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Developing a precise gross motor skills assessment instrument for elementary school students (ages 7-9)

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Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

Abstract

Background and Study Aim The assessment instrument for gross motor skills in physical education is crucial in developing fundamental motor skills in elementary school students. This research aims to formulate an assessment tool for gross motor skills tailored to students aged 7-9, aligning with their specific characteristics.

Material and Methods This study adopts a research and development approach utilizing the 4D development procedure (Define, Design, Develop, Disseminate). It involves the validation process by five experts in motor skills and physical education, comprising faculty members from five distinct universities. The trial subjects encompass 310 elementary school students aged 7-9, while the instrument's effectiveness is evaluated by 35 individuals, including physical education teachers and students. Statistical analyses encompass content validity, criterion validity, test-retest reliability using Cronbach's alpha, and descriptive percentage analysis.

Results This research has produced a gross motor skills assessment instrument comprising 11 movement components: sit and stand up, rolling, one-leg stand, gallop, slide, jump, bouncing a ball, catching, throwing, kicking, and hitting. The content validity result is $1 > 0.763$, criterion validity (r_{xy}) > 0.304 , Cronbach's alpha value for all items > 0.60 , and the average perception assessment of instrument effectiveness $> 93\%$, falling into the category of extremely high.

Conclusions The assessment instrument demonstrates high validity and reliability, effectively addressing the challenges associated with the need for assessments tailored to the evaluated subject's characteristics, objectives, and relevance. An easily comprehensible instrument, coupled with language accessibility, yields positive outcomes for physical education teachers in the assessment process.

Keywords: instruments, assessment, gross motor skills, physical education

Introduction

Physical education plays an immensely vital role in the development of elementary school children, particularly in learning fundamental motor skills. Fundamental motor skills encompass a child's ability to engage their muscles in various physical activities such as running, jumping, walking, throwing, and others [1]. Physical education is a platform for children to cultivate their motor skills through structured and measurable activities. Numerous studies underscore the significance of possessing motor skills in elementary school children, with one highlighting that a child with good motor skills tends to exhibit enhanced self-confidence, aiding in the increase of physical activities and reduction of sedentary behavior [2, 3]. The phenomenon of motor skill development in 7-9-year-old elementary school children represents a crucial period in their motor development process. Within the age range of 7-9 years, children undergo substantial development

in gross and fine motor skills, concentration, coordination, environment, and exercise [4]. During this age, children commence applying basic movements in structured activities in their daily lives and through physical education learning in school. Therefore, by providing appropriate support from internal and external perspectives, children can more easily develop motor skills individually or in groups, supporting their potential to remain active in various activities [5].

The proficient development of motor skills in elementary school children positively impacts holistic child development [6]. Proficient motor skills aid children in cultivating physical abilities for daily life [3, 7]. They can execute various locomotor and manipulative movements without significant hindrance. Physical activities involving diverse motor skills help children maintain a high fitness level. Through active movement, they can sustain an ideal body weight, exercise muscles, and bones to retain strength and uphold the health of the cardiovascular system. This contributes to reducing the risk of cardiometabolic diseases such as obesity and heart-related issues in the future [8].

Each child's motor skills naturally vary; some exhibit proficiency while others lag behind. It is crucial, particularly for physical education teachers, to pay attention to the motor development of each learner [9]. Presently, a significant issue is the prevalence of low fitness levels among many elementary school children [10]. Numerous primary school children are grappling with obesity and diabetes resulting from physical inactivity [5]. Addressing this matter falls within the responsibility of educators, especially physical education teachers, to devise effective physical education programs for elementary school children. Assessment instruments are pivotal in this context, serving as tools to evaluate learners' abilities [11]. Motor assessment instruments gauge a child's motor development and identify motor delays or disorders [12]. In the context of physical education programs, these instruments aid physical education teachers in selecting or crafting learning programs that align with the motor skills proficiency of the learners. Therefore, accurate and validated instruments are essential [13]. Teachers are crucial in advancing the nation's civilization and preparing learners with competent and relevant skills [14]. Achieving these milestones necessitates skills that require teachers to stay updated with knowledge to anticipate various possibilities in the learning process [15]. Learners' attainment of optimal learning outcomes begins with the competencies teachers possess in executing their roles and functions [16].

Based on the preliminary study, many physical education teachers must implement a basic motor skills assessment system. Teachers often focus solely on sports and games, neglecting the fundamental aspects of movement itself. In this process, there needs to be more systematic monitoring of the measurable and planned development of motor skills. This is evidenced by teachers' need to understand basic motor skills assessment instruments better. The lack of understanding among physical education teachers regarding motor skills assessment instruments can be attributed to several factors:

- the complexity of fundamental motor skills instruments may be considered too challenging to comprehend and irrelevant to the school environment. Physical education teachers may struggle to apply these instruments, especially if they are developed using language or terminology that is not easy to understand.
- ineffective and inefficient instruments may result in the wastage of time and energy,
- resource limitations - physical education teachers face constraints in terms of facilities and assistants for assessment implementation,
- low urgency levels - physical education teachers may perceive little importance in assessing

and monitoring the development of motor skills.

Based on the background and problem identification provided, the research problem formulation in this study is how to develop an assessment instrument for basic motor skills in children aged 7-9 years. In line with the research problem, the development objective is to create an assessment instrument for basic motor skills by student characteristics. The product specifications in this study include an assessment instrument for gross motor skills in elementary school students aged 7-9 years, intended to assist physical education teachers in implementing a systematic and planned monitoring and evaluation process for gross motor skills.

Materials and Methods

Participants

The trial subjects in this research comprised 310 elementary school students aged 7-9 years (grades 1-3) from three schools in the Salatiga region: Islamic Elementary School Kurma, Public Elementary School 2 Beringin, and Elementary School Marsudirini 77. The study further included five physical education teachers instructing at elementary schools in Salatiga and 30 students from the Physical Education program.

Research Design

This study adopts a Research & Development (R&D) approach, utilizing research findings to design new procedures and products systematically tested, evaluated, and refined in the field to meet specific criteria. The development procedure follows the Dick & Carey theory's four stages, as developed by various experts:

- (a) Define instructional requirements,
- (b) Design prototypical instructional model,
- (c) Develop tested and reliable instructional model,
- (d) Disseminate instructional model [17, 18, 19].

The application of these developmental steps is not rigid but adaptable to the characteristics of the research subjects and the study location, considering the field's developmental needs.

Stage 1: Define - This stage establishes and defines the necessary conditions for development, considering the learners' requirements. It includes learner analysis, concept analysis, task analysis, and objective formulation.

Stage 2: Design - In this stage, the steps include developing assessment standards, selecting media, choosing formats, and creating initial designs.

Stage 3: Develop - The goal of this developmental stage is to produce the final assessment instrument after revision based on expert feedback and trial data. It involves two steps: (a) Expert Assessment: This step aims to validate the product's suitability and is conducted by five experts in physical

education and sports. Based on expert input, the instrument is revised to enhance effectiveness and user-friendliness. (b) Development Testing: This stage comprises limited-scale testing, product revision, and large-scale testing.

Stage 4: Disseminate - The final stage involves disseminating the product for community utilization. Packaged as a motor skills assessment book, the product undergoes socialization with physical education students and teachers. This aims to gather responses and feedback on the developed instrument. Subsequently, mass printing and marketing are carried out for widespread use. Before field trials, the product undergoes expert content validity testing to ensure its validity [20].

Following this, reliability testing is conducted on elementary school students aged 7-9. The product design revolves around gross motor skills, categorizing movements into balance, locomotion, and manipulative [21]. Each movement category comprises several components. The data collection instruments include assessment rubric questionnaires, perception questionnaires, and cameras. Data collection involves direct performance assessment, with students executing motor skill movements and their performance evaluated through direct observation. Evaluators must be familiar with the assessment indicators. Perception questionnaires are distributed to physical education teachers and students to gather responses, opinions, and assessments of the developed instrument. The assessment rubric questionnaire has undergone expert validation by five lecturers from different universities specializing in physical education and motor skills.

Ethics Committee Approval Statement

Approval from the University, has been granted for conducting this research, confirming its ethical procedure. The research procedures adhere to the principles outlined in the Helsinki Declaration. All research participants willingly consented to become respondents, having previously completed informed consent forms. To ensure comprehensive understanding, the researcher provided a research information sheet detailing the research background, objectives, procedures, potential risks, and benefits to respondents and parents.

Statistical Analysis

Content Validity. Content validity indicates whether a test measures the intended substantive coverage. The Content Validity Ratio (CVR) formula [22]: is as follows:

$$CVR = (n_e - N/2)/N/2 - \text{original [22]}$$

in which n_e is the number of experts that rated the item as “Essential”, and N is the panel size.

The instrument can be deemed valid based on decision-making if the minimum CVR value, with a

significance level of 0.05, is $0.763 <$ the CVR obtained from the five experts.

Criterion Validity. Criterion validity is employed to assess the quality of the developed instrument based on its usage experience [23]. Pearson Product-Moment Correlation statistical test and IBM SPSS Statistics 25 are utilized to determine criterion validity. The instrument can be considered valid based on decision-making if the calculated r-value $>$ the tabled r-value of 0.304.

Test-Retest Reliability. Reliability, interpreted as consistency or stability, is assessed in this study using the test-retest method with Cronbach’s alpha analysis. The decision-making criterion for reliability is if Cronbach’s alpha value $>$ 0.60, the instrument is considered reliable.

Descriptive Percentage. The assessment instrument, having undergone various testing stages and revisions and deemed suitable for use, will be disseminated. Product evaluation employs descriptive percentages to observe the instrument’s feasibility by direct users, namely physical education teachers and physical education program students. Percentage calculations are also applied in the large-scale trial. The percentage calculation for the large-scale trial employs the following categories: Excellent ($x > 36$), Good ($30 < x \leq 36$), Adequate ($25 < x \leq 30$), Insufficient ($19 < x \leq 25$), Very Insufficient ($x \leq 19$).

Results

The research findings elucidate that content validity testing was conducted by five experts in physical education and motor skills. Subsequently, a total of 310 elementary school students participated in both limited and extensive scale trials, which were evaluated through criterion validity and reliability testing, as elaborated in the table 1.

Table 1. Expert Validation Test Results

Skills assessed	minimum CVR value	CVR Value	Description
Sit and stand up	0.763	1	Valid
Rolling	0.763	1	Valid
Standing on one leg	0.763	1	Valid
Riding	0.763	1	Valid
Sliding	0.763	1	Valid
Jumping	0.763	1	Valid
Running	0.763	1	Valid
Bouncing a ball	0.763	1	Valid
Catching	0.763	1	Valid
Throwing	0.763	1	Valid
Kicking	0.763	1	Valid

CVR: Content Validity Ratio.

Based on Table 1, the minimum CVR value at a significance level of 0.05 with a total of five validators, experts in physical education and motor skills education, is 1, more significant than 0.763, the minimum CVR value for five validators. It can be concluded that each skill item is accepted or deemed appropriate and valid based on the expert assessment.

Further, in the expert validation process, several revisions and inputs were obtained, including the following:

1. For the balance movement, the “toe-heel” movement was added to assess the students’ balance during this specific activity.
2. For the manipulative movement, the “hitting” motion was added to complement the existing set of movements.
3. The skill “riding” was renamed.
4. Adjustments were made to the size and type of the ball used in the bouncing skill to align with the characteristics of the students.

Subsequently, revisions were made considering the expert input. The name “riding” was changed to “galloping,” and an additional criterion, “hitting,” was added. The assessment criteria for hitting were carried out using a tennis ball and a hockey stick. Further validation was conducted based on field trials to reinforce the validity and ensure the instrument meets the needs and characteristics of elementary school students aged 7-9. The following are the results of the criteria validity.

Based on Table 2, it is known that the r-table value is 0.304. This means that if the relationship between each skill or item and the total score is $0.000 < 0.05$, and the Pearson correlation is positive $r_{xy} > 0.304$, it can be concluded that the measured skill or item is valid. These skills or items are tools for collecting accurate data.

On the other hand, skills or items deemed invalid or questionable will be excluded from the instrument and not used, resulting in a total of 11 skills or items (table 3).

The Cronbach’s alpha value for all items is > 0.60 . Therefore, as the basis for decision-making in the reliability test, the 11 motor skills items or all items for the gross motor skill variable are reliable or consistent and fall within the high-reliability category.

After undergoing the stages of validation and revision the results revealed that eight students (2.9%) were categorized as insufficient, 27 students (10%) fell into the adequate category, 159 students (59.3%) were categorized as good, and 74 students (27.6%) were classified as excellent, with a mean score of 34.46 (table 4). Therefore, it can be concluded that the majority of students possess gross motor skills falling within the good category.

The feedback results were gathered from physical education teachers and students in the physical education program through a questionnaire comprising six assessment indicators, each containing multiple questions. These six indicators include movement components, instrument suitability, ease of instrument use, facilities, assessment, and language (table 5).

The gross motor skills assessment instrument for elementary school students ages 7-9 proves effective and appropriate. The assessment results from teachers and students majoring in physical education describe that each indicator, including motion components, instrument suitability, ease of use, facilities and infrastructure, assessment, and language, obtained a score of $> 93\%$, indicating a highly effective assessment category.

Table 2. Criteria Validation Test Results

Skills	r_{xy}	r table	Explanation
Sit and stand up	0.689	0.304	Valid
Rolling	0.718	0.304	Valid
One-leg Stand	0.694	0.304	Valid
Gallop	0.520	0.304	Valid
Slide	0.554	0.304	Valid
Jump	0.402	0.304	Valid
Run	0.292	0.304	Invalid
Bouncing a ball	0.310	0.304	Valid
Catching	0.336	0.304	Valid
Throwing	0.368	0.304	Valid
Kicking	0.476	0.304	Valid
Hitting	0.375	0.304	Valid

r_{xy} : calculated value of validation results.

Table 3. Reliability Test Results

Skills	Performance criteria	α
Sit and stand up	Proficient in maintaining a seated position with hands gripping both legs and heels closely aligned. Swinging backward until the shoulders and nape contact the mat, with hands consistently clasping around the shins. Repeat the forward motion while maintaining a grasp on the shins, returning to a balanced seated position. Executing a standing movement without the palms touching the mat, swinging the arms forward with the final motion of the arms facing upward.	0.743
Rolling	The initial position for supine lying entails facing upwards, with legs extended and arms straight overhead. Rolling in a consistent direction from end to end across the mattress. Rolling straight without extending beyond the boundaries of the mattress. Arms and legs remain elevated, not making contact with the floor.	0.636
One-leg Stand	The body is positioned upright and aligned. Arms are positioned beside the waist, with the gaze directed forward. The supporting feet remain stationary and do not shift. Avoiding any falls, ensuring that the feet make contact with the floor.	0.846
Gallop	The body and gaze are oriented forward. One foot is positioned in front, and the other is positioned behind. Progressing forward with the front and back feet remaining fixed without alternation. There is a brief moment of both feet touching the ground with a visible leap in momentum.	0.679
Slide	Moving sideways with an upright posture and a forward-facing gaze. Shifting with feet positioned shoulder-width apart (not excessively wide). Sideways movement followed by the other leg. There is a brief moment of both feet touching the ground with a visible leap in momentum.	0.684
Jump	Repetition of rhythm from alternating leg movements in a stride jump. There is a brief moment of both feet touching the ground with a noticeable leap in momentum. Arm movements are swung alternately to chest height in opposition to the leg jumping motion. Coordination involves lifting the knees to a height of 45° - 90°, followed by a straightening movement of the opposite leg.	0.711
Bouncing a ball	The body and gaze face forward. Legs slightly bent and spaced shoulder-width apart. Bouncing the basketball with fingers rather than palm and dribbling it. Bouncing the ball up to waist height.	0.722
Catching	The body maintains an upright position facing forward with legs spread shoulder-width apart. The ball is thrown and caught using only the same hand when throwing upwards. The ball is caught above the head with the palm facing upwards. The feet remain stationary without shifting positions.	0.717
Throwing	The body maintains an upright position facing forward with legs spread shoulder-width apart. The ball is thrown using only one hand. The ball is thrown from above the head with the palm facing upwards and with the opposite foot. Hip and shoulder rotation face towards the target.	0.710
Kicking	The body maintains an upright position facing forward. Executing a kick using the inner part of the foot. The supporting foot is positioned beside/near the ball. The body is slightly tilted sideways during the kick.	0.792
Hitting	The body maintains an upright position facing forward. Both hands grasp the bat positioned beside the head. The bat is swung towards the ball using both hands. The body's position rotates in alignment with the direction of the swing motion of the strike.	0.708

α : Cronbach's Alpha.

Table 4. Wide scale test results

Criteria	N	M	%
Excellent	74		27.6
Good	159	34.46	59.3
Adequate	27		10
Insufficient	8		2.9
Very insufficient	-		-

N: number of respondents, M : as average value / Mean, % : is percentage

Table 5. Assessment dissemination from physical education teachers and college students

Indicators	PE Teacher	College student
Motion components	93%	96%
Instrument suitability	95%	94%
Ease of use	95%	95%
Facilities and infrastructure	97%	95%
Assessment	96%	95%
Language	95%	96%

Discussion

The findings of this research have reached a significant advancement in the development of assessment instruments for evaluating gross motor skills among elementary school students aged 7-9 years. This study addresses deficiencies in the monitoring and assessment practices of physical education teachers concerning the gross motor skills of elementary school students, which often need more specificity and alignment with the characteristics of these students. The discussion within this research explores novel and critical aspects based on research results that reveal the prevalent lack of precision and measurability in assessing students' motor skills by most physical education teachers. The identified gaps in the current assessment methodologies, which predominantly focus on cognitive and scholastic aspects, underscore the neglect of attention and significance towards gross motor skills.

This study highlights a myriad of significant variables in the gross motor skills of elementary school students. Consistent with recent research findings that emphasize the diversity in students' motor skill development through physical education [24, 25]. In addition, this study also affirms that physical education teachers tend to concentrate on instructing specific sports disciplines without conducting a comprehensive assessment of gross motor skills in general. This practice may adversely affect students' motor development, as the research findings elucidate that disruptions in the motor development of elementary school students can lead to learning difficulties and a decline in academic grades and achievements [26]. Other studies also support the notion that if elementary

school students exhibit poor gross motor skills, it will impact their cognitive abilities. This is due to the positive correlation between low gross motor skills and diminished cognitive capabilities in elementary school students [27]. Content validity testing involved collaboration with motor skills and physical education experts, followed by direct field testing of criterion validity. The research results elucidate the importance of engaging experts in the validity process to ensure the relevance and representativeness of content and the quality of the newly developed instrument [28]. Reliability was assessed through test-retest, calculating the Cronbach's alpha coefficient. The success of this instrument demonstrates its reliability and consistency in providing accurate data across measurements.

The novelty of the research findings lies in developing a user-friendly assessment instrument for physical education teachers. Several research outcomes indicate that the ease of use of this instrument can enhance efficiency in conducting assessments and monitoring the motor skill development of students [29, 30]. This becomes crucial in aiding students' motor skill development and assisting physical education teachers in tracking students' progress beyond the academic context. Appropriate and user-friendly instruments and technology are essential for enhancing the effectiveness of physical education learning for teachers and students [31, 32, 33]. This study significantly benefits elementary school students' physical education learning. The newly developed assessment instrument can transform teachers' assessment paradigms regarding students' gross motor skills, providing accurate and relevant information. From the students' perspective, this

instrument can increase satisfaction with learning and foster students' interest in participating in physical education classes. Research findings expound that using the right instrument can influence students' interest in participating in physical education learning, including developing their social skills [34, 35, 36].

In conclusion, this study provides a more comprehensive understanding of the gross motor skills of elementary school students aged 7-9 years through a specific, user-friendly, and reliable assessment instrument. This instrument has the potential to assist teachers in identifying students' developmental needs and offering timely interventions. Teachers and educational policymakers in elementary schools can apply the implications of this research. The developed assessment instrument can be implemented across various schools to broadly enhance understanding and monitoring of student's gross motor skills. Furthermore, further research can explore the implementation of this instrument in diverse educational contexts and school environments, creating opportunities for further innovation and the implementation of best practices in developing the gross motor skills of elementary school students. This research is the foundation for ongoing efforts to enhance child education by better understanding gross motor skills.

Despite the positive impact of this research on the physical education learning process, particularly in motor skill assessment, certain limitations warrant attention. The developed instrument in this study explicitly targets elementary school students aged 7-9 years, thus necessitating careful consideration and in-depth examination when generalizing results to the entire population of elementary school children. Variations in physical development, learning environments, and age can influence the validity of the assessment instrument. While the assessment instrument is designed to approach skills holistically, individual variations in gross motor skills that this instrument may not

capture should be continually addressed through ongoing development and calibration. Additionally, although research results indicate that physical education teachers find the assessment instrument user-friendly, further research is required to evaluate the readiness of physical education teachers to implement this instrument effectively across diverse school environments. Factors such as adequate training and administrative support need consideration to ensure the sustained use of this instrument over the long term. A deeper understanding of these limitations can pave the way for further research to enhance this assessment instrument's validity, reliability, and applicability in the holistic and comprehensive context of elementary school education.

Conclusions

The assessment instrument demonstrates high validity and reliability, effectively addressing the challenges associated with the need for assessments tailored to the evaluated subject's characteristics, objectives, and relevance. An easily comprehensible instrument, coupled with language accessibility, yields positive outcomes for physical education teachers in the assessment process. This research provides a concrete solution for enhancing the ability to assess and monitor the motor skills of elementary school students. The implications of this study extend to a paradigm shift, emphasizing the significance of understanding motor skill diversity and providing physical education teachers with precise and pertinent assessment tools.

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Effect of a physical education program in early childhood education on the performance of fundamental movement skills based on teaching styles: divergent discovery and practical

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Abstract

Background and Study Aim Various proposals suggest that Physical Education classes (PE) should prioritize the development of fundamental movement skills (FMS), particularly in preschool children. Despite the crucial nature of mastering FMS, there is a paucity of evidence regarding the impact of PE classes on FMS development. The primary objective of this study is to investigate the effect of a physical education program on the performance of preschool students with varying levels of development in fundamental movement skills, employing divergent discovery and practical teaching styles.

Material and Methods Seventy-seven children (35 boys), aged between 4.5 and 6 years were divided into three groups: Control Group (CG) with 25 participants, Divergent Discovery Group (DDG) with 24 participants, and Practice Group (PG) with 28 participants. The intervention program spanned six months, with two 50-minute classes per week for the experimental groups. Conversely, the control group participated in the Classroom Program proposal. All three groups underwent the TGMD-3 motor test. Performance measurement involved the sum of the raw score in the locomotor and object control classes.

