holder, who likewise secured the Olympic gold medal three consecutive times: Barcelona 1992, Atlanta 1996, and Sydney 2000. The name of Uwe Hohn (GDR) remains historical as the first javelin thrower to surpass the 100m threshold. With a remarkable result of 104.80m, he won the competition organized in Berlin in 1984.
At the beginning of the 1990s, the peerless Jan Zelezny made his appearance on the world stage, winning his first Olympic title in 1992, in Barcelona, with a result of 89.66m, and subsequently maintaining supremacy for years to come. He holds the men's world record of 98.48m, achieved in 1996 during a competition in Germany. Subsequently, the 90m boundary was crossed by other top throwers, but the only one who "threatened" the record, after a long period of 24 years, was the German JOHANNES Vetter.

Regarding the women's javelin throw, the first world record after the year 2000 was held by the Norwegian Trine Hattestad, who achieved a distance of 69.48m, before Osleidys Menendez (Cuba) obtained a remarkable performance of 71.54m in 2001. She also won the Olympic gold in 2004, in Athens, finishing 1cm short of her personal best, which was simultaneously the world record.[2]

Barbora Spotáková (Czech Republic) became the Olympic champion in 2008 with an incredible performance of 71.42m, and later that same year, she established the world record of 72.28m, which remains unbroken to this day.

[1] Bartonietz, K. (2000). Javelin throwing, an approach to performance development, în cartea Biomecanics in sports, performance inhancement and injury prevention (p 401-434), Ed. Blackwell Science, International Olympic Committee;
[2] http://www.nemethjavelins.hu/olympic-medalists-women; accesat în februarie 2023;

## 1.2 The Evolution of the Javelin Throw Event in Romania

The first to achieve international recognition is Gheorghe Megelea. He became the European vice-champion at the European Junior Championships in 1973 with a mark of 74.68m, and two years later, he became the world university champion at the World University Games with a surprising throw of 81.30m, becoming the first Romanian to surpass the 80m threshold. At the 1976 Olympic Games in Montreal, he brought honor to the country by securing the bronze medal with a superb result of 87.16m, which also became the national record. In 2018, after nearly 30 years, the national record was shattered by Alexandru Mihăiță Novac, who remains the current men's javelin throw record holder in Romania with an extraordinary performance of 86.37m.

Regarding the women's javelin throw, remarkable international results were achieved—in addition to Mihaela Peneș, who was the Olympic champion in 1964 (Tokyo) and Olympic vice-champion in 1968 (Mexico) by:

- M. Diți-Diaconescu – silver medalist in 1962 at the European Championships (Belgrade) with a throw of 52.10m; bronze medalist in 1959 at the World University Games;
- E. Zorgo-Raduly – bronze medalist in 1975 at the World University Games
- Felicia Țilea – bronze medalist in 1994 at the European Championships (Helsinki) with a throw of 64.34m and silver medalist in 1995 with 65.22m at the World Championships (Gothenburg)
- Claudia Isailă – gold medalist in 1992 at the World Junior Championships (Seoul) with a throw of 63.04m; silver medalist in 1995 with 61.74m at the World University Games (Fukuoka)
- Monica Stoian – silver medalist in 2007 with a throw of 61.19m at the World University Games (Bangkok); and bronze medalist at the World Championships (Berlin) in 2009 with a result of 64.51m.

The current national record of 65.08m was established in 2001, in Bucharest, and is held by Ana Mirela Țermure.

## 2. SPORTS TRAINING, A COMPLEX METHODOLOGICAL CONCEPT OF PREPARATION IN THROWING EVENTS

### 2.1 General and Specific Aspects in Sports Training, a Complex Process of Integrating Motor Qualities

Over the years, sports training has been extensively debated and analyzed by renowned specialists, including Dragnea A. (1992), Alexe N. (1993), Bompa T. (2002), Rață G. (2005), and many others, being presented as a pedagogical process that involves the instruction and education of subjects to transform and adapt the organism to intense efforts, with the ultimate goal of maximizing the aptitudes of the individuals undergoing the process. Specialists Epuran M., Holdevici I., and Ioniță F. (2001, p. 63) state that sports training "remains, in its essence, an instructional-educational process, but with the characteristics of a management process that systematizes laws originating not only from the biological, psychological, and social spheres, but also from the realm of transdisciplinary and integrative phenomena."[3]

Regarding the specialist Bompa, T.O (2002, p 13)[4] we consider valuable his clarifications regarding sports training, stating that "training represents the manipulation of methods to induce adaptation. When adaptation reaches high levels, performance follows suit. Without a continuous increase in the athletes' physical adaptation, improvements are impossible." In athletics, specifically within the javelin throw event, as indeed in all other sporting disciplines, the long-term aspect of preparation is taken into account; training influences the individuals' personality, thereby making the comprehensive knowledge and careful monitoring of the athletes' behavior and traits essential, as well as the manner in which they self-regulate and develop the necessary attributes for adaptation under all conditions. The factors that influence the achievement of high performance are the very foundation upon which individuals' personalities are built and perfected. This staged and phased nature of training is directly linked to the nature and content of socio-cultural influences.

We mention that the term "training dynamics" was defined by the author Bădescu, D. (2010) in her doctoral dissertation, wherein she presents this concept as an active, continuously evolving modality characterized by the "permanent accumulation of knowledge and experience, taking into account the totality of qualitative and quantitative internal changes within the system, the influence of the external environment on this system, and the athlete's movement modality under the action of internal forces and their psyche."[5] The system referred to comprises the athlete, the coach, and the environment.

### 2.2 Objectives of Sports Training in the Javelin Throw Event

Specialized literature presents the objectives of sports training through various perspectives, in both their didactic and practical forms, aiming at the learning, consolidation, and refinement of

[3] Epuran, M., Holdevici, I., & Ioniță, F. (2001). Psychology of High-Performance Sport. Bucharest: FEST;
[4] Bompa, T. O. (2002). Theory and Methodology of Training – Periodization. Bucharest: Ex Ponto Publishing House;
[5] Bădescu, D. M. (2010). Dynamics and Efficiency in the High-Performance Training of the Women's 20km Race Walking Event] (Doctoral dissertation). UNEFS, Bucharest;

motor skills and abilities, as well as the development and formation, at a superior level, of basic and combined motor qualities and aptitudes.
In sports training, specialists Bompa, T. and Haff, G. (2014) maintain that the primary objective is to prepare an individual to achieve the highest possible level of efficiency [6]. The objectives target the development of specific attributes which, when executed in accordance with the specificity of the event, the athlete's age, training level, and talent, lead to progression and performance achievements.
The authors present these attributes as being:

- ✓ *Multilateral physical development;*
- ✓ *Sport-specific physical development;*
- ✓ *Technical procedures;*
- ✓ *Tactical abilities;*
- ✓ *Psychological factors;*
- ✓ *Preservation of physiological health;*
- ✓ *Injury resistance;*
- ✓ *Theoretical preparation.*

### 2.3 Adaptation to the training process in technical events of athletics

The activities conducted within sports training are profoundly linked to the organism's adaptive processes, eliciting complex physiological reactions following the executed workloads; adaptation is applicable across all scenarios and realities associated with training and competitive participation. In sports training for the javelin throw, adaptation occurs gradually over an extended period, as it is a highly demanding event characterized by a heavily complex and intricate technique (Terauds[7], 1985; Morriss și Bartlett[8], 1996).

Consequently, athletes whose strength and power training involves submaximal and maximal workloads (such as throwers) achieve muscular hypertrophy; furthermore, the attainment of elite performance in these speed-power events is closely linked to individual genetics and the dominance of a specific muscle fiber type.

[6] Bompa, T. O., & Haff, G. G. (2014). Periodization: Theory and Methodology of Training. Bucharest: Ad Point Promo Publishing House;
[7] Terauds, J. (1985). Biomechanics of the Javelin Throw. Del Mar: Academic Publishers;
[8] Morris, C.J și Bartlett, R.M. (1996). Biomechanical factors critical for performance in the men`s javelin throw. Sports Medicine, 21(6), 438-446;

## 3. SOMATIC, MORPHO-FUNCTIONAL, AND PSYCHOLOGICAL PARTICULARITIES IN JUNIOR ATHLETES AGED 15-18 YEARS

The transition from puberty to adolescence is characterized by a diversity of perspectives due to the inherent complexity of this developmental period in an individual's life. This stage exhibits an extraordinary temporal dynamic, bound by numerous constraints and determinants, leaving the adolescent in a somewhat ambiguous position, with behavioral patterns oscillating between childhood and maturity. Adolescents undergo a rapid and intensive personality development, marked by profound adjustments and rapidly evolving traits. It represents the period wherein worldviews and life concepts are constructed and outlined, ideals are formulated, and the cognitive, volitional, and affective dimensions of personality are progressively developed.

### 3.1 Somatic characteristics

Toward the age of 18, the skeletal system increases in length, approaching adult dimensions and morphology, yet it remains less developed in terms of hardness and structural resistance. Growth processes generally cease in girls around the age of 17–19 years, whereas in boys, growth continues until approximately 21–25 years of age.
Characteristic age-related parameters:

- Stature in boys reaches a mean value of 175.3 cm;
- Body mass reaches a mean value of 71.630 kg;
- Chest circumference reaches a mean of 85 cm in boys and 80 cm in girls;
- Arm span, compared to standing height, is 3–4 cm greater in boys than in girls;
- Lower limbs are longer in boys compared to girls, with sitting height being shorter relative to total stature, and the Amar index indicating a value of 0.52;
- Girls exhibit superior balance due to a lower center of gravity, by 0.61 compared to boys
- Muscle mass in girls is approximately 13% lower than in boys;
- Respiratory rate is 16–18 breaths/minute, and tidal volume ranges between 400 – 500 $cm^3$;
- By the age of 18 years, heart rate reaches 85–86 beats/minute, and cardiac volume ranges between 250–300 $cm^3$.Capacitatea vitală, măsurată la aparatul spirometru, este de 4000 – 5000 $cm^3$.

### 3.2 Morpho-functional characteristics

The author Ivan, C (2002, p 22)[9] states that regarding elite throwers, neuromuscular excitability exhibits excellent values, as do repetition speed and reaction speed. Furthermore, heart rate and blood pressure must maintain normal values both at rest and during exertion, with a corresponding post-effort recovery.

Javelin throwers exhibit the capacity to maintain a high functional lability of fundamental nervous processes over an extended duration of time. Under the influence of emotional states, competitive throwers generate muscular efforts that can surpass the working capacity threshold

[9] Ivan, C. (2002). *Aruncarea suliței, bazele tehnico-metodice ale antrenamentului sportiv – modele operaționale*, ISBN: 973-0-02845-1, Bucharest;

of neural cells, representing a distinct characteristic specific to the central nervous system. In javelin throwers of this age group, somatic characteristics tend to resemble those of adults; consequently, the somatic biotype features a stature exceeding 180 cm, with a sitting height-to-stature ratio of 51.06% in favor of the trunk. The biacromial diameter values range between 43–48 cm, while the bitrochanteric diameter ranges between 33–36 cm. Due to the pronounced development of the dorsal and pectoral musculature, the chest circumference is large, whereas the abdominal circumference is considerably smaller yet exhibits well-developed musculature. Lean body mass accounts for more than 85% of total body composition, with adipose tissue comprising the remainder. Hip joint mobility is highly pronounced, demonstrating values of +10 cm, and thoracic elasticity is likewise excellent. It is indicated that the strength index relative to lean mass (SI/LM) and relative to body weight (SI/W) should exceed unity. Furthermore, arm span—which represents one of the most critical parameters for achieving elite performance—must register values at least 4 cm greater than standing height. Additionally, tissue oxygenation improves, the dimensions of the heart and blood vessels reach a state of equilibrium, and the endocrine glands develop social characteristics while reaching complete maturation.

## 4. THE EFFORT CHARACTERISTICS IN THE JAVELIN THROW EVENT

### 4.1 The Physiological Characteristics of Effort in the Javelin Throw Event

In athletics, as an individual sport, it is necessary throughout the planning of sports training to address the essential condition of respecting the physiological particularities that occur during the executed effort, relative to each specific event.

Within training preparation, the workload acts upon the organism as a stimulus but also as a stress factor, of either subjective or objective nature, with varying degrees of difficulty that must be overcome.

In throwing events, the prevailing biomotor qualities are strength and speed, alongside their combination; consequently, athletic performance correlates primarily with the functionality and efficiency of the neuromuscular system and the central nervous system (CNS), which ensures the alternation of excitation and inhibition (contraction and relaxation) of the locomotor apparatus through its high functional lability.

The javelin throw event features a non-uniform effort characterized by explosive strength (power), of an anaerobic alactacid type (predicated on ATP energogenesis), executed via maximal neuromuscular tension. The energy pathway utilized is the ATP-PC system, where the primary source of energy is ATP produced in the absence of oxygen, the substrate consists of phosphagens—intramuscular stores of ATP and PCr (phosphocreatine)—the duration is up to 7–10 seconds, the reserves are completely depleted, and their replenishment takes up to 2 minutes.[10]

### 4.2 Specific Demands of the Javelin Throw Event

The specific effort within the throw is of maximal intensity, demanding not only the nervous system but also the muscular and skeletal systems, as well as the internal organs.

The author Ivan, C. (2002) states that "the most convincing biological expression of the degree of neuromuscular demand in javelin throwers is the pronounced muscular hypertrophy, both in the lower body, which prepares and bears the consequences of the explosive thrust (the whipping motion), and in the upper body, which continues and concludes the effort initiated by the lower limbs."

In this event, power refers to the throwing force that the athlete must apply to the implement. Javelin throwers must accelerate continuously throughout the sequence to achieve maximal speed, ensuring that the object possesses maximal velocity at the moment of release.

During training, attention must be paid to preserving symmetry in the muscular hypertrophy of the arms to prevent structural imbalances within the organism. Consequently, appropriate heterolateral development is pursued through carefully selected, specific exercises.