Results The findings revealed that the Control Group, Divergent Discovery Group, and Practice Group exhibited improved FMS performance from pre to post. Concerning intergroup differences, no significant disparities were observed in the pre-test. However, post-intervention results indicated that both the Divergent Discovery Group and Practice Group demonstrated superior FMS performance compared to the Control Group.

Conclusions Physical Education classes for Early Childhood Education play a crucial role in fostering significant effects on children's motor development when offered in an appropriate context and through a systematically structured intervention.

Keywords: children, intervention, fundamental motors skills, TGMD3

Introduction

One of the richest periods in a child's development occurs during preschool. Among several domains of development (e.g., cognitive, social), it is at this stage that children should develop a set of motor skills called fundamental movement skills (FMS) [1]. A fundamental movement skill can be considered a set of movement patterns performed in a coordinated sequence; this sequence takes the form of what we know as running, jumping, throwing, galloping, kicking, among others [2].

In addition to being of great importance for good levels of physical activity during childhood [3] and adolescence [4], FMS is also the basis for acquiring a set of sports skills [5, 6] that the child must develop throughout life. Research worldwide indicates that preschool-aged children perform poorly in the

domain of FMS [7, 8]. Considering that low levels of FMS performance can generate a negative cascade effect in several domains of child development [9], it is imperative to create programs that can reverse this scenario. It is already recognized that the improvement in FMS performance levels occurs through encouragement, guidance, and the provision of motor practices appropriate to the needs of children [10, 11].

When we reflect on these conditions, Physical Education classes during the preschool phase seem to be the most appropriate and democratic environment to promote this facet of human development. According to Barela [12], the breadth of motor experiences in early childhood education combined with a relevant curriculum proposal, the quality of the practice, a safe environment, appropriate equipment, and the mediation of a trained teacher (who recognizes and respects the characteristics and needs of children) can represent a unique learning opportunity for the development of FMS.

In Brazil, there is a great diversity of proposals, namely: the City Curriculum, proposed by São Paulo [13], which brings interactions and games as principles for pedagogical action; the Program proposed by Florianópolis [14], which presents in its curriculum the strategies of the pedagogical action of physical education in early childhood education to the Pedagogical Action Centers (NAPs); the Curriculum Reference Document for Mato Grosso – Early Childhood Education, DRCMT [15], among others. However, few of them were developed with FMS development in mind.

It should be noted here that renowned institutions such as UNESCO [16] and researchers around the world draw attention to the important role of school Physical Education in relation to the motor development of children and young people [9]. Based on this assumption, a curricular proposal in Physical Education that was conceived thinking about favoring the development of FMS in preschool children was created by Ferraz [17]. This proposal in Physical Education was made up of activities that involve the systematic practice of body movement culture, bringing fundamental movement skills as a guiding axis emphasizing the content blocks: 1) Movement: Games Dance (e.g. traditional games from children's culture; rhythmic games). 2) Movement: Capacities, Possibilities, Structure, and Function (e.g., walking, running, and jumping). In addition to the curricular proposal, different teaching styles can enhance or restrict FMS development, especially for preschool children (a phase conducive to the development of FMS) [18]. Although teaching styles are very popular in the teaching of Physical Education, there is little evidence about their benefits for FMS development even when we refer to one of the first teaching styles presented for the area: the Divergent Discovery and Practice teaching style [19, 20].

The Divergent Discovery teaching style allows students to engage in the discovery of new content, develops emotional confidence and the cognitive ability to produce multiple solutions to the same question or to a series of unknown situations, which seek to expand the parameters of the content, beyond what is known and expected. This style allows for ample experimentation by the children, enabling the exploration of movements. The Practice teaching style, on the other hand, develops independent practice of a task. This teaching style allows children a greater degree of decision-making in solving the presented motor problems, providing freedom and flexibility in the learning process. Although the proposal elaborated by Ferraz [17] was conceived thinking about the development of the FMS, it should be considered that there is little incidence of research focused on the effectiveness of these curricular proposals regarding the development of fundamental movement skills

[21]. It is also necessary to consider that within the school context there are children with different levels of development in the FMS; that is, one can question the efficiency of the programs in the face of such a heterogeneous population. Considering the nature of the proposal created by Ferraz [17], which favors the development of FMS, and the structure of teaching styles, our hypothesis is that the performance of the experimental groups will be superior to the performance of the control group after the intervention program. Thus, the objective of the present study was to analyze the effect of a physical education program on the performance of preschool students with different levels of development in the fundamental movement skills, based on the styles of teaching Divergent Discovery and Practice.

Materials and Methods

The project was submitted to and approved by the Research Ethics Committee of the School of Physical Education and Sport at the University of São Paulo. Opinion No.: 3.286.717, CAAE - 09647219.4.0000.5391.

Participants

Seventy-seven children (35 boys and 42 girls), aged between 4.5 and 6 years (mean = 5.32; SD = 0.45), and belonging to a Public School of Early Childhood Education in São Paulo – EMEI, participated in this study.

Research Design

Collection Procedure and Materials

The children's data were collected on the premises of the respective EMEI at the beginning of the 2019 school year (late February and early March) over a period of 15 days. Upon receiving the list of students from the classes participating in the project, they were divided, according to the school's convenience, into three different groups: Control Group (CG) (n=25), Experimental Group 1 - Divergent Discovery (DDG) (n=24), and Experimental Group 2 - Practice (PG) (n=28).

The equipment used for data collection included a digital camera (Sony Model HDR-XR150), a tripod, a volleyball, a tennis ball, a plastic racket, a baseball bat, mini cones.

Assessment of Fundamental Movement Skills

The test used to assess FMS was the TGMD-3 proposed by ULRICH [22]. The TGMD-3 allows evaluating 13 FMS, 6 locomotives and 7 object controls. Each of the 13 motor skills includes three to five components, referred to as performance criteria (items), which represent the appropriate movement pattern for each skill. Following protocol guidelines, task instructions were provided by the researcher who demonstrated and provided verbal explanations of each skill to be performed. In this

execution, each student had three attempts: the first to verify the understanding of the skill and the others for analysis. When necessary, the researcher provided an additional demonstration for the child who did not understand the task.

Criteria are pre-established to evaluate children's motor performance. In this way, if the child performs all the criteria correctly, a score of one (1) will be assigned; otherwise, he or she will receive a score of zero (0) for that component. The sum of these performance criteria for each skill (raw score) was the performance measure used in the present study. This measure comprises the raw scores of each subtest being 0–46 points for locomotor skills, and 0–54 for object control skills. The estimated time for applying the test to each child was approximately 15–20 minutes. The three groups were submitted to the TGMD - 3 motor test battery before starting the Physical Education class program, called pre-test, and after the physical education class program, called post-test.

Data Analysis Quality Control

Assessment Procedure

Training was carried out with the researcher according to the indications in the evaluator's manual [22, 23] for data collection and analysis, through the application of the test in a pilot study.

Analysis Procedure

Reliability in video analysis:

All participants were filmed performing the 13 motor skills of the TGMD-3 to later have their performance analyzed with the help of Kinovea 0.9.5 software. Each child received a number (ID) that identified them before and after the intervention period. A video file was saved for each of the 13 skills the child performed. In total, 2444 video files were created. Of these, 260 videos referring to 130 participants (10 in each of the 13 motor skills) were randomly selected and analyzed by two evaluators to assess the inter-evaluator agreement values.

The inter-rater agreement process relied on an evaluator with extensive experience in the motor skills assessment process, having already evaluated approximately 8000 videos in previous research

using the TGMD-II test. The second evaluator was the first author of this research. The same children (10 for each skill, 130 in total) were assessed independently by both raters. After evaluating each of the 13 skills, the two evaluators met, and an analysis was performed to verify the percentage of agreement. All discordant components were discussed among the evaluators. If the percentage of agreement was less than 80%, another 10 new children (randomly selected) were evaluated for a new agreement process. When necessary, a third evaluator (also experienced in video analysis using the TGMD-II) was called in to discuss any doubts.

After achieving agreement above 80% in each of the components of the 13 motor skills, a Cohen's K analysis was performed to verify the levels of inter-rater agreement. The results of Cohen's K analysis for inter-rater agreement are found in table 1.

The results found for inter-rater evaluation indicate moderate (Skip) to high (Gallop) results. The same children used to perform inter-rater agreement were reassessed to check for intra-rater agreement. The intra-rater assessment took place one day after the first assessment. As in the inter-evaluator analysis, a concordance analysis was performed and only after reaching values greater than 80%, in each of the components, was the evaluator able to evaluate. A Cohen's K analysis was also performed to estimate the intra-rater agreement values, which are shown in table 2.

Values considered moderate (Run) to high (Hop) were found for both inter and intra-rater agreement levels.

Intervention Program

The teaching methodology presented in the table below (Table 3) exemplifies the structuring of the proposed activities concerning the teaching styles that were adopted for each experimental group. The contents of the systematized classes were structured in equivalence in the DDG and PG and they are presented in Supplementary Material.

The intervention program ran for 6 months, with 2 weekly classes of 50 minutes for the experimental groups. Classes for the experimental groups were taught by a teacher licensed in physical education, with professional experience in both teaching styles

Table 1. Cohen's K values (inter-rater) followed by standard error.

Locomotors	Kappa	Object Control	Kappa
Run	0.65 ± .140	Strike 2 hands	0.57 ± .148
Gallop	0.88 ± .110	Dribble	0.61 ± .141
Skip	0.51 ± .140	Catch	0.75 ± .159
Hop	0.66 ± .149	Kick	0.56 ± .164
Slide	0.64 ± .153	Overhead throw	0.53 ± .170
Horizontal jump	0.67 ± .150	Underhand throw	0.58 ± .139
		Strike 1 hand	0.57 ± .159

Table 2. Cohen’s K values (intra-rater) followed by standard error.

Locomotors	Scores	Object Control	Scores
Run	0.61 ± 1.42	Strike 2 hands	0.87 ± 1.78
Gallop	0.91 ± 1.11	Dribble	0.66 ± 1.33
Skip	0.86 ± 1.61	Catch	0.86 ± 1.03
Hop	0.92 ± 1.12	Kick	0.66 ± 1.33
Slide	0.91 ± 1.53	Overhead throw	0.74 ± 1.23
Horizontal jump	0.84 ± 1.22	Underhand throw	0.77 ± 1.21
		Strike 1 hand	0.81 ± 1.82

Table 3. Structuring of teaching styles.

Structure teaching styles	The general objective of the styles	Content blocks for each style	Specificity of content blocks
DIVERGENT DISCOVERY	Expand experimentation, since the student can explore the various possibilities of movement related to the object, games, or proposed motor skills.	Movement: Games, Toys (Movement: Dance, singing circle and mime)	Games based on rules, traditional games from Children’s culture, Toys and Games, contests, fights, and Symbolic Games. Different rhythmic structures, singing and dancing circles, mimes, and dramatization.
PRACTICE	Share with the students the execution and evaluation decisions in the class, guiding only what should be done, not how it should be done.	Movement: Capabilities and Possibilities (Movement: structure and function)	Basic motor skills of object control, locomotion, balance and concepts of movement in dimensions. Body parts and what they can do, breathing and heartbeat, state of relaxation and contraction.

Note: Adapted from Ferraz [17]

for early childhood education. The control group, on the other hand, participated in the proposal that encompasses the Classroom Program of EMEI (Municipal School of Early Childhood Education) called: Exploration of Body Language. The proposed activities involved free-time games performed mainly in the park space, 5 days a week, lasting approximately 50 minutes. These classes were offered by the classroom teachers themselves.

Statistical Analysis

An exhaustive analysis was conducted, involving the frequency distribution of participants’ performance in each of the 13 motor skills. Verification of possible outliers occurred through graphic representation of extremes and quartiles. The assumption of normal data distribution in all collections was assessed using the Shapiro-Wilk test, which indicated an absence of normality.

Considering the initial results revealing the absence of a normal distribution in performance, the descriptive analysis utilized median (Me) and interquartile ranges (IQ) in addition to non-parametric inferential analyses.

To identify differences between the three groups, both pre and post-intervention, the Kruskal-Wallis test for independent groups was performed. In cases of identified differences, the Mann-Whitney U test

was employed and corrected using the Bonferroni method, suitable for non-parametric tests with more than two independent groups [24].

Furthermore, a non-parametric analysis, using the Mann-Whitney U test, was conducted to identify possible differences between genders in locomotor and object control skills across all performance measures.

The Wilcoxon test for repeated measures was employed to investigate the influence of the intervention program on motor skills performance in the three participating groups. A supplementary descriptive analysis illustrated the mean magnitude of change (post-performance – pre-performance) in FMS performance, considering both locomotor skills and object control skills (0-46 points for locomotor skills and 0-54 for ball skills) for the three groups.

Within each group, children were subdivided into three other groups based on their performance in the first collection: group P33, for children who started with performance below the 33rd percentile; group P66, for children who started with performance between the 33rd and 66th percentile; and P99 group, for children with performance above the 66th percentile. The effect size (represented by *r*) in non-parametric analyses with repeated measures was estimated using the procedure suggested by Field

[24]. The magnitude of effects is usually grouped into three levels: $r = 0.10$ (small effect); $r = 0.30$ (medium effect); and $r = 0.50$ (large effect). All these calculations were performed using the SPSS 25.0 statistical package.

Results

The results will be presented in the following order:

1) Effects of the intervention programs in the two experimental groups and the control group on the sum of locomotor skills;

2) Effects of intervention programs in both experimental groups and the control group on the sum of components of object control skills;

3) Effect of intervention programs on the magnitude of change in children with different performance levels (P33, P66, and P99) in the three groups (CG, DDG, PG).

Effect on the sum of components of locomotor skills

When considering only the raw score of the Fundamental Movement Skills (FMS) in the locomotor class, the results indicate that the Control Group (CG), Divergent Discovery Group (DDG), and Practice Group (PG) show significant differences only after the intervention program ($H(2) = 16.560$, $p < .001$); there was no significant difference before the intervention program ($H(2) = 1.34$, $p = .511$). Post-program, differences were found only between CG and DDG ($H = -17.259$, $p < 0.05$, $r = 0.44$) and CG and PG ($H = -24.476$, $p < 0.001$, $r = 0.50$). There were no significant differences between DDG and PG ($H = -7.217$, $p = .733$).

Wilcoxon analysis indicated a significant change in the performance of locomotor skills for all three groups, namely (Table 4).

In the locomotor class, Mann-Whitney U analysis did not identify significant differences between the performance of boys and girls in any of the groups, neither before (CG, $p = .129$; DDG, $p = .424$; PG, $p =$

$.734$) nor after the intervention program (CG, $p = .129$; DDG, $p = .955$; PG, $p = .946$).

Effect on the sum of Object Control components

The same analysis was performed for the raw score in the FMS of the object control class. The results indicated that Groups CG, DDG and PG showed significant differences before ($H(2) = 6.797$, $p < 0.05$) and after ($H(2) = 16.604$, $p < 0.001$) the intervention program. Despite the differences found before the program, the *post hoc analysis* did not identify significant differences between Groups CG and DDG ($H = -14.645$, $p = 0.064$), CG and PG ($H = -13.627$, $p = 0.078$) and DDG and PG ($H = 1.108$, $p = 1.0$). Significant differences were found only after the program between CG and DDG ($H = -21.961$, $p < 0.05$, $r = 0.49$), CG and PG ($H = -22.261$, $p < 0.001$, $r = 0.49$). No significant differences were identified between DDG and PG ($H = -.301$, $p = 1.0$).

Wilcoxon analysis indicated a significant change in the performance of object control skills for the three groups (Table 5).

In the object control class, the results indicated significant differences between boys and girls only in DDG after the intervention program ($U = 35.500$, $p < 0.05$; $r = 0.30$) with superior performance for boys. No significant differences were found between boys and girls in the other groups, neither before (CG, $p = .907$; DDG, $p = 0.06$; PG, $p = .164$) nor after the program (CG, $p = .978$; PG, $p = 0.085$).

Effects on children with different levels of development

The descriptive analysis illustrates the average magnitude of change within each group, considering the initial performance (prior to the intervention program) in the sum of locomotor skills and object control skills.

Based on the results (Figure 1), it can be observed that despite exhibiting similar performances before the intervention program, the improvement in

Table 4. Median and interquartile range (IQ) before and after the intervention program in locomotor skills.

Groups	Pré-Test	Pos-Test	Z	p	R
Control Group	20.50 (7)	27.50 (8.2)	3.761	0.001	0.53
Divergent Discovery Group	20 (6.5)	31 (3)	4.292	0.001	0.61
Practice Group	21.50 (4.7)	33 (3.7)	4.627	0.001	0.61

Table 5. Median and interquartile range (IQ) before and after the intervention program in object control skills.

Groups	Pré-Test	Pos-Test	Z	Sig	r
Control Group	17 (5.5)	25.5 (5)	4.381	0.001	0.61
Divergent Discovery Group	19 (4.7)	30 (7.7)	4.297	0.001	0.62
Practice Group	19.5 (4.7)	30 (7.5)	4.633	0.001	0.61

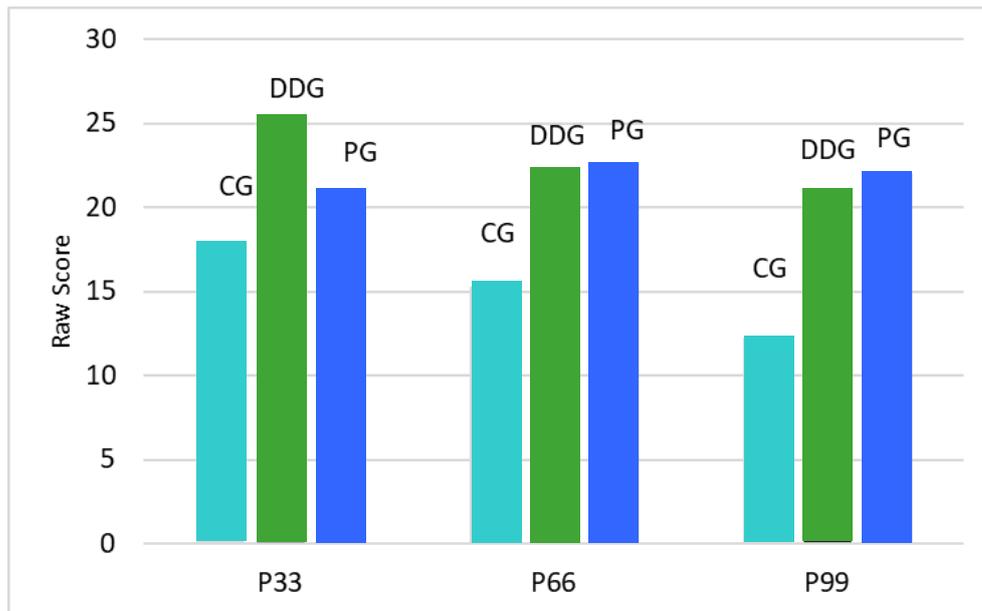


Figure 1. Delta of change from pre- to post-intervention moment for each of the three groups.

average performance was more pronounced in the experimental groups across all three subgroups (P33, P66, and P99). Figure 1 depicts the performance improvement delta within each group concerning the initial performance. Consistent with the previous findings, it can be concluded that the intervention program facilitated greater performance gains among participants in the experimental groups, irrespective of their initial performance levels.

Discussion

The present study aimed to investigate the effect of a physical education program on the performance of preschool students with different levels of development in fundamental movement skills, based on Divergent Discovery and Practical teaching styles.

The results indicated that all groups significantly improved in both locomotor and object control skills. However, the greatest gains occurred for children in the experimental groups. Similar findings were reported in other studies assessing the effects of intervention programs on fundamental movement skills' performance [25, 26]. However, it is worth noting that the present study sought to investigate the effects of a proposed curriculum on the performance of preschool children. In this case, our concern was to test the effectiveness of a proposal that could be easily implemented on a large scale and in different regions of the country.

It is crucial to underscore that the characteristics of the employed teaching styles significantly contributed to the greater gains observed in children from the experimental groups. Specifically, the Divergent Discovery teaching style empowered students to actively explore new content, fostering emotional confidence and cognitive abilities to

generate multiple solutions to the same problem or a series of unknown situations [27]. This approach aimed to expand the content parameters beyond what is conventionally known and expected.

In the case of the Divergent Discovery Group, differentiation was achieved through outcome-based strategies. While the same task was assigned to everyone, it was intentionally open-ended, allowing for multiple interpretations. This deliberate design encouraged students to respond differently and produce a variety of outcomes, enhancing their engagement and creativity in the learning process [27].

The Practice teaching style fostered independent task practice, granting children a greater degree of decision-making in solving the presented motor problems and promoting freedom and flexibility in the learning process [28]. In the Practice group, differentiation was implemented through selected tasks, where the teacher predetermined the activities. Children could then engage in practice without altering their trajectory, while receiving valuable feedback from the teacher. This approach aimed to provide a structured yet adaptive learning environment, allowing for personalized development within the established framework [28].

The teacher, responsible for the intervention, provided guidance on movement execution before and during activities, differentiating the teaching styles from more traditional approaches. Both styles facilitated essential factors for improving performance, such as providing adequate opportunities, encouragement, and guidance [18, 26]. These characteristics likely motivated children with varying performance levels to engage actively in class.

The research also aimed to explore the

intervention program's influence on children with different levels of fundamental movement skill development. According to Stodden [29], children with low motor competence tend to avoid activities in which they do not feel competent. In this way, creating motivating content for all students is undoubtedly a challenge faced by Physical Education teachers worldwide.

Descriptive results indicated that the intervention programs led to greater performance gains in fundamental movement skills for children in the experimental groups, regardless of their initial performance. This outcome can be attributed to the encouragement of children to find diverse motor solutions for the same problem within the teaching styles employed. Consequently, even students with lower motor performance felt motivated to practice and actively participate during the intervention.

Despite the descriptive nature of these results, they underscore the importance of intervention programs in Physical Education classes during preschool. First, it is known that the improvement in motor performance produces a cascade effect that promotes improvement in several other domains of human development, ranging from health-related factors [4, 30] to the development of social skills [31].

It should also be noted that, although the control group also improved from pre to post, the difference in the magnitude of change between groups can be a determining factor in the child's future. Research indicates that the gain of one or more components of a skill (for example, trunk rotation during throwing) can directly impact the acquisition of more complex skills, such as sports [5, 6, 32]. According to the results of two of these recent studies, low performance in the FMS can be considered a proficiency barrier that can restrict the acquisition of more complex skills [5, 6], thus impacting the child's future.

The results also revealed that boys and girls performed similarly in all groups, except for the Divergent Discovery Group (DDG) for object control skills, where boys outperformed girls. Several studies indicate that in object control skills, boys perform better than girls [7, 33]. In our study, the difference found in only one group may have some explanations.