[10] Bompa, T. O., & Buzzichelli, C. A. (2021). Periodization: Theory and Methodology of Sports Training (6th ed.). Bucharest: Lifestyle Publishing House

To achieve a high level of movement mastery and a superior degree of motor skill refinement, it is necessary to engage the nervous system in the challenging task of training coordinative capacities and fine-tuned motor control; this is accomplished through extensive and rigorous repetitions requiring exceptional neural concentration. Throughout this process of mastering and perfecting the javelin throw technique, neural energy is considerably depleted, which emphasizes the necessity for the athlete to be fully recovered prior to training.

## 5. THEORETICAL CONSIDERATIONS ON PERIODIZATION, PLANNING, AND PROGRAMMING IN THE TRAINING PROCESS OF THE JAVELIN THROW EVENT

Periodization, as stated by the author Enoiu, R. (2014), represents "the repetition of certain periods of time containing specific workloads aimed at achieving the objectives. These periods are repeated within the training sessions until the goals proposed during the preparation process are fulfilled".[11]

"Sports training planning represents the strategic approach by which the training means and methods are established, forecasting the achievement of the proposed objectives." It constitutes the component of training programming that divides time into precise structural units (the hour, the day, the week, the month, the year), wherein the applied methods and means are systematically and continuously repeated according to the preparation objectives, which are subordinated to the competition goals.

Training is planned based on the athlete's capacities, their adaptive potential, and rate of development, and is adjusted according to the objective and subjective data obtained by the coach following each training session, particularly those involving control tests.

### 5.1 Competitive Calendar in the Javelin Throw Event for the 15–18 Age Group

In junior javelin throwers, the competitive calendar is divided into two distinct seasons—the winter season and the summer season—with each season featuring a final stage of the National Championship; consequently, training is structured to achieve two peaks of athletic form.

Within athletics, seasons are recognized at both national and international levels as the indoor season and the outdoor season. However, since the shot put is the only throwing event that can be conducted inside an indoor facility, the other three throwing events (javelin throw, discus throw, and hammer throw) hold their winter competitive finale during the National Long Throws Championship.

Accordingly, athletes who have reached the age of 18 typically contest this championship in February, whereas athletes under this age compete for supremacy in March. The summer or outdoor season conducts its competitive events throughout the months of June, July, and August.

[11] Enoiu, R.S. (2014). Programare și planificare în antrenamentul sportiv. Editura Universității Transilvania, Brașov;

## 6. THE CONCEPT OF TECHNICAL PREPARATION AND BIOMECHANICAL ASPECTS IN THE JAVELIN THROW EVENT

### 6.2 Throwing Technique in the Javelin Throw Event

The technique in the javelin throw event is demanding and complex; the over-the-shoulder throwing motion requires extraordinary muscular strength, combined with event-specific speed and highly refined control and coordination capacities to achieve elite performance. The complete approach consists of the preliminary or approach run (*the cyclic phase*), the crossover steps (*the acyclic phase*), the javelin release, and the recovery.

### 6.3 The Importance of the Kinetic Chain in the Javelin Throw

The javelin throw event belongs to the category of sports utilizing the motion classified as *overhead throwing*, which is employed across numerous athletic disciplines, such as baseball, softball, cricket, water polo, handball, and tennis, among others.

The throwing action is a complex movement involving the entire kinetic chain, from the lower extremities to the upper extremities, wherein energy is transferred from the lower body to the upper body, ultimately reaching the implement propelled forward. Executed repeatedly, this action induces mechanical stress on the musculoskeletal system, which can lead over time to overuse syndromes or even injuries

Research in this field demonstrates that the determining biological factors in achieving elite performance within throwing events are the lean muscle mass composition, the neural activation of the primary muscles during the throw, and the cross-sectional area percentage of muscle fibers type II.[12]

Thus, within the kinetic chain, the musculature of the lower body (gastrocnemius, soleus, quadriceps femoris, biceps femoris, and the internal and external hip rotators) acts in full coordination to provide the necessary stability to the trunk, which undergoes rotation and flexion during the throwing action.

### 6.4 Javelin Release Parameters

The distance of a throw is influenced by both internal and external factors; internal factors are those that the athlete can control and modulate, whereas external factors pertain to the environment and meteorological conditions (such as wind speed, wind direction, and rain).

The release parameters are:

- ✓ release velocity (speed);
- ✓ angle of release;
- ✓ release height;
- ✓ angle of attack;
- ✓ yaw angle;

[12] Zaras, N., Stasinaki, A.N. & Terzis, G. (2021). Biological Determinants of Track and Field Throwing Performance. *Journal of Functional Morpholofy and Kinesiology, 6*(2), 40.

- ✓ moment of release from the grip.

The aerodynamic factors are: wind, gravity, and the javelin.

**6.6 Theoretical Conclusions**

The javelin throw event represents one of the oldest technical disciplines within athletics, having undergone significant modifications over the years concerning the structural materials of the implement, the specific weight of the object for certain age categories, and the tactical throwing technique itself.

Sports training has transitioned through a complex process of continuous transformation and adaptation to contemporary athletic requirements; furthermore, the integration of motor qualities has been constantly executed with the primary objective of enhancing procedural efficiency and maximizing motor potential. Consequently, the two fundamental biomotor qualities essential to this event—strength and speed—have been systematically correlated and combined in strict alignment with specific mechanical demands.

Adaptation to the training process constitutes a fundamentally critical concept toward which attention and direction must be oriented to ensure optimal progression throughout an athlete's career; this approach is essential for attaining peak performance metrics specific to the respective age category, while continuously accounting for the somatic, morpho-functional, and psychological particularities of female junior athletes aged 15–18 years, alongside the biomechanical and energetic aspects of the event. At this stage of development, which is characterized by accelerated processes of somatic, neuromuscular, and endocrine maturation, training programming must aim at optimizing structural adaptations (the development of strength, speed, and musculoskeletal structural resistance), functional adaptations (the enhancement of inter- and intramuscular coordination, execution speed, and explosive force generation capacity), and technical-tactical adaptations (the consolidation and stabilization of the throwing mechanism).

The periodization, planning, and programming of training regimens within this event at the junior level are highly influenced by the individual qualities of the athletes involved, as well as by their physical evolution and development; thus, it may exhibit early individualization characteristics due to the structural complexity and difficulty of the throwing technique.

The technical analysis of the event highlights the critical importance of an integrated approach to all phases of the approach run to optimize performance and ensure sustainable motor development. During the cyclic phase of the preliminary run-up, the consolidation of a progressive, controlled velocity is required to maintain postural stability and facilitate an efficient transition toward the specific crossover steps, while keeping the throwing arm optimally oriented backward. In the context of the growth and maturation particularities specific to this age group, it is concluded that the refinement of technique must prevail over the exclusive inflation of strength parameters, with the primary emphasis being placed on articular stability, neuromuscular control, and the correct automation of motor sequences. Such a methodological approach ensures not only an increase in the biomechanical efficiency of each phase of the approach, but also a mitigation of the risk of overuse and acute injury, thereby favoring long-term high-performance evolution.

# PART II

## 7. PRELIMINARY RESEARCH ON THE PREPARATION AND BIOMECHANICAL ANALYSIS OF THE APPROACH RUN IN THE JAVELIN THROW EVENT IN JUNIOR FEMALE ATHLETES

### 7.1. Preliminary Research Premises

The athletic javelin throw event represents one of the most spectacular disciplines within track and field competitions, characterized by a highly advanced degree of technicality; this necessitates exceptional rigor alongside a complex organization and monitoring framework within the structure of sports training.