It is known that girls have lower performances than boys because they are less encouraged to practice object control skills [7, 25]. In this case, it can be assumed that boys and girls participating in the study received similar opportunities during their preschool years. Regarding the group that showed differences (Practice Group), an extra analysis investigated the percentage of children who practiced sports outside school hours. The results of this analysis indicated that the PG was the group with the highest frequency of boys who practiced sports outside school hours, with 80% of the children. In the other groups, only 10% (6% of

the DDG and 4% of the CG) performed sports, which may explain the difference only in this group.

Overall, the results substantiate the hypothesis of the present study, demonstrating that positive changes in motor development can be realized through a conducive environment enriched with materials for the development of fundamental movement skills. Additionally, the findings support the efficacy of a proposed intervention planned and tailored to address the actual needs and motor demands of the targeted age group. This alignment between the intervention and the age-specific requirements underscores the significance of intervention programs.

Despite the favorable results, the present study has limitations, such as the sample size. Although our effect size analysis considers the sample size and our choice for a smaller sample size was made to approximate the reality of Physical Education teachers (e.g., class time and number of students per class), it is suggested that future studies test the effects of teaching styles in larger samples.

Finally, the results found corroborate the studies already established and stimulate us to reflect on the need to align structured programs, which establish objectives, adequate content, organization, implementation of methodological strategies in favor of the development of motor skills together with a careful evaluation of the teaching-learning process. In this scenario, the physical education teacher equipped with appropriate pedagogical proposals can be the key element for children to develop their full potential.

Conclusions

The results found in the present study reinforce the great importance of planning the physical education curriculum for early childhood education, aiming at engaging children in pleasurable activities and valuable experiences. In this sense, we understand that Physical Education classes for preschool using both teaching styles (Divergent Discovery and Practice) is an interesting strategy to help them discover and realize their full motor potential. In addition, this strategy reinforces the essential role of the teacher in the process of learning and developing fundamental movement skills. It is recommended that future studies explore the effects of teaching styles in larger sample sizes and among older children. This approach will contribute to a more comprehensive understanding of the influence of teaching styles on motor development.

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The effect of chronic leg press exercises on hamstring muscle length and different vertical jump performance

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Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

Abstract

Background and Study Aim As it is known, chronic resistance exercises cause limitations in some joints and this negatively affects the normal range of motion. In the present study, it was aimed to analyse the quadriceps-hamstring balance by analysing different vertical jump performances after six weeks of leg press exercise.

Material and Methods Eleven university students aged between 18-30 years were included in this study. The hamstring muscle length, 1 repetition maximum (1-RM) leg press performance were analysed before and after six weeks of leg press exercise. In addition, the vertical jump performances of the participants were analysed with My Jump 2 software programme. In this study, counter movement jumps (CMJ) and squat jump (SJ) performances of the participants were determined.

Results According to the findings, 1 repetition maximum (1-RM) leg press performance and hamstring length of the participants improved significantly ($t=-7.609$, ES: -2.29 , $p<.001$; $t=-2.540$, -0.76 , $p=.029$, respectively). CMJ and SJ parameters of the participants did not change ($p<0.05$). It was concluded that the lengthened hamstring length after the leg press exercise programme had a positive relationship with vertical jump height ($r=0.656$, $p=0.028$), flight duration ($r=0.663$, $p=0.026$), speed ($r=0.657$, $p=0.028$), and average speed ($r=0.669$, $p=0.024$). These relationships were observed among CMJ parameters following the exercise programme. Likewise, a positive correlation was found between hamstring length, which lengthened after the leg press exercise programme, and vertical jump height ($r=0.625$, $p=0.040$), flight duration ($r=0.646$, $p=0.032$), speed ($r=0.646$, $p=0.032$), and average speed ($r=0.637$, $p=0.035$). These correlations were identified among the SJ parameters after the exercise.

Conclusions As a result, it was determined that chronic leg press exercises positively affected hamstring muscle length and muscle strength. Different vertical jump performances such as CMJ and SJ did not change. However, the relationship between hamstring length and vertical jump parameters is interesting.

Keywords: leg press exercise, hamstring length, vertical jump, strength, power

Introduction

It is commonly known that regular resistance training can improve muscle power and strength [1, 2]. On the other hand, it is also acknowledged that extended resistance training might result in joint restrictions [3], which may jeopardize appropriate range of motion and overall athletic performance [4]. The mismatch between the agonist and antagonist

muscle groups, specifically the hamstrings and quadriceps, is a significant component that can affect the effectiveness of movements and injury risk [5]. It is critical to comprehend how various muscle groups interact and how that interaction affects functional movement patterns in order to maximize training results and reduce the likelihood of musculoskeletal problems.

Although the quadriceps and glutes are the main muscles targeted by leg press exercises [6], the hamstring muscles are also important for supporting lower body motions [7]. Long-term resistance

training, like leg press workouts, can cause changes in the length and flexibility of muscles. However, the precise effect on the length of the hamstring muscles may differ based on variables including volume, intensity, and personal biomechanics. According to some research, extended leg press exercise may lengthen the hamstring muscles as the muscles become more flexible in response to the demands of the exercise [8]. On the other hand, insufficient stretches or inappropriate training methods may lead to a reduction in hamstring suppleness and an increased likelihood of injury [9]. Thus, for the purpose of maximizing musculoskeletal health and overall athletic performance, it is imperative to evaluate hamstring muscle length and to conduct suitable flexibility training programs in conjunction with leg press exercises.

By concentrating on the investigation of quadriceps-hamstring balance in the context of chronic leg press activities, the current study tackles this significant topic. Our specific goal is to find out how a six-week leg press exercise plan may impact various components of vertical jump performance – a trustworthy measure of lower limb strength and power. We want to clarify the dynamic link between quadriceps and hamstring muscles in response to resistance training by assessing many vertical jump performance metrics, such as jump height, velocity, and power output. The hypothesis of this study is engaging in a six-week chronic leg press exercise regimen will significantly enhance hamstring muscle length and 1-RM leg press performance in participants.

Materials and Methods

Participants

In our study, the minimum sample size was determined by G power software programme (version 3.1). Accordingly, when $\alpha=0.05$, power $(1-\beta)=0.80$ and effect size 0.9, it was determined that at least 10 participants should be included in the study. Accordingly, 11 male participants aged between 18-30 years were included in the study. Participants who had synovial deficits in the knee joint, meniscus problems, stayed away from sports due to muscle, bone or tendon problems in the last 1 year, or had existing infections were not included in the study.

Prior to this study, all participants signed the Informed Voluntary Consent form and were informed

about the purpose, duration and contribution to the literature. All procedures in the study were carried out in accordance with the principles determined in the Declaration of Helsinki. For this study, the necessary permissions were obtained from Inonu University Health Sciences Scientific Research and Publication Ethics Committee with approval number 5155.

Experimental Design of Study

After obtaining the demographic information of the participants who met the inclusion and exclusion criteria of the study, hamstring muscle lengths were analysed with the sit-and-reach test before the 6-week leg press exercise programme (Table 1) [10]. To determine the 1 RM leg press training load, the 1 repetition maximum (1-RM) values of all participants were calculated according to the Brzycki formula [11]. Counter movement vertical jump (CMJ) and squat jump (SJ) performances of the participants were performed with My Jump application. After the pre-tests were taken, a 6-week leg press exercise programme was applied. Then, post-tests were taken from all participants. Before the tests, the participants performed a 5-minute bicycle warm-up on a stationary bicycle. Participants were asked not to consume food and beverages other than water until at least 3 hours before the tests. All tests were taken in the Faculty of Sports Sciences Fitness Centre and the ambient temperature was between 20-22 degrees Celsius. All participants received instructions on how to perform the tests 24 hours before the tests (Figure 1).

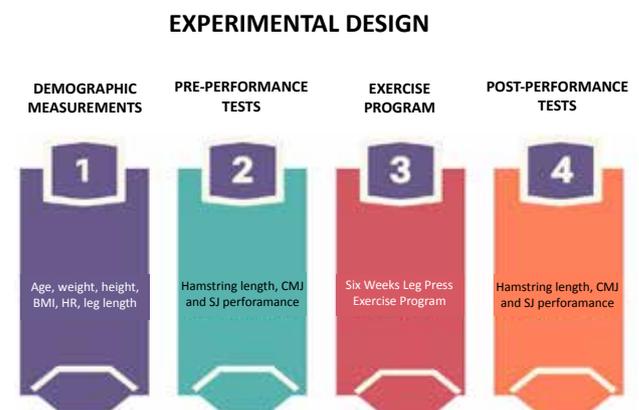


Figure 1. Experimental Design of Study

Procedures

Hamstring Length

The hamstring lengths of the participants were

Table 1. Six Weeks Leg Press Exercise Program

Weeks	Volume (sets ^x repetition)	Intensity (%1-RM)	Interval (s)	Eccentric time (s)	Concentric time (s)
1-2	3x10	70	60	2	1
3-4	3x8	80	80	2	2
5-6	3x6	90	105	2	2-3

1-RM: 1 repeated maximal

measured with the sit reach test. The sit reach test was performed according to the criteria of ACSM [12]. The participants placed their bare feet on the Seat and Reach brand platform. The knee joint was positioned in full extension and the ankle was positioned at 90 degrees. The participants pushed the metal placed on the platform and their maximum reach was recorded [13].

Vertical Jump Performance

The vertical jump performances of the participants were determined by CMJ and SJ. CMJ and SJ measurements were performed with My Jump 2, a smartphone application. Accordingly, 240 Hz videos of the participants were recorded with the help of iPad. In the recorded video, the take-off and landing frames of the participants were identified and defined in the literature;

$$h = t^2 \times 1.22625 \quad (1)$$

the flight time of the CMJ and SJ was calculated by converting this to a jump height using the equation [14]. During the CMJ performance, the individual was asked to start the jump in an upright posture, perform a forward fall movement with knee and hip flexion, then jump vertically upwards, and immediately and violently perform knee and hip extension to jump to the ground [15]. For the SJ measurement, the participants were asked to take a squat position with their knees flexed and jump upwards with maximum force with their hands on their waist [16].

Statistical Analysis

SPSS package programme 26 was used for statistical analyses in the study. Normality analyses of the data were determined according to Shapiro Wilk test and Skewness-Kurtosis values (-1.5+1.5). The data were found to be normally distributed and Paired Sample T test was applied for 1-RM, hamstring length, CMJ and SJ performance measurements before and after six weeks of leg press exercise. In the study,

R Studio (version 369) was used to determine the relationship between hamstring muscle length and vertical jump performances. Effect sizes of statistical analyses were calculated according to Cohen’s d formula [17]. The ES magnitude was defined as follows: <0.2= trivial, 0.2 to 0.6= small effect, >0.6 to 1.2 = moderate effect, >1.2 to 2.0 = large effect, and >2.0 = very large [18]. The significance level in the study was determined as 0.05.

Results

Table 2 shows the demographic information of the participants. Accordingly, the mean age of the participants was 20.81±3.25 years, body weight was 74.53±14.70 kg, height was 178.28±10.04 cm, and BMI was 23.34±3.49 kg/m².

In Table 3, leg circumference, 1-RM, and sit reach test results of the participants before and after leg press exercises were analysed. Accordingly, leg press 1-RM strength [t=-7.609, p<.001, ES=-2.29, (-3.43 to -1.12 95% CI)] and hamstring length results [t=-2.540, p=.029, ES=-.76, (-1.42 to -0.07 95% CI)] increased significantly after the six-week leg press exercise programme (Figure 2). Upper leg circumference did not change significantly after the exercise programme (p>.05).

In Table 4, the CMJ test results of the participants before and after the leg press exercise were analysed. According to this, vertical jump, flight time, speed, average speed, strength and power parameters of the participants did not change significantly (p>.05).

In Table 5, the SJ test results of the participants before and after the leg press exercise were analysed. According to this, vertical jump, flight time, speed, average speed, strength and power parameters of the participants did not change significantly (p>.05).

In Figure 3, the relationship between hamstring length and CMJ parameters of the participants before and after six weeks of leg press exercise is analysed. Accordingly, there was no correlation

Table 2. Demographic Information of Participants

Parameters	Mean	S.D.	Min	Max
Age (year)	20.81	3.25	18	30
Weight (kg)	74.53	14.70	56.80	103.3
Height (cm)	178.28	10.04	165.0	192.5
BMI (kg/m ²)	23.34	3.49	20.02	30.78

S.D.: Standard Deviation, BMI: Body Mass Index

Table 3. Examination of Performance Parameters of the Participants Before and After Leg Press Exercise

Parameters	Pre-Training Mean±S.D.	Post-Training Mean±S.D.	t-Value	ES	p-Value	%95 CI	
						Lower	Upper
Leg Circumference (cm)	53.54±5.49	54.99±5.16	-1.747	-.52	.111	-1.14	0.11
1-RM (kg)	182.21±41.59	240.28±62.14	-7.609	-2.29	<.001	-3.43	-1.12
Hamstring Length (cm)	14.54±7.87	17.00±8.65	-2.540	-.76	.029	-1.42	-0.07

1-RM: Repeat Maximum

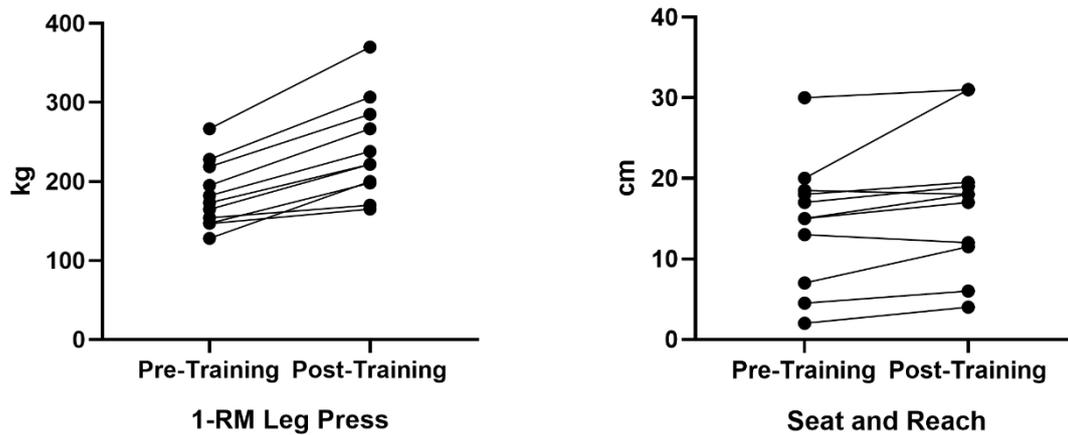


Figure 2. Participants’ 1-RM Leg Press and Sit Reach Test Results

Table 4. Comparison of CMJ test results of the participants

Parameters	Pre-Training Mean±S.D.	Post-Training Mean±S.D.	t-Value	ES	p-Value	%95 CI	
						Lower	Upper
Vertical Jump (cm)	44.45±9.04	43.73±6.35	0.612	0.18	.554	-0.41	0.77
Flight Duration (ms)	599.27±60.46	595.81±42.45	0.433	0.13	.674	-0.46	0.72
Speed (m/s)	2.93±0.29	2.92±0.20	0.396	0.11	.700	-0.47	0.71
Average Speed (m/s)	1.47±0.14	1.46±0.10	0.454	0.13	.659	-0.46	0.72
Strength (N/kg)	24.03±2.74	23.89±2.30	0.364	0.11	.723	-0.48	0.70
Power (W)	35.56±6.97	34.97±4.79	0.543	0.16	.599	-0.43	0.75

Table 5. Comparison of SJ test results of the participants

Parameters	Pre-Training Mean±S.D.	Post-Training Mean±S.D.	t-Value	ES	p-Value	%95 CI	
						Lower	Upper
Vertical Jump (cm)	36.10±7.60	37.20±6.73	-1.306	-0.39	.221	-1.00	0.23
Flight Duration (ms)	539.90±56.99	548.81±50.13	-1.396	-0.42	.193	-1.03	0.20
Speed (m/s)	2.64±0.28	2.69±0.24	-1.396	-0.42	.193	-1.03	0.20
Average Speed (m/s)	1.32±0.13	1.34±0.12	-1.515	-0.45	.161	-1.07	0.17
Strength (N/kg)	21.31±2.12	21.76±2.27	-1.565	-0.47	.149	-1.08	0.16
Power (W)	28.39±5.31	29.42±5.16	-1.429	-0.43	.184	-1.04	0.19

between the participants’ initial hamstring length and CMJ performance. However, it was concluded that the lengthened hamstring length after leg press exercise programme had a positive relationship with vertical jump height ($r=656$, $p=.028$), flight time ($r=663$, $p=.026$), speed ($r=657$, $p=.028$) and average speed ($r=669$, $p=.024$) among CMJ parameters after the exercise programme.

In Figure 4, the relationship between hamstring length and SJ parameters of the participants before and after six weeks of leg press exercise was analysed. Accordingly, no correlation was found between the participants’ baseline hamstring length and SJ performance. However, a positive correlation was found between the length of hamstring after the leg press exercise programme and SJ parameters such

as vertical jump height ($r=625$, $p=.040$), flight time ($r=646$, $p=.032$), speed ($r=646$, $p=.032$) and average speed ($r=637$, $p=.035$).

Discussion

The present study aimed to elucidate the effects of a six-week chronic leg press exercise regimen on hamstring muscle length and its subsequent impact on vertical jump performance. The significant improvement in 1 repetition maximum (1-RM) leg press performance and hamstring muscle length after six weeks of leg press exercises suggests that resistance training positively impacts muscle strength and flexibility. The impact of chronic resistance training on muscle strength, flexibility,

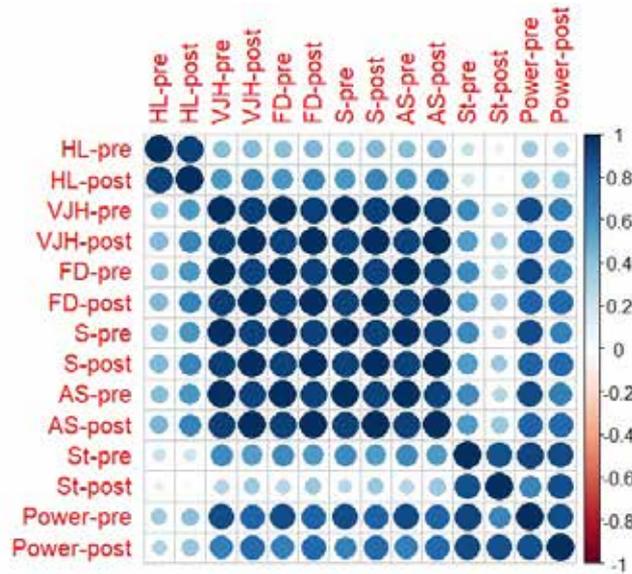


Figure 3. Correlation between hamstring length and CMJ parameters: HL: hamstring length, VJH: vertical jump height, FD: flight duration, S: Speed, AS: average speed, St: Strength

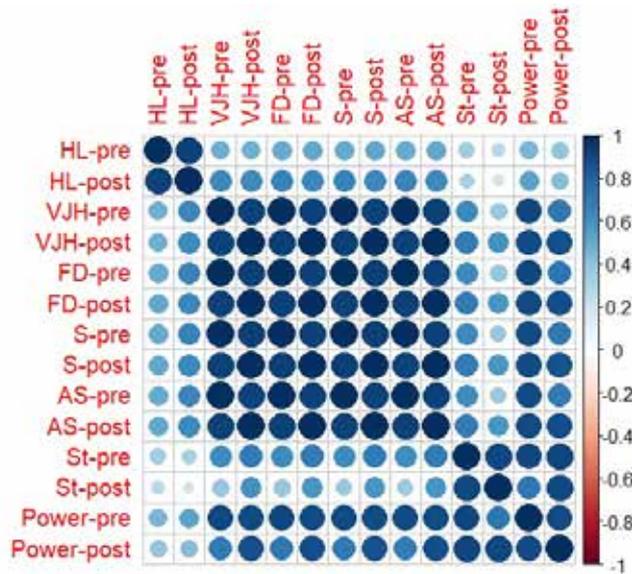


Figure 4. Correlation between hamstring length and SJ parameters: HL: hamstring length, VJH: vertical jump height, FD: flight duration, S: Speed, AS: average speed, St: Strength

and joint range of motion has been the subject of a systematic review and meta-analysis. The review found that resistance training with external loads can improve range of motion to a moderate magnitude, and that additional stretching prior to or after resistance training may not be necessary to enhance flexibility [4, 20, 21]. The study also highlighted that resistance training can be as effective as stretch training to increase joint range of motion [21]. The literature supports the existence of a “strength zone” for increasing one-repetition maximum (1RM), consistent with the concept of a repetition continuum [22]. Furthermore, it was noted that resistance training increases muscle strength by making the muscles work against a weight or force, and the optimal range for improving

muscle strength is 8–12 repetitions [23]. Therefore, the evidence suggests that chronic resistance training can have a positive impact on muscle strength, flexibility, and joint range of motion [4, 20, 21]. This finding is particularly noteworthy as it contradicts the common perception that chronic resistance exercises might limit joint flexibility and subsequently decrease the range of motion.

The lack of significant changes in CMJ and SJ performances, despite improved hamstring length and muscle strength, is an intriguing outcome. This could be interpreted in several ways. Firstly, vertical jump performance is multifactorial, depending heavily on factors like muscle power, coordination, and neural activation, beyond just muscle strength and length. The specificity of training principle also

comes into play, suggesting that improvements in a particular exercise or movement (like the leg press) may not directly translate into performance enhancements in a mechanically different movement (like vertical jumps). But there are some researches that revealed different results. Vertical jump performance is multifactorial and can be improved through various strength training methods. Weight training has been shown to improve vertical jumping performance in most cases by 2-8 cm or 5-15% [22, 23]. Exercises such as squats, lunges, leg presses, and toe raises with heavy loads (80-90% 1-RM) and low repetitions (4-6) are used to improve maximal strength [23, 24]. Plyometric exercises, such as depth jumps, have also been shown to improve vertical jump performance [25].

Moreover, the positive correlation between increased hamstring length and various CMJ and SJ parameters post-exercise (including vertical jump height, flight duration, speed, and average speed) is particularly intriguing. This correlation indicates a potential link between enhanced muscle flexibility and improved performance metrics within the jumps, even though the overall jump performance did not change significantly. This might suggest that while the overall power and ability to perform vertical jumps may not have been impacted, the quality and certain aspects of the jumps could have been subtly enhanced by the improved muscle function. The positive correlation between increased hamstring length and various countermovement jump (CMJ) and squat jump (SJ) parameters post-exercise, such as vertical jump height, flight duration, speed, and average speed, suggests a potential link between enhanced muscle flexibility and improved performance metrics within the jumps. While the overall power and ability to perform vertical jumps may not have been impacted, the quality and certain aspects of the jumps could have been subtly enhanced by the improved muscle function. Research has shown that the hamstrings-to-quadriceps ratio (H/Q ratio) is related to variables that describe CMJ and DJ (drop jump)

heights. A study found that the heights of CMJ and DJ were increased with higher H/Q ratios, indicating a positive relationship between muscle torque and vertical jump performance [24-26]. Another study evaluated the relationship between lower extremity strength, symmetry, and jump performance. It found that there is no negative or positive relationship between inter-limb isokinetic knee strength symmetry angle and jump performances, suggesting that strength symmetry may not significantly impact jump performance [27]. Additionally, a study on predictors of vertical jumping capacity in soccer players aimed to evaluate how isokinetic strength of the thigh muscles is related to jump performance. While the specific relationship to hamstring length is not mentioned, the study provides insights into the relationship between muscle strength and jump performance [28].