The premises of this preliminary research originate from the contemporary analysis of event-specific preparation for the approach run in the javelin throw. Consequently, to maximize the technical proficiency of the athletes while minimizing injury risks, we consider it opportune to conduct an analysis aimed at consolidating and correcting the biomechanics of the throwing approach, as well as optimizing training methodologies to enhance performance outcomes at the junior level.

A critical aspect involves navigating the stages of physical development, alongside the accumulation and acquisition of a highly diversified and multidisciplinary motor repertoire. This approach ensures a solid, general foundation upon which specific technical elements can be constructed, preventing the omission of foundational training phases that could subsequently exert a detrimental impact on the organism. The javelin throw event is highly demanding on the physical body; therefore, it is paramount to correctly establish the base of the training pyramid before attempting performance optimization.

Accordingly, a primary consideration is the strict adherence to and thorough understanding of the age-related characteristics of the subjects. This alignment ensures that the preparation process consistently supports positive development and physical accumulation, while guaranteeing that training methods remain in harmony with the continuous adaptation to the applied stimuli.

The junior stage encompasses several core characteristics, which are enumerated below:

- ✓ The concurrent application within training sessions of all age-specific preparation factors, with primary emphasis directed toward physical and technical preparation;
- ✓ The consolidation and refinement of technical elements from both a global and an analytical, sequential perspective;
- ✓ Directing attention toward posture and the immediate correction of emerging errors;
- ✓ Developing awareness regarding the physical transformations within the organism and dedicating specialized attention correlated with the individual rate of growth;
  The utilization of modern equipment and means for training planning, parameter recording, and the correction of technical errors.

### 7.2. Objectives of the Preliminary Research

Based on these considerations, the preliminary investigation was structured around several clearly defined research directions, which constitute the specific objectives of the present study for athletes in the junior age category (15–18 years), as follows:

To examine the opinions and perspectives of specialists/coaches regarding the importance of technical training and its integration with physical preparation, with the aim of continuously optimizing the biomechanics of the javelin throw and the training methods employed for athletes in the junior age category.

1. To examine the application and use of information technology within the training process, with particular emphasis on technical preparation.
2. To establish the acceptance and validate the research instruments carefully selected and employed in the present study, namely the questionnaire and the experimental mesocycle.

### 7.3. Purpose of the Preliminary Investigation

The primary purpose of this preliminary investigation is to examine the opinions of coaches regarding technical preparation and the optimization of the biomechanics of the approach run in the javelin throw.

A further purpose of the investigation is to highlight the importance of physical preparation, alongside technical training, through the implementation of the proposed training programme

### 7.4. Tasks of the Preliminary Investigation

Considering the sequential methodological stages of the research process, the tasks established to provide the theoretical and methodological foundation of the present study are as follows:

- ✓ To identify the characteristics of the approach run and correlate them with the findings reported in the relevant scientific literature;
- ✓ To identify the participants and allocate them to the athlete groups involved in the preliminary investigation;
- ✓ To establish the research instruments employed in the preliminary investigation;
- ✓ To organize and establish the conditions necessary for conducting the testing procedures;
- ✓ To carefully select the control assessments and testing procedures employed in the preliminary investigation;
- ✓ To administer the selected tests under standardized conditions.
- ✓ To develop and administer a questionnaire designed to examine the opinions of coaches responsible for training male and female junior javelin throwers.
- ✓ To analyse and interpret the responses obtained;
- ✓ To identify the specific parameters required for the interpretation and analysis of the results;
- ✓ To formulate and present the conclusions of the preliminary investigation, together with the recommendations arising from the obtained results.

### 7.5. Hypotheses of the Preliminary Research

Hypothesis 1**.** It is assumed that the administration of the opinion questionnaire to expert coaches will enable the identification of the principal aspects of physical and technical preparation specific to the approach run in the javelin throw.

Hypothesis 2**.** It is assumed that the implementation of physical training methods specifically designed for female athletes aged 15–18 years will lead to improvements in the motor qualities of strength and speed required for the approach run in the javelin throw.

Hypothesis 3**.** It is assumed that the application of tests designed to assess coordinative ability indices will facilitate the identification of the principal components—balance, rhythm, and coordination—involved in the approach run technique in the javelin throw.

### 7.7. Period, Participants, and Setting of the Preliminary Investigation

The preliminary investigation involved six participants, all of whom were female junior javelin throwers aged between 15 and 18 years, enrolled at the Sports High School in Bistrița. Part of the proposed testing and control assessments was conducted at the Research and Development Institute of Transilvania University of Brașov, while the remaining assessments were carried out at the sports facilities of the Sports High School in Bistrița. The initial testing session took place at the end of February 2024, and the final assessment was conducted at the beginning of May 2024. The experimental training programme was implemented throughout March and April 2024 at the sports facilities of the Sports High School in Bistrița.

### 7.8. Research Methods

In accordance with the principles of scientific research methodology and in order to achieve the objectives of the present study, a series of representative and field-specific research methods were employed, as follows:

- Review of the relevant scientific literature;
- Testing and measurement through control assessments and standardized tests;
- Scientific experimental method;
- Survey method – opinion questionnaire;
- Statistical–mathematical and graphical methods for the processing and analysis of the data obtained during the preliminary investigation;

#### 7.8.1. Review of the Relevant Scientific Literature

The primary purpose of this method is to accumulate a comprehensive body of information relevant to the field under investigation and subsequently to identify, analyse, and select the knowledge most pertinent to the scientific topic addressed.

Accordingly, the theoretical foundation of the present study was established through the critical review and analysis of an extensive range of specialized sources, including books, scientific publications, national and international research papers, studies on performance in the javelin throw, doctoral dissertations, and scholarly articles encompassing various interdisciplinary fields, such as the theory and methodology of sports training, physical education and sport, sport psychology, exercise physiology, biomechanics, and related disciplines.

A substantial number of scientific sources were consulted and critically reviewed for the preparation of the present study, focusing on the methodology of javelin throw training, throwing technique, the biomechanics of the javelin throw, and training models aimed at refining technique and enhancing competitive performance.

### 7.8.2. Testing and Measurement through Control Assessments and Standardized Tests

The method of testing and measurement constitutes a fundamental component of the evaluation process within scientific research, providing an objective and reliable means of assessing the dynamics of somatic, functional-physiological, psychomotor, and technical development.

To achieve the proposed evaluation objectives, four categories of control assessments and standardized tests were designed and administered, the results of which provided the objective evidence underlying the conclusions of the present study.

These categories are as follows:

I. Somatic assessment tests: body height, body mass, arm span, and scapulohumeral joint mobility measurements.
II. Tests for the Assessment of Motor Potential:

    **a)** Strength assessments (using the Optojump system): consecutive jumps performed over 6 seconds, Squat Jump (SJ)**,** and Countermovement Jump (CMJ)**;**
    **b)** Speed assessments: 30-m sprint and 50-m sprint;
    **c)** Explosive power assessments: standing pentajump (five consecutive forward jumps performed with both legs);
    **d)** Throwing speed and strength assessments: ball release velocity (measured using the SpeedTrac X Radar Gun Hands Free system) and a two-handed medicine ball throw performed with a crossover step
III. Coordinative ability assessment: Flamingo Balance Test.
IV. Technical skill assessment: javelin throw with a three-step approach (including one crossover step).