There are some limitations in this study. The small sample size and the specific demographic (university students aged 18-30) may limit the generalizability of the results. Future studies with larger, more diverse populations and extended training durations are recommended to validate these findings. Additionally, incorporating a control group and other forms of exercises could provide a more comprehensive understanding of the relationship between resistance training, muscle characteristics, and jump performance.

Conclusions

In conclusion, the study provides valuable insights into the adaptive changes in hamstring muscle characteristics following a chronic leg press exercise regimen and how these changes correlate with vertical jump performance. The findings highlight the complexity of translating muscle strength and flexibility improvements into performance enhancements in different athletic movements. Further research in this domain is essential to fully elucidate these relationships and to optimize training protocols for enhancing performance in jump-related sports and activities.

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Effects of a warm up integrated with core stability exercises on the motor abilities in young soccer players

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Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

Abstract

Background and Study Aim The warm-up phase in youth soccer can be used to introduce drills that do not find space within the training session. Core district exercises give stability to the trunk and hips, allowing for increased performance and reducing the risk of non-contact injuries. This study aims to test the effects of a warm up integrated with core stability exercises on the motor abilities in young soccer players.

Material and Methods Young soccer players (n=32, 12.45±0.52 years, 1.49±0.05 m, 44±2.90 kg) were randomly divided into two groups: experimental (EG=17) and control group (CG=15). The EG performed an integrated warm-up with core stability tasks for 6 weeks (12 sessions). The CG followed the usual training schedule based on technical tactical and physical drills. Performance was assessed through broad jump, Hop test, Side Hop test, 10-meter sprint and 10x5-meter shuttle test.

Results Data analysis returns some statistically significant differences in intergroup comparison (T1): for broad jump (p = .008), for left limb Hop test (p = .02), for right limb Hop test (p = .02), for left limb Side Hop (p = .03), for right limb Side Hop (p = .04), for sprint 10-meters (p = .002), for shuttle run 10x5-meters (p = .03).

Conclusions The core stability exercises in the warm up seems to increase some performance correlated with the motor abilities stressed in the soccer. The warm up through appropriate modifications can represent, a useful and integrative moment to elicit more factors of performance and prevention.

Keywords: trunk stability, young soccer players, strength, sprint, shuttle run, youth soccer

Introduction

Soccer is one of the most popular sports in the world and played by a large number of men and women of all age groups. For this reason, technical staffs are constantly searching for training methodologies and organizational aspects that can improve performance in both the adult and young soccer player [1]. Research is mainly directed toward investigating training methodology that develops strength, speed, and aerobic power, along with technical and tactical skills [2, 3]. However, while training methodologies allow for increased performance by making use of new exercises and new ways of stressing the player, effective organization of the training session allows for better capitalization of the time available for training [4, 5, 6].

Within training sessions, the warm-up phase [7, 8, 9] plays a significant role. In fact, among the phases of the training session that can be used to greater advantage is definitely the warm-up [4, 10]. The warm up is a phase performed before sports performance, whether training or competition, to enable the body to be able to cope with the motor load in the best possible condition and reduce

the risk of injury. The warm-up usually consists of a succession of Research attention toward this important phase has its roots since the early 2000s, when, however, the focus was mainly on the acute effects of warm-up on subsequent performance [11, 12, 13].

Along with this purpose, in recent years, the opportunity to use pre-training warm-ups to introduce injury risk reduction exercises has also emerged [14, 15]. Aerobic exercises aimed at increasing body and muscle temperature followed by joint mobility exercises and ends with sport-specific exercises in preparation for the start of the training session [10].

Thus, the literature has highlighted the effectiveness of these warm-up protocols for injury prevention and has established minimum levels of compliance for them to be effective [15]. These protocols also include drills for the anatomical district of the core as it is considered an element of the kinetic chain of utmost importance for controlling the lumbar stability and technical skills of the soccer player [16, 17].

Some authors recognize core strength as having an influence not only in the coordination and hip control aspects, but especially an influence in lower limb strength [18, 19, 20]. So far, core training has

been organized in specific sessions devoted mainly to this aspect of performance: in these sessions, drills have been aimed at neutral alignment of the lumbar spine [21, 22] to allow optimal load transfer along the different kinetic chains [23, 24, 25].

Generally, these sessions require additional commitment from the players who have to attend them at times other than the technical session and often on an individual basis. In contrast, in organizing the training of young soccer players, it is often not possible to implement the number of sessions or the duration of individual training sessions for school, personal, logistical, etc. reasons so this intervention is often left out.

While evidence emerges in specific core training with elite [26, 27, 28] and professional soccer players [29, 30, 31], an open problem in the literature remains that of evaluating the effectiveness of core training with young soccer players. In fact, among the issues referred to youth sports and soccer in particular is the issue related to the volume and time to be devoted to the weekly sessions offered in the different sports, including soccer [5]. Often the sessions and durations of training sessions do not allow for the solicitation of all functional motor skills for the young soccer player. Therefore, technical staffs prefer to identify priority goals in the training of the young soccer player that are often limited to technical-tactical ones. It is for this reason that in recent years some authors are suggesting to supplement the initial warm up with core stability exercises to optimize the time available and to activate a muscle district that is advantageous for the control of technical skills performed in one-leg support [32, 33, 34].

Therefore, this study aims to verify the effects of a warm up integrated with core stability exercises on motor skills in young soccer players.

Material and methods

Participants

Young soccer players (n=32) whose age, stature and weight were (mean ± ds) 12.45±0.52 years, 1.49±0.05 meters, 44±2.90 kg, respectively, were involved. The sample was randomly assigned in a 1:1 ratio to a one experimental (EG=17) and one control (CG=15). All participants were informed about the purpose of the study and the usefulness of the proposed exercises. Informed consent was acquired from parents, and the study received approval from the Soccer Federation's regional ethics committee (FIGC, n.134/2023) because the procedures were in accordance with the standards set forth in the Declaration of Helsinki.

Procedure

The experimental group performed warm-up integrated with core stability tasks for 6 weeks, with two sessions per week for a total of 12 sessions.

In contrast, the control group followed the usual training schedule based on technical tactical and physical drills.

The integrated warm up program was divided into two interventions: the first was organized in weeks n1, 2 and 3, structuring predominantly static drills (Table 1); the second was introduced in weeks n.4, 5 and 6 involving predominantly dynamic drills (Table 2).

Table 1. Training assigned to each group in weeks 1-3

Group	Week 1	Week 2	Week 3
EG	Warm up with core stability tasks in predominantly static form + technical-tactical training		
CG	Traditional warm up + technical-tactical training		

Table 2. Training assigned to each group in weeks 4-6.

Group	Week 4	Week 5	Week 6
EG	Warm up with core stability tasks in predominantly dynamic form + technical-tactical training		
CG	Traditional warm up + technical-tactical training		

The Table 3 details the exercises scheduled for the 6 weeks of monitored training.

Table 3. Exercises scheduled over the 6 weeks of integrated warm-up.

Core stability exercises in predominantly static form (weeks 1-3)	Core stability exercises in predominantly dynamic form (weeks 4-6)
Plank (static): 3x20 sec	Mountain climber: 3x20 sec
Spiderman plank: 3x20 sec	Plank in pairs: each player perturbed the partner with a touch on the body, 4x15 sec
Side plank in pairs: each player, imitated the upper limb movements performed by the partner, taking care to maintain the correct position: 2x20 sec/side	Plank in pairs: in the plank position, each kicker had to move (toward the partner) the color marker indicated by the strength and conditioning coach: 3x6 reps/side
Reverse plank: 2 x20 sec	Reverse plank in pairs: each player, moved sideways, taking care to maintain correct position, 2 x 20 sec

In total, the warm-up phases lasted about 18 min and included an aerobic phase of running at an

intensity between 50 and 60 percent of maximum heart rate (4-5 min), joint mobility drills (4-5 min), special runs (running drills) and 30-meter progression runs.

In the two sessions prior to the introduction of the integrated warm-up and in the two following the end of the program, assessments were conducted. The tests were presented in random form.

The following assessment tests were presented:

- broad jump, two-leg jump for evaluation of explosive strength (horizontal vector); measurement was performed with metric caster;
- Hop test, for right and left limb, for evaluation of explosive strength of each limb in the sagittal plane; measurement was performed with metric wheel;
- Sidehop test, for right and left limb, for evaluation of explosive strength of each individual limb in the frontal plane; measurement was performed with metric wheel;
- 10-meter sprint, for evaluation of acceleration measured through the photocells, (Globus, Treviso, Italy);
- Eurofit 10x5-meter shuttle test for the assessment of lactic acid anaerobic capacity measured through the photocells (Globus, Treviso, Italy); the young soccer player sprints 10 x 5-meter stretches at the highest possible speed while touching the lines delimiting the 5-meter stretch.

Statistical analysis

Descriptive statistics (mean, standard deviation, confidence interval) were determined for all test data. The Shapiro-Wilk test was first used to determine the normality of the data distribution. Then, to test for within-groups (T0 vs T1) and between groups differences (EG vs CG in T1), the T-test was used, with significance set at $p < 0.05$.

The statistical package SPSS 22.0 for Windows (SPSS Institute, Chicago, IL) was used to analyze all data.

Results

No significant between-group differences were shown at baseline. The results showed an increase in values (pre-intervention, post-intervention) for EG in the standing long jump (135.8±33.1 cm vs 158.7±28.4cm , $p < 0.001$), left limb hop test (114.5 ± 26.1 cm vs 134.2 ± 24.3 cm, $p < 0.001$), in the right limb hop test (116.7±26.9 cm vs 133.7± 24.1 cm, $p < 0.001$), in the left limb side hop test (89.6±11.2 cm vs 105.4±16.6 cm, $p < 0.001$), in the right limb side hop test (88, 1±21.1 cm vs 113.1±18.4 cm, $p < 0.0005$), in the 10 x 5 meter shuttle test (18.44±1.88 sec vs 17.01±1.26 sec, $p < 0.05$) and in the 10 meter sprint (2.31±0.30 sec vs 2.03±0.18 sec, $p < 0.01$).

The CG showed no statistically significant differences when comparing baseline and post values.

In the comparison at T1 between the two groups EG vs. CG, statistically significant differences were observed in the standing long jump ($p < 0.01$), left limb hop test ($p < 0.05$), right limb hop test ($p < 0.05$), left limb side hop test ($p < 0.05$), right limb side hop test ($p < 0.05$), 10x5 meter shuttle test ($p < 0.05$) and 10 meter sprint ($p < 0.01$).

The results obtained in the two groups and the two assessments are summarized in Table 4.

Discussion

The aim of the study was to test the effects of a warm up supplemented with core stability exercises on motor skills in young soccer players.

In the pre-post test comparison in the EG, the results showed statistically significant percentage increases in the long jump from a standing position (+15.5%), left limb hop test (+14.7%), right limb (+12.8%) left limb side hop test (+15.1%), right limb (+22.2%), and in the 10 m sprint (-13.7%) and 10x5 m shuttle (-8.1%) speed tests. It would seem that the introduction of exercises aimed at core activation allowed performance gains in some sport-specific

Table 4. Changes in the EG and CG at T0 and T1. Legend: SLJ, standing long jump; EG, experimental group; CG, control group

Variables	EG (n=17)		p value (T0 vs T1)	CG (n=15)		p value (T0 vs T1)	p value (group)
	Pre	Post		Pre	post		
SLJ (cm)	135.8±33.1	158.7±28.4	0.0004	128.1±7.2	131.36±6.28	0.11	0.008
Hop test left (cm)	114.5 ±26.1	134.2±/24.3	0.0003	114.5±10.3	117.82±8.54	0.14	0.02
Hop test right (cm)	116.7±26.9	133.7±24.1	0.0003	116.7±8.6	117.27±6.75	0.32	0.02
Side test left (cm)	89.6±11.2	105.4±16.6	0.0002	87.4±15.9	92.09± 7.82	0.13	0.03
Side test right (cm)	88.1±21.1	113.1±18.1	0.0003	92.4±16.9	99.1 ±8.6	0.09	0.03
10m. sprint (sec)	2.31±0.30	2.03±0.18	0.007	2.22±0.16	2.19±0.13	0.11	0.005
10 x 5 m shuttle run (sec)	18.44±1.88	17.01±1.26	0.02	18.57±1.14	18.22±0.79	0.21	0.03

gestures. In this regard, the literature points out that jumping performances, with particular reference to those performed on a single limb, as well as sprinting performances, are affected by the control of the trunk and pelvis; in fact, these districts confer stability to the extensor muscles of the lower limb and hip, which are mainly involved in jumping and sprinting performances [17, 23, 25].

When comparing EG and CG in T1, statistically significant differences in favor of EG emerged in the assessments related to long jump from a standing position ($p < 0.01$), right and left hop test ($p < 0.05$), right and left side hop test ($p < 0.05$), 10-meter sprint ($p < 0.01$) and 10 x 5-meter shuttle test ($p < 0.05$).

The CG, which used only sport-specific exercises, showed no statistically significant results at the end of the observed training period in the motor skills assessed.

The results of this study referring to jumping performance return higher percentage increases than similar studies [1, 17] that have described the effects of core training on jumping performance in young soccer players [36, 37] and in young athletes [38]. Probably the observed sample had higher potentials since they had never introduced core stability exercise into their weekly training.

Another explanation may be attributable to the differences in the age of the participants involved in the studies.

The percentage results obtained in this study are also higher than those verified in female futsal soccer players who stressed the core through exercises performed using stable and unstable surfaces [35].

In addition, core activation conditions the ability to stabilize when the individual or athlete is in one-leg landing; this muscle synergy could allow the athlete to better harness the lower limb explosive strength to rely on safer control during ground contact [28, 35, 38].

The results obtained in speed tests are in line with other similar studies that have verified the effects of core training in soccer players [1, 36, 39].

The data obtained from EG at the end of the observation period seems to confirm the effectiveness of core stability exercises on speed and jumping performance [17, 35] as well as indicated in the literature even with different samples [35, 37, 40].

The core district through hip stabilization seems to be an effective support for effectively transferring forces between the athlete and the ground [39, 40].

However, the study has some limitations and did not clarify whether the training age of the participants or the time of the season may have influenced the results.

Moreover, the study that used both static and dynamic core exercises fails to identify which of the two types is more effective.

Further research on the topic may bring new perspectives for practical application by investigating whether (a) different levels of youth sports qualification may return different results or (b) the same results can also be observed in young female soccer players.

Conclusions

The study makes it possible to suggest to technical staffs targeting youth soccer players to introduce core stability exercises in the warm up phase in order to effectively activate the kinetic chains that play the role of stabilizers during the execution of sport-specific skills such as jumps, leaps, in-line sprints and sprints with changes of direction.

The organization of warm ups through integrated motor tasks referable to multiple functional assumptions seems to be adequate (also in duration) to the needs and objectives of youth soccer training sessions. The use of integrated warm ups also allows time to be devoted to the preventive aspects, which, in this way, can be solicited in the activation phase: sometimes, in fact, in youth soccer, the short duration of training sessions undermines the introduction of motor tasks with preventive purposes.

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The effect of plyometric training program on agility, jumping, and speed performance in young soccer players

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Abstract

Background and Study Aim The aim of this study was to examine the effect of a 6-week plyometric training program on agility, vertical jump, squat jump, and speed performance in soccer players.

Material and Methods A total of 26 male soccer players actively playing for Ankara Batıkent Kartal Sports Club participated in the study as volunteers. The players had an average age of 15.04 ± 0.16 years, an average height of 172.48 ± 5.14 cm, and an average body weight of 62.65 ± 0.38 kg. Data on the players' gender, age, body weight (kg), height (cm), body mass index (BMI), agility, vertical jump (cm), squat jump, and 30 m speed were obtained. Statistical analysis was performed using SPSS 25 software. The normality of the data was examined using the Shapiro-Wilk test. Paired samples t-test was used to determine within-group differences, and independent samples t-test was used to determine differences between groups. A statistical significance level of $p < 0.05$ was considered for all evaluations.

Results The plyometric training program was effective in improving agility, vertical jump, squat jump, and speed performance in the experimental group. There was a significant difference in agility and 30 m speed values in the pre-test and post-test evaluations of the Control group, but no difference was observed in vertical jump and squat jump values. Additionally, in the pre-test and post-test comparison between the experimental and control groups, a significant difference was observed in agility, vertical jump, and squat jump values. However, no significant difference was found in 30 m speed values.

Conclusions That plyometric training program is effective in improving agility, vertical jump, squat jump, and 30 m speed values.

Keywords: plyometric training, exercise, strength, performance, soccer

Introduction

Soccer is a highly complex sport discipline involving intermittent and intense loading periods. In contemporary soccer, physiological assessments are increasingly important not only for adults but also for young athletes to achieve optimal performance. Successful performance in soccer relies heavily on fundamental motor skills such as repeated explosive capacity, strength, speed, ball striking ability, as well as additional skills like jumping, turning ability, sprinting, and direction change. All these attributes significantly contribute to enhancing players' performance [1].

Considering the intensive nature of soccer, delivering high-level performance throughout a ninety-minute match can only be achieved through a well-prepared training program that addresses the athlete's physical and physiological needs [2].

Within the scope of soccer, there continues to be debate regarding the extent to which physical components such as speed, agility, and strength – essential attributes of soccer players – can be developed through soccer-specific training.

However, researchers emphasize that plyometric training is one of the training methods that can enhance competition performance along with increasing strength and power components [3].

Plyometrics, a widely used training method among athletes in various sports disciplines, focuses on developing strength and explosiveness [4]. This technique involves the rapid stretching (eccentric movement) of muscles followed immediately by their shortening (concentric movement) [5]. Plyometrics enable athletes to produce more force than would be possible with only concentric movements by utilizing the elastic energy stored in the muscles [6, 7].

The advantages of incorporating plyometric exercises into a periodic strength training program have been repeatedly demonstrated by numerous studies. These benefits include improved proprioception, acceleration, leg strength, muscle power, and jumping performance [8, 9, 10]. These findings highlight the beneficial effects of plyometric exercises when paired with a structured strength training program.

Plyometric exercises typically involve explosive movements that require sudden stops, starts, and changes in direction. These dynamic movements

play a crucial role in developing agility [11, 12, 13]. Agility refers to the ability to rapidly change direction while effectively controlling body position through a series of movements [14]. Agility training aims to strengthen neuromuscular conditioning, adapt muscle spindles, Golgi tendon organs, and joint proprioceptors, enhancing neuromuscular programming [15, 16]. Agility training has the potential to improve overall agility by increasing balance and control of body positions during movement.

This study aims to examine the effects of a 6-week plyometric training program on agility, jumping, and speed parameters – essential elements of the soccer discipline – in young soccer players.

Methods And Materials

Participants

A total of 26 male soccer players actively playing for Ankara Batikent Kartal Sports Club volunteered to participate in the study. The players had an average age of 15.04 ± 0.16 years, an average height of 1.72 ± 0.00 cm, and an average body weight of 62.65 ± 0.38 kg. The athletes were informed about the purpose of the study, and signed informed consents were obtained, in accordance with the requirements of the Declaration of Helsinki for Human Research.

Research Design

The heights of the research group were measured using a stadiometer (Holtain brand), and their body weights were measured using a digital scale (Tanita BC 480). Body Mass Index (BMI) was calculated using the formula:

$$\text{BMI} = \text{body weight (kg)} / \text{height (m)}^2$$

Additionally, participants' speed performances were assessed using the 30-meter sprint test, agility was assessed using the T-test, and vertical jump and squat jump heights were evaluated using the Microgate optojump® system (Microgate, Bolzano, Italy).

Height Measurement. The height of the participating soccer players was measured using a stadiometer (Holtain brand) with a precision of 0.1 cm. To determine height, the stadiometer was positioned at the top of the head after the individual took a deep breath with their head upright and eyes looking straight ahead [17].

Body Weight. The body weights and body fat percentages of the soccer players were measured using a Tanita BC 480 scale while wearing shorts and no shoes.

Body Mass Index (BMI) Calculation. The BMI of the players was calculated using the formula: $\text{body weight (kg)} / \text{height (m)}^2$.

Vertical Jump. The vertical jump test was conducted using two OptoJump devices (Microgate, Italy) placed facing each other. When ready, the

athlete performed a short downward movement followed by jumping upwards with hands on hips and feet fixed on the ground. Any errors such as releasing hands, opening or closing knees or feet during the jump were considered invalid, and the measurement was discarded. The test was repeated twice at 30-second intervals, and the highest jump height was recorded.

Squat Jum. Squat jump tests were conducted using the OptoJump device, which has been validated and found reliable for squat jump tests [18]. Participants were instructed to squat to a 90° angle, pause for 1-2 seconds, and then jump vertically without leaning forward with hands on hips. Bending knees at 90°, separating hands from hips during the jump, or bending knees during flight phase were considered incorrect movements [19].

Sprint Measurement. The 30-meter sprint times of the athletes were measured on the soccer field using photoelectric cells. Each participant performed two rapid sprint tests with a 3-minute rest interval between tests. The best performance between the repeated sprint tests was recorded.

Agility T-Test. The T-Test was conducted on a designated area measuring 10 meters in length and width, forming a T-shape with four contact points. The aim was for the participant to complete a series of movements between these contact points in the shortest time possible. Unlike other agility tests, the participant always faced the same direction and changed direction by shuffling to the right or left or by running backwards. The test required completing two 90° and 180° turns, as well as running forward, right, left, and backward for a total distance of 40 meters.

Training Program. Participants were randomly divided into two groups: experimental (n=13) and control (n=13). The training intervention lasted for 6 weeks, with two sessions per week for the soccer team. While the experimental group followed a plyometric training program, the control group continued with their regular training routine. Pre- and post-training tests were conducted before and after the implementation of the training program. Prior to the test protocols, participants underwent a familiarization session to ensure no issues during the testing. All tests were conducted on a grass field under suitable conditions, at least 48 hours after previous training sessions or matches. Participants were instructed to wear the same athletic gear during testing sessions. Measurements were taken at the same time of day during two testing sessions to minimize the effects of daily fluctuations on selected parameters. Participants were also provided with information regarding nutrition and rest during the training and testing processes to mitigate any factors that could affect the study results. The applied training program is detailed in Table 1.