### 7.8.3. Scientific Experimental Method

The scientific experimental method was implemented through the systematic execution of the procedures and activities established to accomplish the research objectives. The experimental protocol commenced with the administration of the initial testing battery to the selected participants in order to obtain baseline values and determine the initial levels recorded in the control assessments at the beginning of the investigation.

Subsequently, throughout March and April 2024, the experimental training programme was implemented for female junior javelin throwers aged 15–18 years. The design of the experimental programme was based on the evidence derived from the review of the relevant scientific literature, the interpretation and analysis of the responses obtained through the questionnaire administered to coaches across Romania, and the development of training plans incorporating motor qualities specific to the javelin throw, together with technical exercises aimed at correcting, refining, and consolidating throwing technique.

The experimental training programme was structured over two mesocycles, each comprising four microcycles, with five to six training sessions per week. The content of each training session was planned in accordance with the research hypotheses, while the training objectives were established to address the aims of the preliminary investigation. A detailed description of the preliminary experimental programme is provided in Appendix 2 of the present study.

Upon completion of the experimental intervention, the final preliminary assessment was conducted to obtain and record the final values achieved in the control assessments and standardized tests included in the preliminary investigation.

### 7.8.4. Survey Method – Opinion Questionnaire

Within the survey method, an opinion questionnaire was administered to examine the views and perspectives of specialists/coaches regarding the importance of technical training and its integration with physical preparation for the continuous optimization of javelin throw biomechanics and training methodologies applied to junior athletes.

The questionnaire comprised 22 items and was distributed electronically to a total of 32 coaches from both Romania and abroad. The compilation and analysis of the responses were undertaken to identify the prevailing coaching perspectives and practices related to the research topic.

### 7.8.5. Statistical, Mathematical, and Graphical Methods for the Processing and Analysis of the Preliminary Investigation Data

Statistical analysis of the study data was performed using IBM SPSS Statistics for Windows, Version 29.0 (30-day trial version) (Armonk, NY: IBM Corp.).

Nominal data were presented as absolute frequencies and percentages, whereas continuous variables were expressed as means and standard deviations.

A comprehensive battery of assessments, standardized tests, and measurements was employed and subjected to statistical analysis, thereby ensuring the consistent reporting of the results and providing the basis for formulating the conclusions of the preliminary investigation.

## 7.9. Results of the Preliminary Research and Their Interpretation

### 7.9.1. Results of the Somatic Assessment Tests

The preliminary investigation included the statistical analysis and interpretation of four anthropometric parameters—body height, body mass, arm span, and scapulohumeral joint mobility—measured in the participants at both assessment time points.

### 7.9.2. Results of the Motor Potential Assessment Tests

The second component of the assessment battery included in the preliminary investigation comprised four categories of tests designed to evaluate motor qualities and technical skills, as follows:

a) Strength assessments: consecutive jumps performed over 6 seconds; Squat Jump (SJ); Countermovement Jump (CMJ).
b) Speed assessments: 30-m sprint and 50-m sprint;

c) Explosive power assessments: standing pentajump and five consecutive forward jumps performed with both legs;
d) Throwing-specific speed and strength assessments: ball release velocity and a two-handed medicine ball throw.

The results demonstrated improvements in the recorded performance indicators, reflecting the development of the motor qualities specific to the javelin throw.

### 7.9.3. Results of the Coordinative Ability Assessment Test

The Flamingo Balance Test was selected to assess coordinative ability by evaluating static balance, a component that is essential during the final phase of the javelin throw following implement release, in order to ensure the validity of the attempt.

### 7.9.4. Results of the Technical Skill Assessment Test

The final category of assessments focused on the technical skill of performing the javelin throw with a single crossover step, as this movement sequence constitutes the fundamental component of the entire approach run. The crossover steps represent the acyclic phase of the approach and therefore correspond to the technically most demanding segment of the throwing movement. The results obtained indicate improvements in the consolidation and refinement of this technical element among the participants in the preliminary investigation.

## 7.10. Results and Interpretation of the Questionnaire on Physical and Technical Training, and the Use of Equipment and Information Technology in the Training of Female Junior Javelin Throwers

One of the objectives of the preliminary investigation was to examine the opinions of specialist coaches regarding the importance of physical and technical training in female junior athletes, as well as the role of specialized equipment and information technology throughout the training process. This objective provided the rationale for the development and administration of an opinion questionnaire.

The questionnaire was administered to a sample of 32 coaches from across Romania and its validity was assessed using Cronbach's alpha coefficient, a statistical measure commonly employed to evaluate the internal consistency and reliability of an assessment instrument. Cronbach's alpha values typically range between 0.50 and 0.90, with a threshold of 0.70 generally considered acceptable by most researchers. The questionnaire used in the present study yielded a Cronbach's alpha coefficient of 0.708, indicating satisfactory internal consistency.

## 7.11. Conclusions of the Preliminary Research

Based on the analysis of the responses obtained from the opinion questionnaire, the following conclusions can be drawn:

- In the physical preparation of junior female athletes, muscular power (explosive strength) represents a fundamental motor ability, while speed is also considered a dominant physical quality essential for the javelin throw event.

- Sequential biomechanics represents the technical component that undergoes the greatest consolidation between the ages of 15 and 17 years in the javelin throw, with particular emphasis on the individual phases of the approach run, including the single crossover step, the double crossover step, and subsequently the overall approach run technique
- Nearly all coaches considered the kinetic transfer from the lower to the upper extremities during the javelin approach run to be of paramount importance, while emphasizing that the rhythm of the crossover steps and the coordination between the blocking leg and the throwing arm are essential for successful execution.
- The majority of coaches emphasized the importance of incorporating specialized equipment into the physical and technical preparation of female athletes, as well as the use of information technologies to optimize the approach run, particularly during the final crossover step and the power position, where force is transferred from the lower limbs to the throwing arm.Această analiză a răspunsurilor primite ca urmare a aplicării chestionarului a confirmat prima ipoteză din cercetarea preliminară.

Furthermore, the following conclusions can be drawn regarding the implementation of the experimental training programme, based on the results obtained from the four categories of assessments and control tests:

- No major differences were observed between the initial and final assessments of the somatic variables, as these measurements were intended primarily to establish the participants' anthropometric characteristics. Body height and body mass remained virtually unchanged throughout the preliminary investigation.
- The second category of assessments, evaluating motor potential, revealed moderate to large, and in several cases statistically significant, improvements within the experimental group between the initial and final testing sessions. These findings indicate the effectiveness of the training methods implemented during the investigation. Specifically, improvements were observed in the motor qualities of strength and speed, as expressed through variables directly related to the approach run and throwing performance, including explosive strength, reactive strength index, sprint speed, movement execution speed, and throwing velocity. These results support the second hypothesis of the preliminary investigation.
- The third and fourth categories of assessments, namely those evaluating coordinative ability and technical skills, also demonstrated significant improvements in the experimental group. The participants exhibited increased balance maintenance time, reflecting enhanced postural stability, together with improved coordination between the approach run and the throwing action, ultimately resulting in superior throwing performance.
- The findings concerning the role of balance and coordination in the technique of the javelin approach run provide support for the third hypothesis of the preliminary investigation.

Overall, the findings indicate that the implemented training programme promoted the development of the motor qualities of strength and speed, as reflected in the results of the control assessments and standardized tests. Furthermore, key components of coordinative ability, particularly balance and rhythm, which are fundamental to the approach run and throwing technique in female junior javelin throwers, were successfully identified and enhanced. These findings confirm the second and third hypotheses of the preliminary investigation.

Accordingly, it can be concluded that the hypotheses formulated at the outset of the preliminary investigation were fully supported by the results obtained, thereby confirming the validity of the proposed research approach.

# PART III

## 8. FINAL RESEARCH ON THE TRAINING AND BIOMECHANICAL ANALYSIS OF THE APPROACH RUN IN FEMALE JUNIOR JAVELIN THROWERS

### 8.1. Premises of the Final Research

The proposed experimental training programme was designed to optimize the biomechanics of the approach run and enhance the efficiency of kinetic energy transfer from the lower to the upper extremities, thereby contributing to improved throwing performance.

Within the training process for female junior athletes, the primary objectives included both the implementation of the proposed experimental programme and the integration of information technologies and specialized equipment to optimize throwing biomechanics and improve competitive performance.

Furthermore, the rationale underlying the final experimental investigation focused on the consolidation and refinement of throwing technique, together with the observation, identification, and correction of technical errors. Accordingly, biomechanical analysis supported by information technologies was employed to identify technical deficiencies and their underlying causes, enabling timely corrective interventions before incorrect movement patterns became automated and substantially more difficult to modify.

### 8.2. Objectives of the Final Research

The final investigation was designed to achieve the following objectives specific to the javelin throw:

- To analyse and improve the biomechanics of the approach run and the efficiency of kinetic transfer from the lower to the upper extremities;
- To integrate information technologies and specialized equipment into the control assessments and standardized tests administered to the selected participants;
- To optimize throwing biomechanics and technique through the effective integration of physical and technical training components, tailored to the developmental level of female junior athletes aged 15–18 years.

### 8.3. Purpose of the Final Research

The purpose of the final investigation is to demonstrate the importance of using specialized equipment, information technologies, and kinematic recordings to identify and correct technical and biomechanical errors in the approach run of the javelin throw, thereby enhancing the effectiveness of training programmes.

### 8.4. Tasks of the Final Research

- The methodological framework of the final experimental investigation was established through the following research tasks:
- To identify the participants to be included in the experimental investigation;

- To select the research instruments employed in the final investigation;
- To establish the control assessments and standardized tests to be administered during this phase of the study;
- To administer the selected assessments and tests
- To design and implement the experimental training programme aimed at improving the biomechanics of the approach run and the efficiency of kinetic transfer in the javelin throw;
- To monitor the training sessions and collect the data obtained from the participating athletes;
- To present the specialized equipment and information technologies employed throughout the investigation;
- To compile and organize the collected data and research results;
- To analyse and interpret the findings of the final investigation;
- To formulate the conclusions of the final investigation and propose recommendations based on the results obtained.

### 8.5. Hypotheses of the Final Research

Hypothesis 1. It is assumed that the development of the motor qualities of strength and speed within the training process will optimize the technique and kinematics of the approach run, thereby leading to improved athletic performance.

Hypothesis 2. It is assumed that the implementation of training systems specifically designed to enhance coordination and rhythm in female junior athletes aged 15–18 years will result in superior biomechanics of the approach run, as reflected in improved competitive performance.

Hypothesis 3. It is assumed that the use of modern, sport-specific equipment and information technologies in the training of female junior javelin throwers will enhance the principal technical components—balance, rhythm, and coordination—that influence the biomechanics of the approach run in this event

### 8.7. Location, Period and Subjects of the Final Research

The final investigation was conducted between October 2024 and June 2025. Part of the testing and assessment procedures was carried out at the Faculty of Physical Education and Mountain Sports, Transilvania University of Brașov, with the approval of the faculty administration. Additional assessments were conducted at the Iolanda Balaș Soter Stadium in Bucharest, with the authorization of the Romanian Athletics Federation, while the remaining testing sessions took place in the athletes' respective cities of residence.

The study included 15 female junior javelin throwers, aged 15–18 years, representing the final investigation cohort. The participants were affiliated with the following sports clubs across Romania: CS Giroc Chișoda, CSM Sighetu Marmației, CES Adjud, CSS Clubul Istrati Câmpina, CSS Viitorul Cluj, LPS Cluj-Napoca, LPS Baia Mare, CS Orășenesc Voluntari, CSS Târgoviște, and CSS Tulcea.

The inclusion criteria for participation in the experimental group were the absence of injuries and regular attendance at a minimum of five training sessions per week.

### 8.8. Research Methods

The preparation of the present study was supported by an extensive review of the relevant scientific literature. The research itself was conducted in accordance with the principles of scientific research methodology, employing a series of representative methods, which are presented below:

- The research methodology applied in the present study included the following methods:
- The review of the relevant scientific literature.
- The scientific experimental method.
- Statistical and mathematical methods for data processing, supported by graphical analysis.
- Performance assessment through standardized control tests and computer-assisted testing technologies.

### 8.8.2. The scientific experimental method

The scientific experimental method comprised the implementation procedure of the tasks proposed for the final investigation. The research process began with the initial testing of the 15 female junior javelin throwers who constituted the study sample. The participants were affiliated with various sports clubs and school sports clubs across Romania, namely: CS Giroc Chișoda, CSM Sighetu Marmației, CES Adjud, CSS Clubul Istrati Câmpina, CSS Viitorul Cluj, LPS Cluj-Napoca, LPS Baia Mare, CS Orășenesc Voluntari, CSS Târgoviște, and CSS Tulcea.

The initial assessment was conducted in January 2025 to establish the baseline performance level for the final investigation. During February, March, and April 2025, the participants followed the final experimental training program specifically designed for the junior age category. The program incorporated sport-specific training methods aimed at improving physical conditioning through the development of explosive strength (power) and speed, as well as optimizing the biomechanics of the approach run and enhancing power transfer from the lower to the upper extremities during the throwing movement.

The experimental training program extended over three training mesocycles, each consisting of four weekly microcycles. In turn, each microcycle included five or six training sessions. The objectives and training themes focused on optimizing biomechanics and refining the throwing technique through specific technical exercises.

An additional objective of the study was the development of the motor qualities of strength and speed, together with the improvement of coordinative abilities, particularly balance and coordination, in order to consolidate technical proficiency during the junior developmental stage (15–18 years).

Following the completion of the three-month training period, the final assessment was conducted to evaluate the values of the performance indicators obtained after the implementation of the experimental training program.

### 8.8.2.1. The applied intervention within the final Research

The experimental intervention was implemented over a 12-week period and consisted of three mesocycles, each comprising four microcycles, for a total of 69 training plans. The average duration of each training session was approximately 90 minutes. Training intensity increased during sessions focused on speed and balance development, while lower intensity levels were maintained during sessions emphasizing coordination and technical execution.