Statistical Analysis

The SPSS 25 software was utilized for statistical analysis of the collected data. Descriptive statistics, including arithmetic mean and standard deviation, were used to present the data. The Shapiro-Wilk test was employed to assess whether anthropometric and performance parameters followed a normal distribution. It was observed that the data exhibited a normal distribution. Therefore, paired samples t-test was used for data showing normal distribution, while independent samples t-test was used to determine differences between groups. A significance level of $p < 0.05$ was considered for all evaluations.

Upon examination of the table, it can be observed that the experimental and control groups have similar descriptive statistics (tbl. 2).

Results

This section presents the statistical analysis and interpretations of the data obtained from the research group.

Upon examination of Table 3, statistically significant differences are observed in the pre-test and post-test values of agility, 30m sprint, vertical jump, and squat jump for the Experimental group ($p < 0.05$). Based on these findings, it can be concluded that the applied plyometric training is effective in improving agility, 30m sprint, vertical jump, and squat jump.

Upon examination of Table 4, statistically significant differences are observed in the pre-test and post-test values of agility and 30m sprint for the Control group ($p < 0.05$). However, no significant differences are observed in the values of vertical

Table 1. Plyometric Training Program

Week	Training Days	Plyometric Training	Sets	Reps	Rest	Training Duration
1. ve 2. week	96	-Side to Side Hops	2	8	3 min.	35-40 min.
		-Box Jump (15 cm)				
		-Drop Jump				
		-Hurdle Jump (15 cm)				
		-Squat Jump				
3. ve 4. week	144	-Side to Side Hops	2	12	3 min.	35-40 min.
		-Box Jump (20 cm)				
		-Drop Jump				
		-Hurdle Jump (20 cm)				
		-Squat Jump				
5. ve 6. week	180	-Side to Side Hops	3	10	3 min.	35-40 min.
		-Box Jump (30 cm)				
		-Drop Jump				
		-Hurdle Jump (30 cm)				
		-Squat Jump				

Table 2. Descriptive Statistics for the Research Group (n=13)

Group	Variables	Mean	Standard deviation
Experiment	Age (Year)	15.00	0.22
	Body Weight (kg)	62.92	6.51
	Height (cm)	173.23	6.45
	Body Mass Index (BMI)	20.90	0.20
Control	Age (Year)	15.08	0.23
	Body Weight (kg)	62.38	4.59
	Height (cm)	172.54	5.21
	Body Mass Index (BMI)	22.93	0.22

Table 3. Dependent Samples t-Test Results for Pre-test and Post-test Evaluations of the Experimental Group

Variables	Tests	Mean	Sd	t	p-value
Agility (s)	Pre-test	12.28	0.56	3.17	.000*
	Post-test	12.11	0.52		
30m Sprint (s)	Pre-test	5.19	0.05	18.50	.000*
	Post-test	5.16	0.05		
Vertical Jump (cm)	Pre-test	32.61	2.95	-32.18	.000*
	Post-test	35.70	2.73		
Squat Jump (cm)	Pre-test	24.79	1.29	-19.54	.000*
	Post-test	27.24	1.51		

P<0.05*; Sd: Standard deviation

Table 4. Dependent Samples t-Test Results for Pre-test and Post-test Evaluations of the Control Group

Variables	Tests	Mean	Sd	t	p-value
Agility (s)	Pre-test	12.92	1.30	4.60	.043*
	Post-test	12.81	1.23		
30m Sprint (s)	Pre-test	5.20	0.06	2.92	.013*
	Post-test	5.19	0.07		
Vertical Jump (cm)	Pre-test	35.70	2.79	3.68	.159
	Post-test	33.29	2.71		
Squat Jump (cm)	Pre-test	25.77	1.62	-1.62	.131
	Post-test	25.92	1.54		

P<0.05*; Sd: Standard deviation

Table 5. Independent Samples t-Test Results for Pre-test and Post-test Comparisons between the Experimental and Control Groups

Variables	Tests	Experiment		Control		P-value
		Mean	Sd	Mean	Sd	
Agility (s)	Pre-test	12.28	0.56	12.92	1.30	.123
	Post-test	12.92	0.52	12.81	1.23	.047*
30m Sprint (s)	Pre-test	5.19	0.05	5.20	0.06	.568
	Post-test	5.16	0.05	5.19	0.07	.276
Vertical Jump (cm)	Pre-test	31.61	2.95	35.70	2.79	.122
	Post-test	35.70	2.73	33.29	2.71	.034*
Squat Jump (cm)	Pre-test	24.79	1.29	25.77	1.62	.101
	Post-test	27.24	1.51	25.92	1.54	.038*

P<0.05*; Sd: Standard deviation

jump and squat jump ($p>0.05$).

In Table 5, the pre-test and post-test means of agility, 30m sprint, vertical jump, and squat jump for the Experimental and Control groups were compared. Statistical analysis revealed a significant difference in the mean values of agility, vertical jump, and squat jump ($p<0.05$). However, no significant difference was found in the mean values of the 30m sprint test between the Experimental and Control groups ($p>0.05$).

Discussion

The aim of this study was to investigate the effects of a 6-week plyometric training program on agility, vertical jump, squat jump, and speed performance in soccer players. The results indicate that the 6-week plyometric training led to improvements in jumping, speed, and agility performance. This suggests that plyometric training can enhance jumping performance and explosive power.

Vertical jump, a physical attribute crucial for high-level performance, varies in importance

depending on the position in football. Explosive strength, associated with high-level performance, is crucial in sports like football [20]. Researchers have pointed out that these attributes can be improved with plyometric training [21, 22].

Previous studies consistently report significant improvements in vertical jump performance among male and female athletes after plyometric training [23, 24]. The findings of this study support these results, as the plyometric training program resulted in a significant difference in jumping ability between the experimental and control groups.

Plyometric exercises can be performed with or without external loads, and both modalities have been shown to increase strength, jump height, and sprint performance [25, 26].

Many studies in the literature support our findings [27, 28]. The results of this study suggest that plyometric training methods enhance jumping performance more than traditional football training.

Additionally, plyometric exercise has been described as biphasic [29] in the countermovement jump (CMJ) or monophasic in the squat jump (SJ). The plyometric protocol used in this study not only allows for greater power production and neuromuscular adaptation through the stretch-shortening cycle (SSC) but also improves the activation of synergistic muscles and concentric contraction due to the variation and combination of different exercises [30].

Jumping performance assessed through SJ and CMJ tests is improved by the reactive ability of muscles trained in both plyometric and specific training [31].

Plyometric training, which plays an important role in strength and jumping efficiency in football training, positively affects athletes' jumping and explosive power, improving their performance [32].

When examining the physical properties affecting high performance in sports, speed, mobility (flexibility), and coordination can be considered determinants [33]. In this context, when the pre-test and post-test measurement values of the experimental group are examined, statistically significant differences in speed values are observed. It is seen that the post-test measurement values are better when the mean values are compared.

In previous studies, Markovic et al. [34] conducted a study with 93 male students, divided into sprint, plyometric, and control groups. The study found statistically significant increases in values in the sprint and plyometric groups. Similarly, Arslan [35] indicates that combined plyometric applications with other training programs improve sprinting ability. In another study, Agilonu and Kiratlı [36] found a statistically significant difference in the 30m speed values of the experimental group. In a study by Villarreal et al., [37] it was found that plyometric training combined with maximal strength and

heavy resistance training significantly improved sprint and endurance performance. In a study with a sample of basketball players, Bavlı [38] concluded that 6 weeks of plyometric exercises improved vertical jump and 30m speed performance. It can be said that the development in the experimental and control groups, in line with the results obtained, affects the speed property together with plyometric training and football training.

In sports where instant change of direction is necessary, quick force and elastic force performance are determinant characteristics. Athletes require a lot of elastic force when they need to change direction instantly. Plyometric exercises are of great importance in sports to develop the ability to instantly change direction and maintain balance in the game. In this context, when the pre-test and post-test measurement values of the experimental group are examined, statistically significant differences in agility values are observed. It is seen that the post-test measurement values are better when the mean values are compared [39].

In a study investigating the effect of 6 weeks of plyometric training on agility, the t-test found statistically significant differences in agility values between the pre-test and post-test of the experimental group athletes. The control group was not found to be statistically significant [40]. In another study examining the effect of plyometric training on athletes' agility performance, improvement in agility values was observed after 8 weeks of training [41].

Upon reviewing the findings in the discussion section, jumping and speed ability are directly related to leg and hip strength. Various methods have been developed, especially to improve leg strength. Plyometric training is the most commonly used method [42]. When plyometric exercises are performed regularly and correctly, they contribute to performance improvement in sports (e.g. , football, handball, volleyball), where jumping and speed parameters are crucial [43, 44].

Conclusion

The results of this study clearly demonstrate the efficacy of a 6-week plyometric training program in enhancing key athletic performance indicators among young male soccer players. These enhancements are particularly relevant for soccer players, as agility and jumping capabilities are critical for competitive performance, affecting everything from evading opponents to aerial duels. This study affirms the value of incorporating plyometric exercises into the training regimens of young soccer players to enhance their physical capabilities, thereby potentially improving their on-field performance. Coaches and trainers should consider integrating plyometric training into their athletic development programs to exploit its benefits fully.

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Conflict of interest

The authors declare no conflict of interest.

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Functional movement screen score to predict injury risk of sports students: a review of foot shape and body mass index

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Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

Abstract

Background and Study Aim Excessive physical activity poses a risk of injury, particularly when coupled with high exercise intensity. Factors such as Body Mass Index (BMI) and foot morphology may contribute to this risk. This study seeks to evaluate the relationship between BMI, foot shape, and the likelihood of injury among sports students.

Material and Methods A total of 119 sports students, comprising 33 females and 86 males, participated in this study. Purposive sampling was employed to select participants. BMI was determined using height and weight measurements, while foot shape was assessed through footprint measurements. The Functional Movement Screening (FMS) instrument, encompassing 7 movements: Deep Squats, Hurdle Steps, Inline Lunges, Shoulder Mobility, Active Straight Leg Raises, Trunk Stability Push-ups, and Rotary Stability, was utilized to assess injury risk. Data analysis was conducted using Microsoft Excel and IBM SPSS v.25.0, employing descriptive statistics.

Results Based on data analysis, the FMS value in females shows a mean of 18.7 and a standard deviation of 1.21. At the same time, the FMS value in males shows 18.5 and a standard deviation of 1.41. BMI values in females showed a mean of 21.6 and a standard deviation of 3.03. At the same time, BMI values in males showed a mean of 22.9 and a standard deviation of 4.62. The results were that all FMS scores were ≥ 14 . While of BMI measurements, some samples obtained $< 18 \text{ kg/m}^2$ and $> 30 \text{ kg/m}^2$. BMI measurements according to gender were mainly in the normal weight category. However, those who fall into the obesity category are primarily males. With the results of measuring the foot's shape, the percentage of flat feet is only 0.84% in females and 7.59 in males, while the rest of the sample has a normal foot shape.

Conclusions Individuals with a BMI in the overweight to obese category are more susceptible to high-category injuries, likely due to limited motion range. However, the study did not find evidence linking flat foot shape to high-category injury risk. This inability to establish a correlation may be attributed to the predominantly normal foot shape observed in the sample, resulting in a prediction of low-category injury risk.

Keywords: sport injury, FMS, foot shape, BMI

Introduction

The foot is part of the body most often in contact with the ground, which is needed to exert energy when walking, running and jumping. Foot shape consists of several types, such as normal, flat, and high. Flat and high foot shape can be one of the intrinsic factors for the risk of lower extremity injuries [1]. It was revealed that those with a flat foot shape are more susceptible to injuries from abnormal joint rotation. On the other hand, someone who has

a high foot shape has less foot mobility, making them more susceptible to injury. An abnormal foot shape leads to abnormal compensatory movements, thus increasing the risk of musculoskeletal injuries [2]. In addition to this, foot arch geometry and arch mechanics are also associated with the occurrence of injuries [3]. Factors such as age and anatomical features can affect the dynamic shape of the foot. The shape of the foot can also change with the footwear worn, as the heel height of the footwear changes the width of the foot and the arch length of the foot in a nonlinear manner [4]. In addition, Body Mass Index (BMI) also has a significant influence on arch height in foot shape [5].

The fact that BMI can change the shape of the foot has also been revealed in studies that have been conducted, revealing that individuals with more weight can increase the risk of lower extremity injuries [6, 7]. Lower extremity injuries, such as Anterior Cruciate Ligament (ACL) injuries, while ACL injuries require a lengthy healing time so that they can interfere with activities in individual careers [8]. A BMI below normal can also affect balance because it will be difficult to maintain body balance. After all, the body cannot resist external forces [9]. These statements argue that injuries can occur in every individual with fairly dense physical activity. Since sports students must master all sports, each student must have an excellent physical condition to achieve lecture targets.

Physical activity, especially in sports, whether in education or training, will face injury risk [10]. Sports in education have a level of physical activity that exceeds normal activities. Mastering almost all sports is one of the demands of a sports student. So sports students have quite a lot of physical activity, considering that almost every day they do sports activities that are not enough with one sport. When individuals are injured, it can have a significant impact on their daily routine activities and participation [11]. A sports injury is any physical complaint resulting from training or education that can limit an individual's participation [12]. Injury can lead to a lack of confidence when performing sports activities [13]. Individuals who have a history of injury will incur considerable treatment costs, which have an impact on their long-term quality of life. The history of injury experienced by each individual can hinder the improvement of one's abilities, even the achievements one wants. Even though the individual has entered the recovery phase of the injury, the physical activity performed cannot be as optimal as that of someone who has never experienced an injury. Based on the many losses that will occur if an individual is injured, prevention efforts are needed to minimize the occurrence of injuries.

One way to prevent injury is to know the potential risk of injury that is likely to occur in each individual. Functional Movement Screening (FMS) can evaluate the quality of 7 fundamental movement patterns to identify individual movement limitations and asymmetries. The FMS used to identify these limitations and asymmetries can be used to determine the risk of future musculoskeletal injuries [14, 15]. Therefore, it is necessary to conduct research that measures FMS in sports students to identify the risk of injury in each individual. So far, researchers have never found a study that measured FMS in a sample of sports students with a review of foot shape and BMI. Previous studies used FMS measurements with a sample of athletes or only took measurements on one variable.

This study aims to identify the risk of injury that sports students may experience in a review of BMI and the shape of the feet owned by sports students.

Materials and Methods

Participants

This study involved 119 sports student participants consisting of 33 females and 86 males. This study used a purposive sampling technique. The inclusion criteria for sample selection include a) active sports students, b) not currently experiencing injury or injury recovery, c) sports students with an age range of 17 to 20 years, and d) willingness to be a sample from the beginning to the end of the study. At the same time, the exclusion criteria are not sports students who have injuries or are recovering from injuries and are not willing to be research samples from the beginning to the end of the study.

Research Design

This research is a type of quantitative descriptive research. This study aims to determine the risk of injury to sports students by reviewing foot shape and BMI. Researchers use height tests and weight tests to determine BMI. While measuring the shape of the soles of the feet, researchers use *footprint measurement* [16]. FMS is used to obtain potential injury risk data. FMS consists of 7 movements: Deep Squat, Hurdle Step, Inline Lunge, Shoulder Mobility, Active Straight Leg-Raise, Trunk Stability Push-up and Rotary Stability [17, 18].

The data obtained from measurements using the FMS instrument were analyzed and categorized using the assessment norm guidelines applied in previous studies [18, 19, 20] (Table 1).

Table 1. FMS Scoring Norms

Points	Injury Risk Category
≤14	High Risk
15-18	Medium Risk
19-21	Low Risk

The BMI measurement results of each sample will be adjusted to the BMI category. Table 2 shows the BMI categories [21].

Table 2. Categories of BMI

Scores	Categories
15-19.9	Underweight
20-24.9	Normal weight
25-29.9	Overweight
≥30	Obesity

The height and weight measurements were analyzed to calculate the BMI score using the formula: body weight (in kilograms) divided by height squared (in meters). Subsequently, the BMI score was categorized according to the BMI

categories outlined in Table 2. Regarding the foot shape measurements, the data analysis method differs from that used for analyzing the results of FMS and BMI measurements. The results are adjusted based on the shape of each individual's feet and their corresponding foot arch type [22], as illustrated in the following figure.

Figure 1 clearly shows three types of foot arch shapes: flat foot (low arch), normal foot (medium arch), and hollow foot (high arch). The measurement results of the foot shape will be adjusted to Figure 1 above to find out how the foot shape of the research sample.

Statistical Analysis

The data was analyzed using both a computerized Microsoft Excel program and IBM SPSS v.25.0 statistics. Descriptive statistics were employed to analyze the research data.

Results

The results of data analysis are illustrated in Table 3, differentiating between genders: female (n=33) and male (n=86). It presents descriptive statistics of research data (n=119), showcasing

height, weight, BMI score, and FMS score, thereby providing a comprehensive overview of the physical attributes and functional movement capacities of the study participants.

Furthermore, the frequency and percentage of samples analyzed according to the categorization of BMI scores, FMS scores, and foot shapes are presented (Table 4).

Table 4 provides a breakdown of BMI scores for females and males. In females, the majority fell within the Normal weight category, while in males, Normal weight was also prevalent, followed by the Overweight category. Regarding FMS scores, both genders predominantly showed a Low-Risk category. Additionally, the analysis of foot shape revealed that the majority of females and males had a Normal foot shape, with a small percentage exhibiting a Flat foot shape. High foot shape was not observed in any of the samples.

The analysis of foot shape and BMI score was used to review the prediction of injury risk through the FMS score. Table 5 will present the study samples with predicted injury risk levels across different foot shapes and BMI categories.

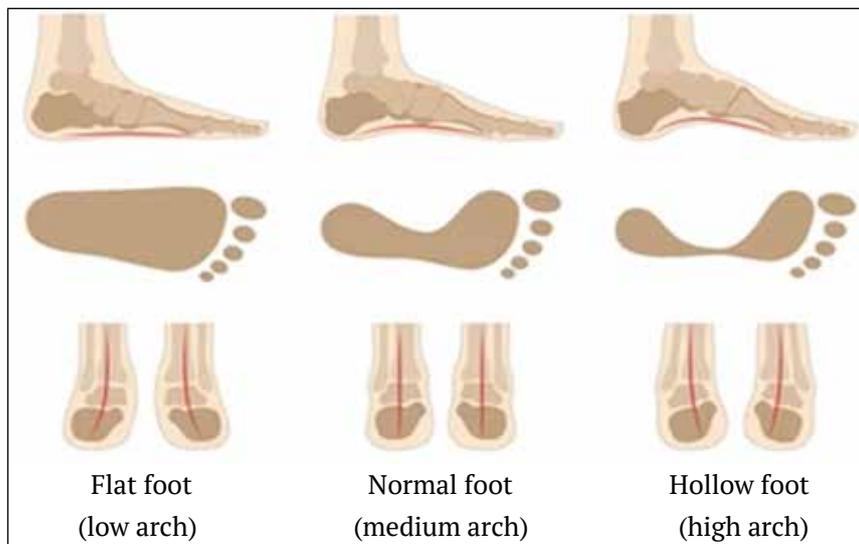


Figure 1. Three types of human foot arches.

Table 3. Descriptive statistics of research data (n=119)

Gender	Number (n)	Variable	Mean ± SD	Min.	Max.
Female	n = 33	Height (cm)	156.9 ± 5.89	148	169
		Weight (kg)	53.6 ± 8.03	41.5	70.5
		BMI (kg/m ²)	21.6 ± 3.03	15.1	29
		FMS (points/21)	18.7 ± 1.21	16	21
Male	n = 86	Height (cm)	167.9 ± 5.38	156.6	179.5
		Weight (kg)	64.0 ± 10.81	47.2	94.8
		BMI (kg/m ²)	22.9 ± 4.62	16.7	50.2
		FMS (points/21)	18.5 ± 1.41	16	21

Note. n = Sample Number, SD = Standard Deviation, Min. = Minimum Value, Max. = Maximum Value

Table 4. Percentage category results of BMI, FMS and foot shape data (n=119)

BMI			
Gender	BMI Categories	Frequency	Percentage (%)
Female (n=33)	Underweight	5	4.20
	Normal weight	24	20.17
	Overweight	4	3.36
	Obesity	0	0.00
Male (n=86)	Underweight	9	7.56
	Normal weight	57	47.90
	overweight	14	11.76
	obesity	6	5.04
FMS			
Gender	FMS Categories	Frequency	Percentage (%)
Female (n=33)	Low Risk	22	18.49
	Medium Risk	11	9.24
	High Risk	0	0.00
Male (n=86)	Low Risk	43	36.13
	Medium Risk	43	36.13
	High Risk	0	0.00
Foot Shape			
Gender	Foot Shape Categories	Frequency	Percentage (%)
Female (n=33)	Normal	32	26.89
	Flat	1	0.84
	High	0	0.00
Male (n=86)	Normal	77	64.71
	Flat	9	7.56
	High	0	0.00

Note. n = Sample Number

Table 5. A review of foot shape and BMI in injury risk prediction (n=119)

FMS Categories			
	High Risk (n)	Low Risk (n)	Medium Risk (n)
Foot Shape			
Flat	0	7	3
Normal	0	58	51
High	0	0	0
BMI Categories			
Underweight	0	7	7
Normal	0	52	29
Overweight	0	4	14
Obesity	0	2	4

Note. n = Sample Number

Table 5 above indicates that samples without gender distinction and low risk of injury consist of 7 individuals with flat feet and 58 individuals with normal foot shapes. Furthermore, individuals with low risk of injury are distributed as follows: 7 in the

underweight BMI category, 52 in the normal weight category, 4 in the overweight category, and 2 in the obesity category.

Additionally, Table 5 demonstrates that samples with a medium risk of injury include 3 individuals

with flat foot shape and 51 individuals with normal foot shape. Moreover, individuals with a medium risk of injury are categorized as follows: 7 in the underweight BMI category, 29 in the normal weight category, 14 in the overweight category, and 4 in the obesity category.

Discussion

This study found that the FMS scores obtained were related to the sample's BMI and foot shape measurements. The average combined FMS score was 18.2 ± 1.36 points. These results indicate that samples with high FMS scores tend to have normal body weight and foot shape. The results of the FMS measurements in this study predicted that the samples had a moderate risk of injury, and there were no samples that had a high predicted risk of injury. Samples who have a moderate risk of injury by having excessive body weight to obesity amounted to 15.12%. At the same time, samples that have a flat foot shape are partly predicted to have a moderate risk of injury and partly have a low risk of injury. The BMI of the sample influences this.

The results above illustrate that samples with BMI $>24.9 \text{ kg/m}^2$ tend to have FMS scores <19 points. Samples with optimal FMS scores have lower injury rates than non-optimal ones [23]. These results align with the results of a study which revealed that people with BMI $>30 \text{ kg/m}^2$ had an average combined FMS score that was 2 points lower than people with BMI $<30 \text{ kg/m}^2$ [24]. A higher BMI was found to be more common in those with limitations in performing daily activities [25]. It was revealed that a dynamic and reciprocal relationship exists between body weight, motor skill competence, and physical fitness [26, 27]. Our results showed that samples with BMI results $>$ normal showed lower FMS movement quality. Research also reveals that samples with higher body weight will produce lower FMS total scores [28]. This opinion also aligns with the results that revealed samples that obtained a total FMS score ≤ 14 points were significantly greater in overweight samples [14]. Individuals with excess BMI will experience limitations in performing movement activities, so individuals with excess BMI will also have difficulty performing a series of FMS movements [29]. Therefore, the FMS score will decrease as BMI increases.

Additionally, the analysis encompassed reviewing the FMS value against the BMI of the sample, along with assessing the shape of the sample's feet. The results of this study show that only a few samples have a flat foot shape, and none even have a high foot shape. The dominant sample has a normal foot shape. The findings of this study, FMS measurements in terms of foot shape, did not show a prominent difference. Samples with a normal foot shape have more predicted levels of low injury risk, but there is not much difference in samples

with a moderate risk of injury. Likewise, samples with flat feet had more low injury risk than those with moderate injury risk. Our results show that the shape of the foot in the sample does not affect the prediction of the risk of injury that the sample has. This can happen if the sample has a level of physical condition and other supporting factors that make the sample have a low risk of injury. According to research that has been conducted, many researchers have revealed that foot arch correlates with lower extremity injuries [30]. Most commonly, flat feet show significant changes in the talocalcaneal joint and talonavicular joint, resulting in an increased risk of injury [31].

According to research [30], it has been shown that flat feet are associated with improper static force distribution, causing the forefoot to have lower pronation in walking than normal feet. Some studies have also found an association between excessive foot pronation and an increased risk of acute injury [32]. Excessive pronation transmitted to internal rotation of the tibia may cause overloading of the knee joint or other changes in the proximal part of the lower extremity. Individuals with low foot arches are thought to have disproportionate foot flexibility, allowing the foot to pronate excessively during the standing phase, such as when running [33]. In addition, it has been found that stress fractures of the metatarsals are more common in feet with flat arches [34]. These phenomena will have consequences such as dysfunction or weakness of the active support of the medial longitudinal arch (MLA), which can lead to injury. Although the results of this study did not find a significant difference between foot shape and injury risk prediction, our study may suggest intrinsic factors, such as the influence of BMI on injury prediction outcomes.

Conclusions

The total FMS score obtained in the review of the foot's shape shows that the dominant sample has a normal foot shape with a low predicted risk of injury. However, those who have a flat foot shape have yet to be proven they will be at risk of high-category injuries. While the results obtained in the review of BMI, it is proven that individuals who have normal BMI have a lower risk of injury compared to individuals who have a BMI in the overweight to obese category. These results may be due to the limitation of movement that results from having a BMI above normal

According to the research results, individuals can improve their lifestyle, especially by maintaining their BMI. The risk of moderate to high-category injuries is mainly experienced by individuals who have a BMI above normal. Meanwhile, individuals with a foot shape other than normal can strive to improve their physical condition and other

supporting factors. This is because, despite having an abnormal foot shape, it does not rule out the possibility that individuals are included in a group with a low predicted risk of injury.

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Use of indices to assess women's health in wellness fitness

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Abstract

Background and Study Aim With increasing focus on women's health and well-being, there's a pressing need for efficient tools to accurately reflect their physical condition and health status. This study aims to substantiate the use of indices as effective instruments for assessing women's health and wellness fitness.

Material and Methods This study involved 40 women, aged 43.33 ± 0.93 years, who participated in a wellness fitness program for 8 months. Sessions were held three times a week, each lasting 1 hour. A comprehensive health improvement program was utilized, incorporating dance aerobics, strength fitness, and stretching exercises. Anthropometric measurements were taken, and the Stange test was administered to calculate 12 health-related indices. The significance of differences was evaluated using the sign criterion (z) and Rosenbaum's Q index. Assessments were conducted both before the initiation and upon completion of the wellness program.

Results Significant changes were observed in several indices, including the Body Mass Index ($z=2$), Erisman Index ($z=0$), Vital Index ($z=0$), Skibinsky Index ($z=1$), Kerdo Autonomic Index ($z=2$), Robinson Index ($z=3$), Waist-to-Hip Ratio ($z=11$), Systolic Blood Pressure Index ($z=5$), Diastolic Blood Pressure Index ($z=4$), and Livy Index ($z=0$). Additionally, a reliable improvement in the left arm strength index was confirmed using Rosenbaum's Index ($Q=7$).

Conclusions The results validate the use of specific indices to evaluate the efficacy of wellness fitness programs. Notable improvements were observed in the Body Mass Index, Erisman Index, and Livy Index, indicative of enhanced physical condition and normalization of body mass, particularly significant among overweight and obese participants. An increase in the strength index reflects augmented hand muscle strength, while enhancements in the vital index signal boosted respiratory system functionality. Furthermore, changes in the Skibinsky Index, Robinson Index, and Kerdo Autonomic Index highlight an elevated adaptation capacity of the cardiorespiratory system. The comprehensive set of indices employed offers insights into the cardiovascular, respiratory, and musculoskeletal systems' state. Their applicability at both individual and group levels, combined with the simplicity of calculations, clarity, and informativeness, markedly improves the monitoring effectiveness of health and fitness status.

Keywords: wellness fitness, women, indices, physical development, cardiorespiratory system, adaptation potential.

Introduction

Ensuring the health of the population is a crucial aspect of the policies of many countries. The study by Cunningham and Ohles [1] highlights the critical importance of maintaining high physical fitness levels in women. It is observed that women often trail behind men in both health and physical fitness, being generally less active and more affected by sedentary lifestyles, especially in middle age [2]. Hypodynamia, or reduced physical activity, significantly increases the risk of obesity and metabolic syndrome, leading to a higher likelihood of chronic non-communicable diseases. Implementing group fitness programs emerges as a

vital health policy strategy and an effective means to positively impact women's health.

In another study [3], the relationship between physical fitness and mortality among women with metabolic syndrome was examined over a follow-up period of 16.6 ± 8.7 years. Wellness fitness programs are advocated to decrease mortality rates and enhance physical fitness in women diagnosed with metabolic syndrome.

A review and meta-analysis conducted by Farrell et al. [4] investigated the impacts of various exercise types on cardiorespiratory performance and muscle strength in postmenopausal women, demonstrating the effectiveness of physical exercise in enhancing these indices. Notably, a positive effect was observed for both aerobic and weight training, whether implemented independently or in combination.

Further research [5, 6, 7] has explored the broad

effects of multimodal wellness fitness programs. These studies report improvements in cognitive functions, correction of metabolic abnormalities, and enhancement of functional indices among elderly women [5]. Incorporating strength and flexibility exercises was found to facilitate body weight normalization [6]. Additionally, another study [7] highlighted the beneficial outcomes of exercises using water motorcycles on the strength and cardiorespiratory capabilities of women.

The effectiveness of a comprehensive health improvement program for women aged 40–53 years was demonstrated in a study by Karatrantou et al. [8]. Conducted over 10 weeks, the program included aerobic dancing alongside flexibility, coordination, and strength exercises utilizing participants' body weight. The results highlighted normalization of physiological indices, enhancement of physical qualities, and improved outcomes in functional tests. These findings are in line with earlier research [9], which also explored the benefits of a holistic fitness program over an 8-month period. Participants in this program engaged in stretching, dance, and strength training exercises, leading to improved morphofunctional indices and reduced fat deposition.

Among various health fitness types, dance fitness has emerged as particularly popular among women [10, 11]. A study by Hellem et al. [11] investigated the impact of such exercises on physical fitness and homeostasis parameters, confirming a normalizing effect on body weight and blood lipid levels.

Pilates exercises have gained popularity among women, with an 8-week program demonstrating improvements in participants' somatotype and fitness levels [12]. Interestingly, these benefits persisted even during a subsequent 3-week period without exercise.

In a different vein, a study by Reppa et al. [13] investigated the impact of high-intensity Tabata interval training on affective, cognitive, and physiological measures among women. Participants were categorized according to their fitness levels, revealing a consistency in their responses to the physical activities undertaken.

The index method has become a staple in sports science due to its simplicity, clarity, and informative value [14, 15, 16]. A comparative analysis utilizing indices to examine the physical development of athletes across various martial arts disciplines elucidated characteristics crucial for success [14]. Furthermore, the efficacy of employing specialized indices for monitoring athletes' functional states has been validated, underscoring the method's utility in sports research.

The application of indices in a comparative analysis of anthropometric measurements among athletes in karate, taekwondo, judo, and kickboxing [15] underscored the utility of several indices,

including the Monourier index, acromial index, Martin index, biacromial index, and hip index, for their informativeness.

Hence, existing literature reinforces the significance of employing indices within the realms of sports and wellness physical culture. Building on this foundation, the objective of our study was to advocate for the use of indices as a methodological approach for evaluating women's health and wellness fitness.

Materials and Methods

Participants

Forty women, aged 43.33 ± 0.93 years, participated in this study. All participants were injury-free at the time of the study. The research protocol was approved by the Ethics Committee of the Kharkiv State Academy of Physical Culture, ensuring adherence to ethical standards. Informed consent was secured from all individuals participating in the study.

Research Design

Over an 8-month period, participants engaged in a wellness fitness regimen three times weekly, with each session lasting one hour. The comprehensive wellness program comprised dance aerobics on Mondays, strength fitness on Wednesdays, and stretching classes on Fridays.

The study's methodology included the assessment of morphofunctional indices both before and after the program, with subsequent calculation of indices derived from these measurements. Adhering to the international standardized methodology for anthropometric studies [17], the following were measured: body length and weight, chest circumference at rest, waist and hip circumferences, grip strength of both the right and left hands, lung vital capacity, blood pressure, and heart rate. Pulse pressure was calculated as the difference between systolic and diastolic blood pressure. Additionally, the breath-holding time in seconds was recorded while performing the Stange test.

Procedure

The study employed a comprehensive set of indices to assess participants' health and fitness levels:

- Body Mass Index (BMI) is calculated as weight (kg) divided by the square of body length (m^2). A BMI within the range of 19–24 kg/m^2 is considered normal.
- The Erisman Index is defined as the difference between the chest circumference (cm) and half of the body length (cm), with a value of at least +3.3 cm deemed normal for women.
- The Strength Index is the ratio of grip strength (kg) to body weight (kg), expressed as a percentage. Normal values range between 30%

- and 50%.
- The Waist-to-Hip Ratio is calculated as the waist circumference (cm) divided by the hip circumference (cm), with values not exceeding 0.75 considered normal.
- The Livy Index is the ratio of chest circumference at rest (cm) to body length (cm), expressed as a percentage, with a normal range of 50-55%.
- The Vital Index is the ratio of lung vital capacity (ml) to body weight (kg), with normal values within 55-60 ml/kg.
- The Skibinsky index (IS) is calculated as follows:

$$IS = (VCL \cdot t) / (HR \cdot 100) \quad (1),$$

where IS – Skibinsky index, LEF – vital capacity of lungs (ml), t – result of Stange test (s), HR – resting heart rate (min^{-1}).

The index is interpreted using the following scale: less than 5 indicates a very poor condition, 5-9 is unsatisfactory, 10-30 is satisfactory, 31-60 is good, and more than 60 signifies an excellent condition.

- The Kerdo autonomic index is calculated as follows:

$$KAI = (1 - DP/HR) \cdot 100 \quad (2),$$

where KAI – Kerdo autonomic index, DP – diastolic arterial pressure (mm Hg), HR – resting heart rate (min^{-1}).

The index was evaluated on the following scale: value not less than 10 – normal state of adaptation, 0-9 – adaptation stress, less than 0 – disadaptation.

- The endurance coefficient was calculated as the ratio of resting heart rate (min^{-1}) to pulse pressure (mm Hg). The dynamics of the index were assessed. Increase in the process of exercise means weakening of functional capabilities of the cardiovascular system, decrease-increase of adaptation potential.
- Robinson's index was is calculated as follows:

$$RI = HR \cdot SP / 100 \quad (3),$$

where RI is Robinson's index, HR is resting heart rate (min^{-1}), and SP is systolic blood pressure (mm Hg).

The index was evaluated on the following scale: less than 69 – excellent, increased reserves of cardiovascular system, 70-84 – good, the state of reserves is normal, 85-94 – average index, possible insufficiency of functional capabilities of cardiovascular system, 95-110 – low level, signs of dysregulation of cardiovascular system activity, 111 and more – very low level, expressed dysregulation of cardiovascular system activity.

- The systolic and diastolic pressure indices were calculated as the ratio of the actual pressure (mm Hg) to the proper pressure (mm Hg) in percent.
- The values of proper blood pressure were found according to the following formulas:

$$PSP = 102 + 0.6 \cdot B \quad (4),$$

$$PDP = 63 + 0.4 \cdot B \quad (5),$$

where PSP – proper systolic blood pressure, PDP – proper diastolic blood pressure, B – age (years).

The index was assessed using the following scale: 85-115% – physiological norm, less than 85% – tendency to hypotension, more than 115% – tendency to hypertension.

Statistical analysis

Statistical analysis of the collected data was conducted using licensed MS Excel software. Given the sample size and distribution characteristics, the median (Me) along with the first (25%) and third (75%) quartiles were calculated to characterize the dataset. The reliability of differences between groups was evaluated using non-parametric sign (z) and Rosenbaum (Q) criteria, with differences deemed significant at $p < 0.05$.

Results

The results obtained are summarised in Table 1.

Table 1's data highlight substantial modifications in most assessed indices. Significant alterations were observed in the Body Mass Index (BMI) with a z-value of 2, Erisman index and vital capacity of lungs index both registering a z-value of 0, Skibinsky index at $z=1$, Kerdo autonomic index at $z=2$, Robinson index at $z=3$, and the waist-to-hip ratio marked significantly at $z=11$. Additionally, changes in the systolic pressure index ($z=5$) and diastolic pressure index ($z=4$) were notable, with the Livy index also recording a z-value of 0. A remarkable shift in the left arm strength index was validated by Rosenbaum's index ($Q=7$). However, no significant differences were detected in the right arm strength index and the endurance coefficient.

Initially, the median Body Mass Index (BMI) of participants was above the normal range. Following the program, this index declined to the upper boundary of the normal range. Prior to initiating the program, the distribution of BMI among participants was as follows: 65% had a BMI above the normal range, 32.5% were within the normal range, and 2.5% fell below the normal range. Upon completing the program, the distribution shifted to 47.5% of participants having a BMI above the normal range, another 47.5% achieving a normal BMI, and 5% registering a BMI below the normal range.

The wellness program led to a noticeable reduction in the median Erisman index. Initially, 90% of the participants had values within the normal range, while 10% were below normal. Post-program, the distribution changed to 82.5% with normal values and 17.5% below normal.

Regarding the right arm strength index, there was a shift in values through the course of the program. Before starting, 60% of the participants had below-normal values, 35% were within the normal range,

Table 1. Dynamics of indices during performance of a comprehensive wellness fitness program by second-maturity women

Index	Start of the program			Finish of the program		
	25%	Me	75%	25%	Me	75%
Body mass index, kg/m ²	23.24	25.47	30.46	21.28	23.98*	27.84
Erismann index, cm	7.00	15.75	22.13	5.75	11.00*	17.13
Right arm strength index (%)	23.81	26.82	33.92	22.02	27.09	34.84
Left arm strength index (%)	28.11	30.84	37.88	27.23	31.70	38.97
Waist-to-hip ratio, abs	0.73	0.79	0.84	0.74	0.80*	0.85
Livy index, %	0.54	0.60	0.63	0.54	0.57*	0.60
Vital capacity of lungs index ml/kg	31.04	36.07	45.52	37.50	43.33*	50.77
The Skibinsky index, c.u.	8.03	9.75	15.59	12.04	15.48*	23.00
Kerdo autonomic index, c.u.	-66.67	-51.39	-38.54	-15.71	-2.94*	3.19
Endurance coefficient, c.u.	1.52	1.80	2.00	1.50	1.70	1.88
Robinson index, c.u.	81.20	87.75	110.10	74.10	80.78*	90.25
Systolic pressure index, %	89.00	92.59	98.26	84.53	89.14*	96.61
Diastolic pressure index, %	90.32	96.15	100.50	85.06	90.44*	97.92

Note. * - differences by the signs criterion are reliable ($p < 0.05$).

and 5% were above normal. After completing the program, 57.5% remained below normal but there was an increase to 42.5% in the normal range, indicating a positive impact of the program on right arm strength.

The left arm strength index demonstrated the following trends: initially, 42.5% of participants were below normal, 50% were within the normal range, and 7.5% were above normal. Post-program, there was a decrease to 37.5% below normal, an increase to 57.5% within the normal range, and a slight decrease to 5% above normal.

The median waist-to-hip ratio remained within the risk zone throughout the program, indicating no significant change. Initially, 35% of participants were at a low risk level, and this figure remained unchanged after the program.

For the Livy index, the median value began above the average range and showed a movement towards normalization after the program. Before the program, 72.5% of participants had an above-average index, which decreased to 57.5% afterward. The percentage of participants with an average index value increased from 22.5% to 37.5%, while the proportion with a below-average index value remained constant at 5%, confirming the effectiveness of the program in influencing this index.

Before the program commenced, the medians of the vital capacity of lungs index were consistently below the normal range and remained so even after the program's conclusion. However, the median value at the end of the program indicated an effort to enhance this index, as evidenced by the index's dynamic structure. Initially, a significant majority (92.5%) of participants had a vital capacity of lungs index below the norm, which decreased to 82.5%

following the program. Concurrently, the proportion of participants with index values within the normal range increased from 7.5% to 17.5%, showcasing a positive shift towards improving the vital capacity of the lungs among the participants.

The most obvious dynamics were observed in the Skibinsky index. The median value of this index before the start of the program was unsatisfactory. The median at the end of the program belonged to the satisfactory assessment interval. The pattern of this index before the program was as follows: 7.5% of participants – very bad, 47.5% – unsatisfactory, and 45% – satisfactory. After the program, there were no participants with a very bad index, 12.5% had index at the unsatisfactory level, 85% had a satisfactory index, and 2.5% had a good index.

The endurance coefficient showed no significant differences in the dynamics of the wellness program. Improvement of functional capabilities according to this index was found in 52.5% of participants, 7.5% had no changes.

The median value of Robinson's index before the program is typical of the average index, and it can be assumed that the functional capabilities of the cardiovascular system are insufficient. After the program, the median decreased to a level that assessed the state of reserves as normal.

The structure of participants according to this index before the program: 7.5% – elevated cardiovascular reserves, 22.5% – state of reserves as normal, 35% – median, 10% – low reserves, 25% – very low reserves. After completion of the program: 17.5% – increased cardiovascular reserves, 42.5% – reserve status normal, 25% – average, 5% – low reserves, 10% – very low reserves.

The median of Kerdo autonomic index before

the program characterises the presence of disadaptation and the predominance of the tone of the parasympathetic nervous system. After the finish of the program, this index reflects a decrease in disadaptation, a transition to adaptation tension as a less dangerous state.

The median systolic pressure index before and after the program was within the normal range. At the end of the program, a decrease in this index was observed. The structure of the participants according to this index before the program was as follows: the tendency to hypotension was found in 12.5%, normal in 82.5%, and hypertension in 5%. After the program: tendency to hypotension in 27.5%, norm in 72.5%, no participants with tendency to hypertension. Similarly, the median diastolic pressure index can be evaluated. The dynamics of the pattern of this index were similar to those of the previous one. Before the program: tendency to hypotension in 17.5%, normal – 75.0%, tendency to hypertension in 7.5%. After the program: 25.0% tended to hypotension, the norm was 75.0%, and no participants had a tendency to hypertension.

Discussion

The application of indices for assessing the physical condition of both professional athletes and fitness enthusiasts is widespread in the realm of sports and wellness. Notably, the efficacy of using a comprehensive set of physical development indices for predicting the performance of athletes across various martial arts disciplines has been examined [14].

A crucial aspect in utilizing these indices effectively lies in their selection based on high informativeness and relevance to the specific sport or fitness activity in question. This approach was employed in evaluating the physical development of kickboxing athletes, demonstrating the utility of such indices in assessing athletes' condition at the early stages of training [18]. The findings underscore the necessity of employing sport-specific indices for a more accurate and informative assessment.

The group of female participants exhibited notable variations in physiological indices and levels of physical fitness, a differentiation commonly acknowledged in scientific research [6, 11, 13]. This distinction underscores the varied emphasis placed on sports and fitness within research domains.

Unlike the competitive and performance-oriented goals inherent in sports, the primary objectives of health and fitness programs are geared towards optimizing physical health, with a significant focus often placed on the normalization of body weight. The success of this health-centric approach is well-documented across numerous studies [9, 11, 19, 20].

The program's multifaceted nature was evident in its impact on key bodily systems, including the

cardiovascular, respiratory, and musculoskeletal systems. This necessitated the utilization of indices capable of reflecting the status of these systems comprehensively. Consequently, the selected battery of indices comprised five indicators of physical development and six markers of cardiorespiratory system condition, providing a holistic assessment framework.

An integrated approach is crucial for accurately assessing the impact of health-enhancing activities. Similar to the methodology [12], where somatometric and physiometric indices, outcomes of functional tests, and somatotype data were utilized to validate the benefits of Pilates classes, our study adopted a comparable strategy. The indices applied in our research offer insights into the nuances of physical development and the health of cardiovascular, respiratory, and musculoskeletal systems.

Incorporating classes with varied orientations within the program significantly boosts its overall efficacy. Each class type targets different bodily systems, aligning with findings from existing literature [4, 5, 6, 7, 8], and underscores the comprehensive impact of such diverse interventions on health improvement.

The essence of health fitness programs lies in their focus on regular and sustained exercise. Opting for an 8-month program duration in this study has demonstrated efficacy in significantly influencing the morphofunctional indices of participants. This observation is in harmony with the results reported by Hong et al. [5], where a holistic 12-week program yielded significant improvements in various health aspects, including psycho-emotional status, bone mineral density, blood lipid levels, limb flexibility, dynamic balance, and endurance.

Moreover, the review by Khalafi et al. [4] underscored the augmented benefits derived from incorporating both strength and cardiovascular exercises into a fitness routine. Such a multifaceted approach was found to considerably enhance muscle strength across different groups and elevate the functional performance of the cardiovascular and respiratory systems.