The training sessions primarily focused on consolidating throwing technique and improving the biomechanics of the approach run through age-specific exercises adapted to the athletes' level of preparation. These objectives were pursued by developing coordinative abilities (balance, coordination, and agility), as well as by enhancing the sport-specific motor qualities of explosive strength (power) and speed. Throughout the intervention period, continuous communication was maintained with the athletes' coaches, and athlete–coach interaction was encouraged to optimize the implementation of the training exercises.

Computer-assisted technologies were employed through video recordings of both the athletes participating in the experimental program and elite world-class javelin throwers. The recordings were analyzed either during the training sessions or separately to facilitate a better understanding of both the sequential and the overall movement patterns involved in the throwing approach. The methodology of video analysis differed between Mesocycles 1 and 3, allowing the comparison of the initial and final stages of the investigation. During these mesocycles, athletes were filmed while performing the main training sequences to identify, recognize, and correct technical execution errors. In Mesocycle 2, video analysis focused primarily on the correctness of technical execution in order to reinforce the movement pattern and establish a stable motor stereotype.

The technical objectives targeted the consolidation and refinement of the following components: javelin release, trunk rotation, and overall throwing technique. Video analysis pursued two main objectives: the identification of technical execution errors and the selection of specific corrective exercises. Video analysis sessions were conducted both with the athletes participating in the study and through the examination of performance models demonstrated by world-class javelin throwers.

The experimental program introduced five specific exercises designed to improve throwing technique, refine the final phase of the transition into the power position, and enhance lower-limb power.

To develop trunk strength and speed, the following exercises were implemented: seated trunk rotations with a 5-kg weight and seated lateral medicine ball throws using a 2-kg medicine ball.

To improve the balance and stability of the throwing arm, as well as to optimize the javelin release angle, the following exercises were applied: two cross-over steps with the javelin and 30-m cross-over running drills with the javelin. In addition, forward jumps while holding a 2-kg medicine ball were used to develop lower-limb explosive strength (power).

### 8.8.4. The method of assessment through control trials and computer-assisted testing technologies.

In the final stage of the study, a series of tests and control trials were selected in accordance with the training methodology specific to the javelin throw and appropriate for the junior age category (15–18 years). These assessments were organized into four categories to enable the specific evaluations required for the final experimental investigation and to provide an objective basis for the formulation of the final conclusions.

1. Assessment tests**:** height measurement, body mass measurement, arm span measurement, and assessment of scapulohumeral joint mobility.

2. Tests for the assessment of motor potential:
   a) Strength tests (using the Optojump system): countermovement jump (CMJ); drop jump (DJ);
   b) Speed test: 30-m sprint;
   c) Throwing speed and power tests: ball throwing velocity (measured using the SpeedTrac X Radar Gun Hands Free system); two-handed medicine ball throw; three consecutive jumps followed by a medicine ball throw.

3. Tests for the assessment of coordinative abilities (using the Gyko Microgate sensor): transition into the power position; throwing arm balance.

4. Test for the assessment of technical skills: javelin throw with approach run (determination of the javelin release angle using the Kinovea software).8.9. Interpretarea și prezentarea rezultatelor cercetării finale

### 8.9. Interpretation and presentation of the final research results

### 8.9.1. Results of the final Research for the somatic assessment tests

The same anthropometric parameters assessed during the preliminary investigation were retained for the final investigation, namely: body height, body mass, arm span, and shoulder mobility. These variables were subjected to statistical analysis and interpreted using the same methodological approach applied in the preliminary investigation.

### 8.9.2. Results of the final Research for the motor potential assessment tests

In the final investigation, tests assessing the dominant motor qualities required for the javelin throw, namely strength and speed, were analyzed as follows:

a) Strength tests (using the Optojump system): countermovement jump (CMJ) and drop jump (DJ).
b) Speed test: 30-m sprint.
c) Throwing speed and power tests: ball throwing velocity, measured using the SpeedTrac X Radar Gun Hands Free system, through which the parameters of general throwing power and specific throwing-arm power were identified; two-handed medicine ball throw; three consecutive jumps followed by a medicine ball throw.

The development of these motor qualities from the initial to the final assessment was statistically evident.

### 8.9.3. Results of the final Research for the coordinative abilities assessment tests

The two tests included in this category were assessed using the **Gyko** inertial sensor, which provides a two-dimensional (2D) graphical representation of the athlete's movement trajectory in both the horizontal and vertical planes. The tests consisted of the transition into the power position and the assessment of throwing-arm balance. The results were statistically analyzed and interpreted, demonstrating improvements in both throwing technique and throwing biomechanics.

### 8.9.4. Results of the final Research for the technical skills assessment test

Within this category, the javelin throw with approach run was assessed using the **Kinovea** software to determine the javelin release angles at the moment of release and to examine the relationship between the release angle and throwing distance. Statistical analysis demonstrated that, in female junior athletes aged 15–18 years, a release angle approaching or slightly below 40° was associated with greater throwing distances and, consequently, superior performance.

### 8.9.5. Correlation between the javelin release angle and throwing distance

In the final investigation, the correlation analysis of selected performance parameters indicated that the javelin release angle was significantly and negatively associated with throwing distance in both the initial and final assessments, with a stronger relationship observed at the beginning of the experimental intervention. From an applied perspective, these findings support the importance of optimizing throwing technique, particularly the javelin release angle, in order to maximize throwing performance.

### 8.9.6. Correlation between the three-jump medicine ball throw and javelin throwing distance

The next important correlation analysis demonstrated a significant positive relationship between performance in the three-jump medicine ball throw test and javelin throwing distance at both assessment time points. These findings indicate that improvements in performance during the three-jump medicine ball throw test were accompanied by corresponding increases in javelin throwing distance.

These results provide strong support for the research design, the validity of the selected assessment procedures and experimental methodology, and the effectiveness of the training methods implemented within the experimental intervention program conducted during the final stage of the investigation.

# 9. CONCLUSIONS AND ORIGINAL CONTRIBUTIONS

## 9.1. Innovative and original elements found in the final research

One of the original contributions of the present scientific investigation is the design of the experimental training program implemented during the final investigation, which was developed on the basis of the training program applied in the preliminary investigation.

A further original contribution lies in the research methodology implemented throughout the scientific investigation. The originality of the study derives from the findings obtained during the preliminary investigation, which provided the foundation for the development of the experimental training program used in the final investigation. The program consisted of three mesocycles, each including four microcycles comprising five or six training sessions, and incorporated training themes focused on the motor qualities and technical skills required for the javelin throw at the junior level, together with general and specific objectives adapted to each stage of the training period. The implementation of the experimental program also enabled the validation of the technologies employed, as reflected in the results obtained from the control trials and assessment tests. Furthermore, the proposed training program served as an instrument for evaluating the effectiveness of the innovative equipment and technological tools upon which several of the final conclusions of the investigation were based.

Another original and innovative aspect of the study is its interdisciplinary approach, integrating concepts related to the biomechanics of the throwing approach with the psychological components involved in both the training process and competitive performance.

The innovative dimension of the research is further reflected in the integration of modern equipment and computer-assisted technologies to optimize the throwing approach and refine throwing technique. The use of advanced assessment equipment, including the speed radar, together with computerized technologies such as the Optojump system, the Gyko inertial sensor, and the Kinovea motion analysis software during both control assessments and selected training sessions, enhanced the athletes' awareness of movement at both the sequential and global levels, thereby contributing to improvements in throwing technique among the junior athletes participating in the stud

## 9.2. Conclusions

The modern methods, training means, equipment, and computer-assisted technologies employed throughout both the assessment procedures and the implementation of the experimental training program facilitated the achievement of the proposed objectives for female junior javelin throwers aged 15–18 years. These objectives included optimizing the biomechanics of the throwing approach and enhancing the kinetic (power) transfer from the lower extremities to the upper extremity responsible for the throwing action.

The findings demonstrate that the proposed experimental training program was effective in improving both the results of the physical performance tests and the biomechanical indicators of throwing technique. Following the initial assessment, the athletes completed the experimental training program over the course of the three mesocycles, performing the specific exercises designed to develop and optimize the physical and technical parameters while adhering to the prescribed training requirements and instructions. The final assessment

revealed improvements in overall athletic performance, optimization of the evaluated physical qualities, and enhanced performance in the final tests, thereby confirming the effectiveness of the implemented training program.

The implementation of the experimental training program led to significant improvements in the dominant motor qualities required for the javelin throw, namely speed and explosive strength, as demonstrated by the results obtained during the final assessment, thus confirming the first research hypothesis. The tests performed using the Optojump system provided the clearest evidence of improvements in strength performance, with very large effect sizes observed for the *power* and *reactive strength* parameters measured during the drop jump test, as well as for the *jump height* parameter assessed through the countermovement jump test. Speed development was demonstrated by the results of the 30-m sprint test and the specific ball-throwing velocity test, both of which showed statistically significant improvements at the final assessment.

Overall, the combination of specific exercises aimed at developing general and sport-specific strength, improving coordination, rhythm, and balance, together with video analysis of the throwing approach technique and the integration of computer-assisted technologies, contributed to optimizing performance, enhancing the biomechanics of the throwing approach, and improving kinetic energy transfer during the javelin throw in female junior athletes aged 15–18 years. The complete confirmation of the research hypotheses supports the validity of the proposed research design and fully validates the experimental approach adopted in this investigation.

## 10. RESEARCH LIMITATIONS AND DISSEMINATION OF THE RESULTS

### 10.1. Research Limitations

The present study, which was designed to consolidate and refine javelin throwing technique through the optimization of the approach run and kinetic transfer using modern technologies and specialized equipment, has several limitations.

First, the relatively small sample size, resulting from the limited number of female javelin throwers competing at the national level, led to the adoption of a single-group pre-test/post-test experimental design. Consequently, the study does not provide the same level of methodological rigor as investigations including both experimental and control groups. Nevertheless, within the context of sports training research, where practical constraints often prevent the formation of both experimental and control groups, such research designs are widely accepted.

A second limitation relates to the age of the participants, who were female junior athletes aged 15–18 years. At this developmental stage, athletic performance may be influenced by the biological and psychological changes characteristic of adolescence. Furthermore, participation in high-performance javelin throwing tends to decline considerably as athletes approach the senior category. Consequently, the findings of the present investigation cannot be readily generalized to other age groups.

Another limitation concerns the use of only a selected range of computer-assisted technologies and specialized equipment, some of which are too costly to be acquired by the sports clubs where the participating athletes conduct their regular training.

Despite these limitations, the findings support the recommendation that the proposed training program be implemented within the U16 and U18 female junior categories. In addition, the integration of the computer-assisted technologies and specialized equipment employed in this investigation is recommended as an effective means of enhancing athletic performance.

### 10.2. Dissemination of the Results

Throughout the course of the research conducted on the optimization of throwing technique, the biomechanics of the approach run, and kinetic transfer in the javelin throw among female junior athletes, several scientific papers were produced and subsequently published in peer-reviewed scientific proceedings and specialized academic volumes.

The published scientific papers are as follows:

1. CUCIOROVSCHI LIGIA, ENOIU RĂZVAN SANDU. **„Theoretical Aspects regarding Athletics and the Event of the Javelin Throw”,** Bulletin of the Transilvania University of Brasov, Vol. 16(65), No. 2 (2023), Series IX – Sciences of Human Kinetics, pp 9-14, ISSN 2344-2026 (Print), ISSN 2344-2034 (CD-ROM), ISSN 2971 – 978X (Online), ISSN-L 2344 – 2026;

2. CUCIOROVSCHI LIGIA, ENOIU RĂZVAN SANDU, MINDRESCU VERONICA. **„Educational Approach to Testing with New Technology in Junior Javelin Throwing”,** Revista Românească pentru Educaţie Multidimensională, 17(3), 191-213, p-ISSN 2066-7329, e-ISSN 2067-9270, FI 0,4;

3. CUCIOROVSCHI LIGIA, BRUS DENISA-IULIA, TERIȘ ȘTEFAN, ENOIU RĂZVAN SANDU. **„Functional Biomechanical Analysis of Javelin Throw Technique in Junior Athletes”**, Journal Of Functional Morphology and Kinesiology, Biomechanics of Human Movement in Sports and Analysis of Sport Techniques, 11(2), 145-164, ISSN 2411-5142, FI 2,5.

**Abstract**

This doctoral thesis adheres to the methodological requirements of the doctoral field and is structured into three main sections. The first section provides the theoretical foundation, supported by a comprehensive review of the relevant literature. The second section presents the preliminary research, outlining the premises, objectives, purpose, tasks, and hypotheses, followed by a series of tests. The final section details the main research, which builds upon the established premises and objectives, and includes control trials, experimental tests, and the results obtained through the implementation of the proposed experimental training program.

The experimental design comprised four categories of assessment: somatic evaluation, motor potential, coordinative capacity, and technical skills. The central aim of the thesis was to optimize the biomechanics of the javelin throw in junior female athletes aged 15–18, with the objective of enhancing performance in overall throws. This was achieved through the integration of information technologies, specialized equipment, and an experimental training program focused on developing both sequential and global movement awareness, while improving the efficiency of kinematic transfer from the lower body to the throwing arm.

Given the high technical demands of the javelin throw, particular attention is required during the acquisition and consolidation of technical elements, as incorrect automatisms, once established, are difficult to correct. The junior stage represents a critical developmental period in which both beneficial automatisms and faulty executions can become ingrained, with the age of 18 marking a decisive threshold for the transition to elite performance.

The research employed the SpeedTrack X Radar Gun Hands-Free to measure throwing velocity with the small ball during the experimental training phase of the preliminary research. In addition, the Kinovea motion analysis software was utilized to determine the release angles of the javelin during both the testing sessions and the final experimental training program.

The original contribution of this study lies in the specific methodology developed to optimize technical execution and enhance the biomechanics of the approach run, emphasizing increased body awareness both in isolated movement sequences and in the complete throwing phase. The results of the final tests confirm the effectiveness of the proposed training program, while also demonstrating psychological benefits through increased confidence, improved technical mastery, and enhanced performance derived from the optimization of throwing biomechanics.

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