In their study, Lee et al. [6] explored the impact of cycling and water exercises on women's health, confirming enhancements in cardiorespiratory system functioning and strength indices. Similarly, another investigation [7] evaluated the ABS+FLEX fitness program's efficacy in weight management among women, employing a combination of strength training focused on abdominal and lower back muscles, alongside flexibility exercises. The study reported favorable outcomes from this innovative approach.

Dance fitness, a preferred choice among many women [10, 11], was the subject of research by Wang et al. [11], where the influence of dance-based exercises on body composition, cardiorespiratory

system efficiency, and blood lipid profiles in obese women was analyzed. The participant demographic in Wang et al.'s study [11] closely matched that of our study, making their findings particularly relevant. They reported significant improvements in anthropometric measurements and aerobic capacity, outcomes that resonate with the results of our research. The congruence of findings across these studies reinforces the validity of incorporating dance elements into fitness programs, highlighting their efficacy in promoting women's health.

The body mass index (BMI) is a pivotal metric serving as a benchmark for evaluating nutritional status and physical fitness. Gacek et al. [19] established a direct correlation between BMI and the physical fitness levels of women, noting that individuals of normal weight outperformed their obese counterparts in tests of agility and endurance.

Prior to initiating the wellness program, a significant portion of participants were classified as overweight or obese. The observed BMI dynamics throughout the program underscore its efficacy, showcasing the beneficial impact of regular exercise on body composition. A noteworthy shift was observed as the number of participants categorized as obese or overweight decreased, while those with a BMI within the normal range saw an increase.

Echoing these findings, Horbacz et al. [20] utilized BMI as a metric to evaluate the effectiveness of wellness interventions for women over 60. This comprehensive program, which focused on enhancing aerobic endurance, strength, and dynamic balance, resulted in a notable reduction in BMI values.

These studies collectively affirm the instrumental role of BMI in gauging the success of physical fitness and wellness initiatives, particularly highlighting the positive transformation achievable through consistent exercise regimens.

The observed changes in the Erisman index align with the patterns noted in BMI analysis, with decreases particularly marked among overweight participants. Similarly, adjustments in Livy's index support BMI analysis, indicating a normalization of body weight as reflected by the shift in average values. These trends underscore the wellness program's impact.

This study utilized three indices, including body weight, to gauge the program's effectiveness. Their collective dynamics affirm the positive outcomes of the wellness initiative.

Notably, the strength index (SI) increase serves as evidence of enhanced hand muscle strength, attributable to the strength fitness component of the program. A noteworthy trend is the right-hand SI improvement, demonstrating a shift from lower to normal SI values among participants.

This observation suggests the strength index (SI) might not be as informative for monitoring the

condition of female participants in health fitness programs as it is for athletes in strength sports and street workouts, where its high informativeness has been confirmed [21]. The distinct nature of health fitness necessitates the development of new indices that more accurately reflect strength capabilities, potentially incorporating grip strength measured in pulse mode. Such indices have shown promise in studies assessing the condition of street wrestling athletes [21].

It's noteworthy that the baseline vital index for most female participants was below normal, a trend that persisted even after the program's conclusion. This finding underscores the need for continued exercises specifically aimed at improving the functional state of the respiratory system.

Similar outcomes were seen in the research by Ljubojevic et al. [2], where Zumba Fitness® training's impact on respiratory function and body composition among healthy sedentary women was examined. Vital lung capacity, body mass index, and somatotype components served as markers of the training's effectiveness.

An enhancement in vital capacity indicates improved functionality of the respiratory system. Incorporating dance fitness into a broader wellness program plays a crucial role in boosting the capabilities of the cardiorespiratory system and overall endurance. Consequently, a notable rise in the vital index is a rational expectation.

These hypotheses are supported by the changes observed in the Skibinsky index, which serves as an indicator of the cardiorespiratory system's adaptability. The health improvement program facilitated a noteworthy advancement in this index, evidencing positive shifts in the participants' results. The fitness regimen resulted in the elimination of participants categorized under the very poor index values, and a nearly fourfold decrease in those with unsatisfactory indices. Concurrently, the count of individuals with satisfactory index values saw a twofold increase.

For the evaluation of the cardiovascular system's functional capacity, indices such as the endurance coefficient, Robinson index, Kerdo autonomic index, and the indices for systolic and diastolic blood pressure were employed.

The evolution of the endurance coefficient primarily indicates a trend towards the enhancement of the functional capabilities of the participants throughout the course of the program. However, this index is deemed to be of limited informativeness.

The Robinson index emerged as a definitive measure of the program's success. Notable improvements in this index were observed across the entire participant group. Initially rated at an average level, by the program's conclusion, the Robinson index reached a level indicative of good cardiovascular health. The program effectuated

more than a two-fold increase in the number of participants with high cardiovascular reserves. Simultaneously, the cohort of individuals with normal reserves expanded, while those categorized under low and very low reserve levels saw nearly a 50% reduction post-program.

The dynamics observed underscore an enhancement in myocardial power as a consequence of participating in health fitness activities. The outcomes support the use of the Robinson index as a viable criterion for monitoring the recreational fitness of amateurs.

Prior to the initiation of the program, all participants exhibited negative Kerdo Autonomic Index (KAI) values, indicating a predominance of the parasympathetic nervous system's tone and a state of disadaptation among them. Following the conclusion of the program, there was a noticeable shift in this distribution: the proportion of participants with such negative indices decreased to 52.5%, 30% transitioned into a state of adaptation stress, and 17.5% achieved a normal state of adaptation. This progression in the Kerdo autonomic index is indicative of an increase in the participants' adaptive capabilities.

The comparison of actual blood pressure values with optimal ones aids in forecasting the potential onset of conditions like hypertension and hypotension. Initially, the participants predominantly displayed normal levels, with a small subset showing tendencies towards hypotension (12.5%) and hypertension (5%). Upon concluding the program, a noticeable shift towards hypotension was observed, while tendencies towards hypertension were completely absent. This transition underscores the beneficial impact of regular exercise on the cardiovascular system. Engaging in recreational fitness activities enhances overall bodily health, steering it towards more efficient operation. The observed shift towards hypotension is indicative of this improvement.

The waist-to-hip ratio is advocated as a predictive measure for assessing the risk of metabolic syndrome development, which itself is a precursor to various chronic non-communicable

diseases. This function of the index was validated in our research, revealing a considerably elevated risk level among participants. These findings align with those reported in the study by Farrell et al. [3], where a higher degree of physical fitness was shown to notably diminish mortality risk in women diagnosed with metabolic syndrome. Consequently, monitoring physical fitness and adhering to physical activity recommendations are strongly advised.

The program incorporated stretching exercises targeted at enhancing flexibility. The efficacy of these exercises is typically assessed through the goniometric method or specific exercises. Previous studies, such as [9], have validated the effectiveness of goniometric measures in health and fitness contexts.

The objective of this research was to test and validate indices. However, the absence of specialized indices for assessing flexibility somewhat limits the study's validity. This gap underscores the need for the development and evaluation of indices specifically designed for flexibility assessment.

Conclusions

The findings validate the use of indices for evaluating the impact of health and fitness programs. Improvements in physical condition are indicated by changes in the body mass index, Erisman index, and Livy index, with these indices' dynamics reflecting weight normalization, particularly notable among overweight and obese participants. An increase in the strength index denotes enhanced hand muscle strength, while a rise in the vital index signals augmented respiratory system functionality. Furthermore, changes in the Skibinsky index, Robinson index, and Kerdo autonomic index demonstrate an elevated adaptation capacity of the cardiorespiratory system. The comprehensive set of indices employed permits assessment of cardiovascular, respiratory, and musculoskeletal system states. These indices, applicable both individually and collectively, simplify the monitoring process, enhancing the oversight of health and fitness participants through easy calculations, clear results, and informative insights.

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Psychophysiological states of elite athletes after critical life events

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Abstract

Background and Study Aim Military conflicts are a stress factor that provokes negative changes in the mental state of people. But, how susceptible are athletes to post-traumatic disorders at the level of psychophysiological functions? The purpose is to study the psychophysiological state of the elite athletes after critical life events related to the war in Ukraine.

Material and Methods Twelve elite female fencers, aged 18-23 years and members of the National Team of Ukraine, were examined. Their mental condition was assessed using the Lüscher color test, neurodynamic functions were evaluated with an anticipation test, cognitive characteristics through a decision-making test, and levels of anxiety were also measured. The psychophysiological state of the fencers was studied both before and after six months of the Russian military aggression against Ukraine.

Results The results indicated changes in the mental state of fencers under military conditions. Six months after the onset of the war, elite fencers exhibited signs of mental stress and a decreased resistance to stress. According to the obtained results, during the war, athletes showed a predominance of excitation processes over inhibition processes. The study revealed a deterioration in performance on decision-making tests and a decreased ability to perceive visual information in fencers six months into the war. As a compensatory mechanism for the reduced ability to process visual stimuli under conditions of information overload, a decrease in impulsivity among fencers was observed. Research on anxiety demonstrated that, over the six months of war compared to peacetime, trait anxiety among athletes significantly increased.

Conclusions Significant impacts of military actions on the psychophysiological state of elite athletes have been observed. This deterioration in mental state, along with decreases in neurodynamic and cognitive functions and an increase in personal anxiety levels, calls for the development and implementation of specialized psychological support programs. Such programs should aim to bolster athletes' resilience to stressful situations. The importance of accounting for psychophysiological aspects in the training of athletes within conflict zones is underscored, providing a basis for further research in this field.

Keywords: psychophysiological states, elite athletes, critical life events, fencers, war, Ukraine.

Introduction

In the modern world, numerous crisis points have emerged, characterized by a series of local military conflicts throughout the 20th century and into the first half of the 21st century. The repercussions of these conflicts are complex and often unpredictable, serving as significant stressors that provoke negative changes in individuals' mental states [1]. Among the severe impacts on those who have survived warfare is post-traumatic stress, a consequence of traumatic experiences that can elicit emotions such as fear, anxiety, and distress, potentially leading to avoidance of similar situations in the future [2]. For some individuals exposed to traumatic events, this emotional response can become overwhelming

and may evolve into post-traumatic stress disorder (PTSD) [3]. While most individuals diagnosed with PTSD eventually recover, a minority may develop chronic PTSD one year following the event [4].

One of the most significant crises of the 21st century is Russia's full-scale invasion of Ukraine on February 24, 2022. In terms of the scale of the events unfolding in Europe, this conflict can be compared to the Second World War.

Millions of refugees from the occupied territories have relocated to safer places, while millions more have left Ukraine in search of safety. Despite this, many individuals have chosen to remain in areas close to the front lines. Preliminary studies indicate that over 80% of Ukrainian citizens affected by the conflict develop post-traumatic stress disorder [5]. Recent research on mental disorders has established that mental harm is more likely to occur when traumatic events are experienced repeatedly [6].

Psychogenic shock, resulting from the suddenness of these events, leads to psychotrauma. This condition is further exacerbated by emotional conflict and the loss of future plans.

War constitutes a profound psychotraumatic event with significant effects on individuals' well-being and psychological state [7]. Post-traumatic stress disorder emerges as a primary health concern among those who have endured such experiences. PTSD represents a pathological reaction to traumatic events, including combat, natural disasters, or instances of physical or sexual assault [8].

Causes of PTSD in Ukraine include armed conflicts between states, explosions, arson, and other acts that terrorize the population; severe accidents at strategic facilities; direct experience or witnessing of physical or sexual abuse; shortages of water, food, electricity, and heating; and destruction of homes and cities [9]. Furthermore, the question arises: how susceptible are athletes to post-traumatic disorders at the psychophysiological level? Finding answers to this question is crucial for developing strategies to prevent post-traumatic syndrome among elite athletes.

Purpose: To investigate the psychophysiological state of elite athletes following critical life events associated with the war in Ukraine.

Materials and Methods

Participants

Twelve elite female fencers, aged 18-23 years and members of the National Team of Ukraine, were examined. Following the guidelines of the Biomedical Research Ethics Committees, all participants provided informed consent for the use of the research results for scientific purposes.

Research Design

Our approach was grounded in the understanding that psychophysiological states encompass various properties, including mental, neurodynamic, cognitive, and emotional characteristics. To assess mental properties, we utilized the modified Lüscher color test. Our previous research indicates that the Lüscher color test parameters accurately reflect the current mental state of athletes [10]. From the test results, we determined the following characteristics: mental performance, fatigue, anxiety, deviation from autogenic norms, eccentricity, concentricity, autonomic coefficient, heteronomy, and autonomy.

The neurodynamic functions are crucial for athletes in terms of perception and information processing, requiring a balanced excitation and inhibition within the nervous system for optimal performance. To assess this balance, an anticipation test was employed, yielding parameters such as accuracy, stability, arousal, and arousal tendency. Cognitive abilities were evaluated through a decision-making test, which examines an athlete's

problem-solving skills in response to environmental challenges [11, 12].

The athletes' anxiety levels and emotional stability were diagnosed using the Spielberger State-Trait Anxiety Inventory, assessing both situational and trait anxiety. To explore the impact of psychophysiological states following critical life events related to the Russian military aggression against Ukraine, studies were conducted on elite athletes before the onset of the conflict (December 2021) and six months afterwards (September 2022).

Statistical analysis

For the assessment of individual differences between the study groups, the Statistics 12 software was employed. Nonparametric statistical methods were utilized, focusing on the lower (25th percentile) and upper (75th percentile) quartiles.

Results

The analysis revealed significant changes in the mental state parameters of fencers during wartime, including deviations from autogenic norms, alterations in eccentricity and concentricity, as well as variations in the vegetative coefficient (Table 1). These findings demonstrate a marked impact of the military situation on the mental state of the fencers.

Before the onset of full-scale military aggression, fencers exhibited an average level of autogenic norms. Six months following the commencement of hostilities, a notable increase in the autogenic norm rates was observed. This elevation signifies heightened mental stress and a reduction in the ability to resist stress. Additionally, an increase in concentricity alongside a decrease in eccentricity among the athletes suggests a trend towards mental exhaustion and an inclination towards energy conservation.

A significant rise in the vegetative coefficient was recorded, indicative of a sympathetic tone predominance and neuropsychic stress under military conditions. Therefore, the military context has been identified as a catalyst for mental stress and diminished stress resilience, with an overwhelming sympathetic tone contributing to mental fatigue.

Table 1 demonstrates significant changes in the psychophysiological state of elite fencers during wartime, highlighted by an increase in the rates of deviation from autogenic norms, concentricity, and vegetative coefficient, alongside a decrease in eccentricity. These shifts signify heightened mental stress and reduced stress resilience, underscoring the impact of military conditions on the athletes' mental state.

A study of anticipation among fencers revealed significant differences in arousal values between the pre-war period and six months following the onset of war (Table 2). The findings suggest that during the war, arousal processes in athletes predominated

Table 1. Mental State Variables According to the Luscher Test in Elite Fencers (Median, Lower and Upper Quartiles)

Variables	Before War	Six Months After War
Psychosocial Capacity, conditional unit	11.32 (10.57; 12.28)	11.73 (10.53; 13.84)
Fatigue, conditional unit	2.45 (2.52; 4.74)	2.52 (1.56; 5.53)
Anxiety, conditional unit	1.64 (0.98; 3.52)	1.47 (0.96; 3.65)
Deviation from Autogenously Norms, conditional unit	11.47 (8.64; 13.53)	13.65* (12.14; 14.64)
Eccentricity, conditional unit	10.63 (8.56; 10.83)	8.01* (6.52; 10.73)
Concentricity, conditional unit	6.12 (4.72; 10.62)	8.68* (7.37; 11.63)
Vegetative Coefficient, conditional unit	12.50 (10.42; 15.68)	14.36* (12.79; 18.52)
Heteronomy, conditional unit	7.52 (6.87; 8.12)	7.50 (6.52; 10.76)
Autonomy, conditional unit	8.73 (8.83; 10.38)	8.73 (8.52; 9.78)

*Legend: *p ≤ .05, compared to the pre-war period.

Table 2. Results of Anticipation Test in Elite Fencers (Median, Lower and Upper Quartiles)

Variables	Before War	Six Months After War
Accuracy (Number of Errors)	2.73 (2.44; 3.10)	2.51 (2.14; 2.60)
Stability (%)	3.54 (3.31; 4.46)	3.47 (3.33; 3.82)
Arousal (Conditional Unit)	-0.16 (-0.36; -0.005)	-0.04* (-0.22; 0.001)
Arousal Trend (Conditional Unit)	-82.12 (-132.25; 5.61)	-87.94 (-162.90; 1.50)

*Legend: *p ≤ .05, compared to the pre-war period.

Table 3. Results of Decision-Making Test in Elite Fencers (Median, Lower and Upper Quartiles)

Variables	Before War	Six Months After War
Dynamism, conventional units	64.36 (62.51; 64.96)	59.89* (56.94; 62.42)
Capacity of visual analyzer, conventional units	1.49 (1.43; 1.68)	1.34* (1.33; 1.40)
Decision making time, ms	350.00 (350.00; 410.00)	410.00* (380.00; 440.00)
Impulsiveness, conventional units	-0.23 (-0.30; -0.21)	-0.44* (-0.51; -0.18)

Legend: *p ≤ .05, compared to the pre-war period

over inhibition processes.

Table 2 reveals that the anticipation ability among elite fencers exhibits significant changes during the wartime, particularly in terms of arousal values. A notable shift towards increased arousal and a dominance of arousal processes over inhibition is observed six months post-war, indicating a heightened state of readiness and potentially altered stress response mechanisms in athletes under military conditions.

A study on decision-making abilities reveals this trait as a marker for athletes' capacity to rapidly process information across various complexity levels (Table 3). Results indicate a decline in decision-making test variables among fencers six months post-war. Dynamism, reflecting the swift alternation of excitation and inhibition processes within the nervous system, significantly decreased, highlighting a decline in the development of new technical skills. Similarly, a deterioration in the capacity of the visual analyzer was observed, indicating a reduced ability to perceive visual information after six months of wartime conditions.

The significant deterioration in decision-making

abilities among elite fencers, as indicated in Table 3, suggests a slower processing of information and a decline in psychophysiological functions six months into the wartime period. Notably, an increase in decision-making time and a decrease in dynamism and visual analysis capacity point towards an adaptive response to heightened stress, potentially involving the mobilization of internal resources and the development of mechanisms for stress prevention.

Research into the anxiety levels among elite fencers indicates that situational anxiety has remained stable over six months of war, compared to peacetime conditions (Table 4). However, there has been a significant increase in trait anxiety among these athletes during the same period. These results suggest an elevated sense of danger, uncertainty, and anticipation of negative outcomes, processes that are accompanied by the depletion of internal resources, potentially culminating in mental exhaustion and disorders.

Situational anxiety reflects the immediate reaction to external threats and is expected to rise amidst military dangers [13,14]. However, the

Table 4. Results of Anxiety Test in Elite Fencers (Median, Lower and Upper Quartiles)

Variables	Before War	Six Months After War
Situational Anxiety, conventional units	20.53 (16.27; 22.63)	19.00 (15.00; 21.00)
Trait Anxiety, conventional units	34.26 (23.63; 42.26)	50.50* (40.00; 56.00)

Legend: * $p \leq .05$, compared to the pre-war period

stability of situational anxiety levels among elite fencers over the duration of the conflict suggests a high level of stress resilience within this group. In contrast, the increase in trait anxiety underscores the profound psychological impact prolonged exposure to war conditions has on athletes. Trait anxiety represents a more enduring predisposition to perceive situations as threatening.

Discussion

The contemporary global landscape is marked by numerous military conflicts involving various countries. The military aggression by Russia against Ukraine stands out due to its extensive scale, involving a significant number of individuals and resulting in considerable destruction and loss of life [15]. In the wake of these events, over ten million Ukrainian citizens have been compelled to flee the country in search of safety. The continued military actions induce a pervasive sense of fear for one's life, alongside anxiety and mental health disorders among those affected by the conflict [16].

Despite the ongoing conflict, Ukrainian athletes continue to participate in national and international competitions. However, the pervasive military situation in Ukraine challenges these athletes' true readiness for competition. This study aimed to examine the psychophysiological state of elite athletes in the aftermath of critical military events, specifically focusing on those associated with Russian military aggression against Ukraine. To achieve this, we assessed the psychophysiological state post-critical life events in a group of 12 elite fencers, analyzing key components such as mental, neurodynamic, cognitive, and emotional characteristics.

Our research identified significant alterations in the psychophysiological state of fencers exposed to a military environment. Notably, an elevation in the deviation from autogenic norms among fencers, observed six months into the military aggression, suggests an increased stress level and diminished stress resilience. These findings align with those of other scholars who have documented heightened levels of anxiety, depression, and stress among the Ukrainian population due to the ongoing conflict [17, 18].

The stress induced by the ongoing war has led to increased tension within the autonomic nervous system and mental fatigue among elite fencers, indicative of chronic war-related stress [19]. As a compensatory mechanism to avoid overstrain under

military conditions, a tendency to conserve mental energy has been observed in these athletes.

Neurodynamic assessments conducted six months after the onset of the war reveal a predominance of excitation processes in the nervous system among elite fencers, aligning with the identified chronic military stress. Furthermore, cognitive evaluations have uncovered a decline in the athletes' capabilities for visual perception and information processing.

Furthermore, six months into the war, a notable slowdown in the decision-making process was observed among fencers. This decrement in cognitive function is a recognized consequence of war-induced stress and post-traumatic disorders [13, 20]. Our findings corroborate that wartime conditions adversely affect the cognitive performance of elite athletes. This impact is particularly pronounced in the diminished capacity for developing new technical skills and processing visual information among elite fencers.

To counteract cognitive decline, elite fencers demonstrate reduced impulsivity during wartime, serving as a compensatory mechanism to conserve mental energy. This aligns with their subjective inclination to preserve cognitive resources. Comparable findings are supported by existing literature [21].

An examination of anxiety levels among elite fencers in a military setting showed no alterations in situational anxiety but revealed a noteworthy rise in trait anxiety. This finding underscores the notable stress resilience of elite fencers. The heightened trait anxiety observed in elite athletes is linked to the prevalence of post-traumatic disorders related to war [22, 23].

The results suggest an enhancement in the mental mechanisms of stress resilience among elite fencers, which serves to mitigate adverse outcomes and fosters the development of psychophysiological adaptive mechanisms in response to military conditions.

Conclusions

The findings revealed that six months into the war, elite fencers experienced heightened mental stress and diminished stress resilience. Additionally, in athletes, excitation processes overshadowed inhibition processes, leading to a decline in cognitive performance, as evidenced by poorer results in decision-making tests and reduced visual information processing abilities. Concurrently,

there was a notable increase in trait anxiety among the athletes.

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Conflict of interest

The authors declare that there is no conflict of interest.

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Influence of dancesport on segmental coordination development in 6-8-year-old children

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Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

Abstract

Background and Study Aim Dancesport significantly contributes to segmental coordination development in 6-8-year-old children through rhythmic movements and interaction with dance partner. The study aimed to investigate the impact of dancesport on segmental coordination development in children aged 6 to 8.

Material and Methods The study involved a group of 14 children aged 6 to 8 from the National Children's Palace in Bucharest. Research was conducted from February to June 2023. Segmental coordination assessment for upper limbs was done using Witty SEM, with 16 impulses of the smart semaphores (Lap L1-16) at 4 difficulty levels. Parameters measured: visual reaction time for each Lap (seconds), Lap mean (seconds), and total time (seconds). During the study period, a program with dancesport elements (Standard and Latino styles) was implemented for 36 hours, 2 hours per week. Comparative analysis between difficulty levels was done using ANOVA test, Single Factor Analysis of Variance, and Paired Comparison for Means. Statistical significance was set at $p < 0.05$.

Results Comparative analysis between difficulty levels in the initial and final tests reveals an increase in Lap mean from L1-2 (24.5%) in the final test to L2-3 (53.8%) and L3-4 (24.6%) in the initial test. Comparing the average results of difficulty levels between tests, a decrease in visual reaction time by 0.04 seconds at L1, an increase by 0.03 seconds at L2, a decrease by 0.08 seconds at L3, and a decrease by 0.19 seconds at L4 were observed. Comparative analysis results of segmental coordination between tests at each difficulty level show significant differences of 5.6% ($p < 0.05$) and 22.2% ($p < 0.01$). Negative differences, indicating better performance between tests, are also observed at L1 by 33.3%, at L2 by 55.5%, at L3 by 38.9%, and at L4 by 27.8%.

Conclusions The study results reveal a significant increase in difficulty level among 6-8-year-old children, emphasizing the positive influence of dancesport elements on segmental coordination development. Comparative analysis of visual segmental reaction across different difficulty levels highlighted significant differences. Superior performances observed at lower difficulty levels comparing initial with final tests indicate an improvement in segmental coordination abilities.

Keywords: difficulty level, visual reaction, comparative analysis, performance

Introduction

Dance has been proposed as a means to elevate physical activity levels among youth. However, the physiological attributes of youth dance classes, particularly in terms of achieving moderate to vigorous physical activity levels during sessions, remain underexplored [1, 2]. Engaging in dancesport

activities offers manifold advantages for the psychomotor development of children aged 6-8 years. These advantages encompass improvements in motor coordination through intricate and synchronized movements, betterment of balance and posture via specific exercises, and enhanced flexibility and joint mobility. Additionally, dancesport fosters cognitive skill development by requiring the memorization and synchronization of movements with music [3, 4, 5, 6]. Beyond physical and cognitive benefits, dancesport encourages

social interaction through group or team-based activities, facilitating avenues for communication and collaboration. These elements significantly contribute to children's holistic development, bolstering their physical, cognitive, and social capabilities [7].

Numerous studies have demonstrated that children aged 5 to 12 possess the potential to develop artistic-sports motor skills, particularly in areas related to general coordination and balance [8, 9]. As children grow, the interaction between experience and maturation significantly influences the development of their musculoskeletal and neuromotor systems. This interaction facilitates the enhancement of motor skills with age. While the development of movement coordination skills is commonly associated with chronological age, it is recognized that these skills are age-related but not strictly age-determined [10]. The development of segmental coordination in children aged 6-8 years is a critical component of their early physical and cognitive development. Segmental coordination involves the ability to control and synchronize movements of various body parts to execute precise and efficient motor actions. This capability is crucial not only for their engagement in sports activities but also for their overall performance in daily activities.

As children grow, they experience changes in body size, shape, and gross motor coordination (GMC). Furthermore, GMC is anticipated to correlate with variations in body size, physical activity levels, and fitness in children [11]. Dancesport, in particular, stands out as a discipline with a significant impact on the development of segmental coordination among children in this age bracket. It encompasses rhythmic and coordinated movements of the entire body, demanding precision and synchronization. Additionally, the process of learning and practicing dancesport — through the repetition and refinement of complex movement sequences — prominently supports the enhancement of motor skills and coordination during this critical period of development [12].

Key elements of dancesport, such as music, choreography, and interaction with dance partners, serve as facilitating factors that positively influence segmental coordination in children [13, 14]. Dancesport commonly requires the coordinated use of upper and lower limbs in a manner that is both synchronized and collaborative. Engaging in such activities can substantially bolster motor control and segmental coordination.

Purpose of the Study: The aim of this study was to investigate and assess the impact of dancesport activities on the development of segmental coordination among children aged 6 to 8 years.

Materials and Methods

Participants

The study engaged 14 children, ages 6 to 8, all of whom were enrolled at the National Children's Palace in Bucharest. Prior to the commencement of the research, parental consent was obtained and documented, adhering to the ethical guidelines set forth in the Declaration of Helsinki. The research protocol received approval from the Ethics Committee of the Doctoral School of Physical Education and Sport Science (ID: 09/17.11.2024), at the National University of Science and Technology Politehnica Bucharest, University Center Pitești, Romania.

Research Design

The research was conducted from February 2023, starting with the initial testing, through to June 2023, concluding with the final testing. Throughout this period, the children attended two classes per week, accumulating approximately 36 hours of participation in total. The assessment of segmental coordination for the upper limbs utilized the Witty SEM device (Microgate SRL, Bolzano - Italy), which features 16 impulses from smart semaphores (Lap L1-16) across four levels of difficulty. These semaphores were arranged in a linear fashion, side by side, at a height of one meter.

Each participant was required to respond to 16 visual stimuli emitted by the semaphores, tailored to four distinct difficulty levels. The visual reaction time for segmental coordination was recorded in seconds, providing precise measurements for analysis.

The content of the tools used:

1) The curriculum for the standard dance category, including the slow waltz, Viennese waltz, and tango, comprises:

- Education in rhythm and movement coordination aligned with the music's rhythm.
 - Slow Waltz: Introduction to the dance style, music appreciation, and learning the basic steps.
 - Practicing choreography in the Slow Waltz with a partner.
 - Viennese Waltz: Introduction to the dance style, music appreciation, and learning the basic steps.
 - Practicing choreography in the Viennese Waltz with a partner.
 - Quick Step: Introduction to the dance style, music appreciation, and learning the basic steps.
 - Integrating all three learned dance styles (Slow Waltz, Viennese Waltz, Quick Step) through practice.
 - Presentation of a mini dancesport show.
- 2) Latin Dance Style (Cha-Cha, Samba, Jive):
- Music and Movement: "Dance with Me!" introduction to the joy and rhythm of Latin

- dance.
- Cha-Cha: Introduction to the dance style, including music appreciation and learning the basic steps.
 - Performance of a Cha-Cha choreography with a partner.
 - Samba: Acclimatization to the dance style, music listening, and mastering basic step execution.
 - Jive: Getting familiar with the dance style through music appreciation and learning of basic steps.
 - Practice Session: Rehearsing all learned dance steps and choreographies in preparation for the end-of-year school celebration.
 - Final Show: “The Best Dancers” presentation, showcasing the students’ progress and achievements in Latin dance.

Statistical Analysis

The statistical analysis was performed using KyPlot version 6.0 software (©1997-2020, KyensLab Inc). This involved the calculation of the mean, standard deviation (SD), and other pertinent indicators. To compare segmental coordination variables across different difficulty levels, an Analysis of Variance (ANOVA) test, specifically a Single Factor Analysis of Variance (Completely Randomized Design), and Bartlett’s Test for Homogeneity of Variances were employed. Additionally, a Paired Comparison for Means was utilized to contrast variables across difficulty levels between tests. The threshold for statistical significance was established at $p < 0.05$.

Results

To assess the impact of dancesport elements on the development of segmental coordination in children aged 6 to 8, a comparative analysis was conducted across different difficulty levels and among their respective tests. The findings for the examined variables are detailed in Tables 1, 2, and 3, along with Figure 1.

The initial testing results for segmental coordination in children aged 6 to 8, as detailed in Table 1, demonstrate a progressive increase in mean Lap times across difficulty levels. Specifically, there was an increase of 0.17 seconds (22.2%) from Level (L) 1 to L2, an increase of 0.64 seconds (53.8%) from L2 to L3, and an increase of 0.45 seconds (24.6%) from L3 to L4. Additionally, the total time taken escalated by 2.88 seconds (17.7%) between L1 and L2, by 10.12 seconds (52.8%) between L2 and L3, and by 7.19 seconds (24.5%) between L3 and L4.

When examining the variability in performance, indicated by the range between the minimum and maximum Lap times at each difficulty level, a notable variation is observed. At L1, the range is 0.43 seconds (between Lap11 and Lap13), at L2 it narrows to 0.32 seconds (between Lap4 and Lap15),

expands to 0.66 seconds at L3 (between Lap5 and Lap14), and further widens to 1.01 seconds at L4 (between Lap6 and Lap12).

In the comparison of Lap means across difficulty levels, conducted using ANOVA - Single Factor Analysis of Variance (Completely Randomized Design), significant differences were noted: 50% of these differences were significant at $p < 0.05$, and another 50% were highly significant at $p < 0.001$, according to Bartlett’s Test for Homogeneity of Variance. Additionally, a striking 94.4% of differences were highly significant at $p < 0.001$, with the remaining 5.6% significant at $p < 0.01$ (specifically noted in Lap13). These notable differences between difficulty levels in the initial testing underscore the escalating challenge of the segmental coordination tasks faced by children aged 6 to 8.

The final testing results for segmental coordination among children aged 6 to 8, as depicted in Table 2, indicate an increase in the average Lap time of 0.24 seconds between Levels (L) 1 and 2 (24.5%), 0.53 seconds between L2 and L3 (43.4%), and 0.34 seconds between L3 and L4 (19.4%). Additionally, the total time taken rose by 3.78 seconds between L1 and L2 (23.9%), 8.47 seconds between L2 and L3 (43.3%), and 5.46 seconds between L3 and L4 (19.5%). When examining the range between the minimum and maximum Lap times at each difficulty level, variations are noted as follows: 0.24 seconds at L1 (between Lap4 and Lap14), 0.41 seconds at L2 (between Lap8 and Lap15), 0.49 seconds at L3 (between Lap7 and Lap3), and 1.00 seconds at L4 (between Lap1 and Lap8).

In the comparison of average Lap times across difficulty levels using the ANOVA test, significant differences were identified: 22.2% at $p < 0.05$, 11.1% at $p < 0.01$, and a notable 50% at $p < 0.001$ according to Bartlett’s Test for Homogeneity of Variance. Additionally, 94.4% of differences were highly significant at $p < 0.001$, with 5.6% not reaching statistical significance ($p > 0.05$, specifically noted in Lap3). These significant variations in Lap times underscore the increasing challenge presented by the different levels at final testing and reflect the positive impact of dancesport elements on segmental coordination development in children aged 6 to 8.

The influence of dancesport elements on the development of segmental coordination in children aged 6 to 8 is depicted in Figure 1. Specifically, the comparison of average difficulty levels between tests revealed changes in visual reaction times: a reduction of 0.04 seconds at Level (L) 1, an increase of 0.03 seconds at L2, a reduction of 0.08 seconds at L3, and a significant decrease of 0.19 seconds at L4. These variations, particularly the reductions in visual reaction time, suggest an enhancement in segmental coordination among children in this age group, attributable to the engagement with dancesport elements.

Table 1. Segmental coordination results and differences between difficulty levels at initial testing for 6-8-year-old children (n=14)

Variables, sec	Mean±SD				Single Factor Analysis of Variance	
	Level 1	Level 2	Level 3	Level 4	t; P-value	F; P -value
Lap L1	1.00±0.47	1.27±0.56	1.73±0.82	2.27±0.99	8.52; 0.036*	7.95; 0.0001***
Lap L2	0.95±0.29	1.05±0.29	1.80±0.92	1.91±0.55	22.75; 0.0001***	10.49; 0.0001***
Lap L3	0.99±0.26	1.19±0.42	1.84±0.95	2.46±0.52	21.34; 0.0001***	17.54; 0.0001***
Lap L4	0.94±0.28	1.05±0.27	1.66±0.49	1.92±0.54	9.60; 0.022*	18.21; 0.0001***
Lap L5	1.01±0.36	1.10±0.34	1.51±0.49	2.29±1.38	36.72; 0.0001***	7.93; 0.0002***
Lap L6	0.98±0.31	1.13±0.44	1.95±0.72	1.71±0.62	9.75; 0.021*	10.00; 0.0001***
Lap L7	0.99±0.50	1.31±0.33	2.05±1.37	2.34±0.77	26.86; 0.0001***	7.85; 0.0001***
Lap L8	0.95±0.51	1.12±0.25	1.68±0.50	2.12±0.72	12.47; 0.006*	14.81; 0.0001***
Lap L9	1.03±0.48	1.18±0.34	1.72±0.57	2.15±0.79	8.74; 0.033*	11.36; 0.0001***
Lap L10	1.05±0.35	1.34±0.55	1.74±0.51	2.69±1.68	38.67; 0.0001***	8.24; 0.0001***
Lap L11	0.90±0.33	1.26±0.33	1.68±0.53	2.42±0.74	11.86; 0.008*	5.98; 0.0001***
Lap L12	1.08±0.19	1.12±0.32	2.11±0.98	2.72±1.03	38.88; 0.0001***	16.51; 0.0001***
Lap L13	1.33±0.63	1.30±0.30	2.05±1.17	2.04±0.46	23.89; 0.0001***	4.79; 0.005**
Lap L14	1.04±0.39	1.18±0.39	2.17±0.63	2.91±1.19	22.15; 0.0001***	20.44; 0.0001***
Lap L15	1.03±0.36	1.37±0.43	1.91±0.66	2.22±0.82	10.44; 0.015*	11.22; 0.0001***
Lap L16	1.01±0.35	1.19±0.49	1.69±0.35	2.27±0.72	9.19; 0.027*	17.68; 0.0001***
Mean Laps	1.02±0.09	1.19±0.10	1.83±0.19	2.28±0.32	28.21; 0.0001***	138.6; 0.0001***
Time	16.29±3.54	19.17±3.13	29.29±6.63	36.48±6.54	10.99; 0.012*	44.38; 0.0001***

Note. Lap L1-16 - impulses of the smart semaphores; Single Factor Analysis of Variance (Completely Randomized Design); t Test statistic - Bartlett's Test for Homogeneity of Variance; F – ANOVA test, df = 3; * - p<0.05; ** - p<0.01; ***- p<0.001

Table 2. Segmental coordination results and differences between difficulty levels at final testing for 6-8-year-old children (n=14)

Variables, sec	Mean±SD				Single Factor Analysis of Variance	
	Level 1	Level 2	Level 3	Level 4	t; P-value	F; P -value
Lap L1	1.03±0.27	1.13±0.25	1.60±0.32	1.54±0.35	1.93; 0.587	6.51; 0.0008***
Lap L2	0.93±0.25	1.16±0.39	1.61±0.58	2.19±1.09	28.37; 0.0001***	9.62; 0.0001***
Lap L3	0.98±0.38	1.19±0.35	2.03; 1.26	1.76±0.69	21.19; 0.0001***	2.31; 0.087
Lap L4	0.89±0.19	1.19±0.28	1.67±0.52	1.87±0.78	26.54; 0.0001***	11.38; 0.0001***
Lap L5	1.05±0.49	1.21±0.30	1.67±0.50	1.92±0.71	8.18; 0.042*	8.26; 0.0001***
Lap L6	0.97±0.32	1.24±0.58	1.56±0.48	1.96±0.78	9.29; 0.026*	7.82; 0.0002***
Lap L7	0.94±0.34	1.15±0.31	1.54±0.35	2.13±0.85	20.32; 0.0001***	14.45; 0.0001***
Lap L8	1.02±0.26	1.03±0.24	1.89±0.72	2.54; 1.12	37.49; 0.0001***	15.95; 0.0001***
Lap L9	0.89±0.28	1.43±0.66	1.85±0.68	2.05±0.71	10.86; 0.012*	9.75; 0.0001***
Lap L10	0.94±0.29	1.19±0.32	1.86±0.95	2.53±1.10	30.30; 0.0001***	12.32; 0.0001***
Lap L11	0.92±0.32	1.20±0.37	1.66±0.52	2.15±0.74	10.71; 0.013*	15.27; 0.0001***
Lap L12	0.99±0.26	1.29±0.47	1.80±0.51	2.23±0.76	12.89; 0.004**	14.49; 0.0001***
Lap L13	1.06±0.30	1.31±0.40	1.97±0.90	2.07±0.27	22.46; 0.0001***	6.60; 0.0007***
Lap L14	1.13±0.30	1.25±0.36	1.75±0.53	2.13±0.84	15.49; 0.0014**	9.92; 0.0001***
Lap L15	1.01±0.32	1.44±0.44	1.78±0.52	2.35±1.01	18.69; 0.0003***	11.17; 0.0001***
Lap L16	1.03±0.44	1.14±0.34	1.79±0.66	2.09±0.65	7.07; 0.069	12.64; 0.0001***
Mean Laps	0.98±0.07	1.22±0.11	1.75±0.14	2.09±0.26	27.21; 0.0001***	155.4; 0.0001***
Time	15.79±3.55	19.57±4.02	28.04±5.66	33.50±6.89	6.92; 0.074	33.30; 0.0001***

Note. Lap L1-16 - impulses of the smart semaphores; Single Factor Analysis of Variance (Completely Randomized Design); t- Test statistic - Bartlett's Test for Homogeneity of Variance; F – ANOVA test; df = 3; * - p<0.05; ** - p<0.01; ***- p<0.001

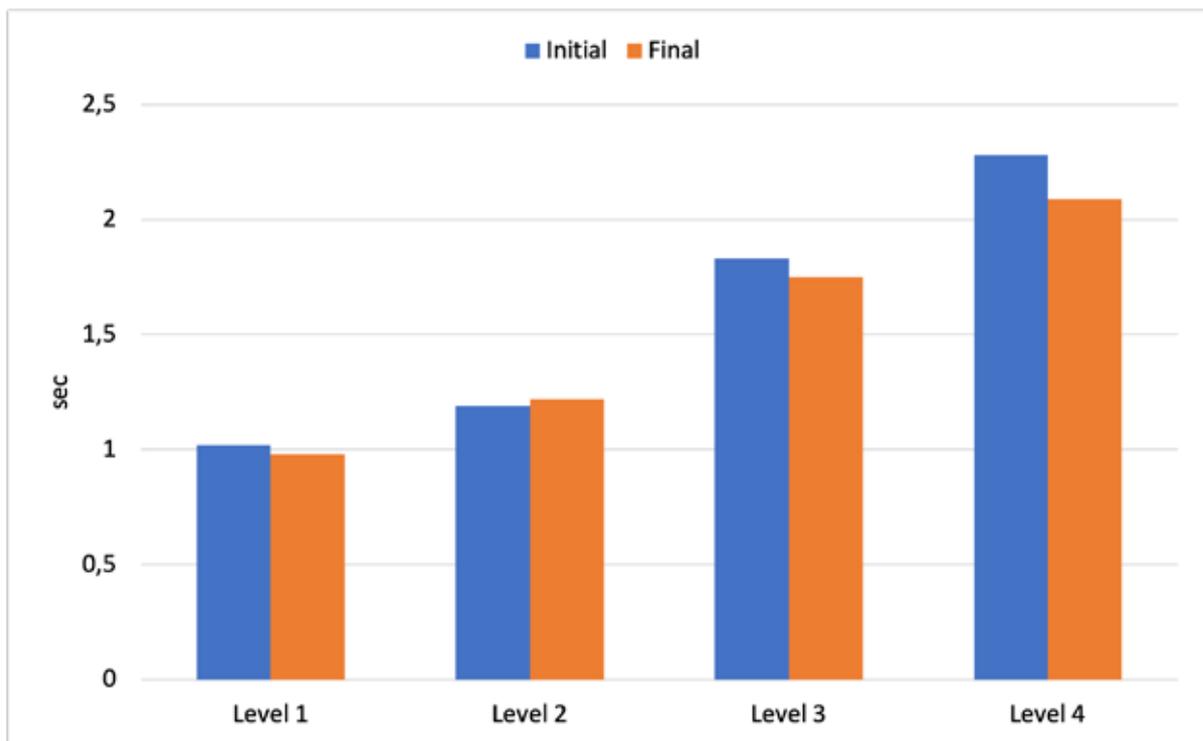


Figure 1. Average difficulty levels of segmental coordination in 6-8-year-old children

Table 3. Results indicating the significance of differences in segmental coordination between tests at each difficulty level (n=14)

Variables, sec	Paired Comparison for Means, n=14 (t-Test; P-value)			
	Level 1	Level 2	Level 3	Level 4
Lap L1	-0.26±0.79	0.88±0.39	0.52±0.61	2.73±0.017*
Lap L2	0.41±0.69	-1.18±0.26	0.69±0.49	-0.86±0.408
Lap L3	0.04±0.96	0.004±0.99	-0.47±0.64	3.98±0.0016**
Lap L4	0.74±0.47	-1.98±0.07	-0.08±0.94	0.41±0.69
Lap L5	-0.24±0.81	-1.62±0.13	-0.79±0.44	0.99±0.33
Lap L6	0.04±0.97	-0.81±0.43	2.97±0.011*	-1.01±0.33
Lap L7	0.48±0.63	1.55±0.14	1.39±0.18	1.15±0.27
Lap L8	-0.64±0.53	1.19±0.25	-1.35±0.19	-1.18±0.26
Lap L9	1.47±0.16	-1.31±0.21	-0.53±0.60	0.46±0.65
Lap L10	1.80±0.09	1.06±0.31	-0.55±0.59	0.41±0.69
Lap L11	-0.16±0.87	0.42±0.68	0.10±0.92	1.51±0.16
Lap L12	1.08±0.29	-1.99±0.07	1.37±0.19	1.69±0.11
Lap L13	1.78±0.09	-0.08±0.93	0.25±0.81	-0.10±0.92
Lap L14	-0.72±0.48	-0.70±0.49	2.04±0.06	2.42±0.03*
Lap L15	0.19±0.85	-0.51±0.62	0.63±0.54	-0.38±0.71
Lap L16	-0.15±0.88	0.31±0.76	-0.59±0.56	0.72±0.48
Time	1.23±0.24	-0.64±0.53	1.26±0.23	3.33±0.005**

Note. Lap L1-16 - impulses of the smart semaphores; * - p<0.05; ** - p<0.01

In the comparative analysis of segmental coordination between initial and final tests across each difficulty level for children aged 6 to 8, as detailed in Table 3, notable significant differences were observed: 5.6% at Level (L) 3 with a p-value less than 0.05, and 22.2% at L4 with a p-value less than 0.01. Furthermore, improvements in performance, indicated by negative differences, were recorded between the tests across all levels: 33.3% improvement at L1, 55.5% at L2, 38.9% at L3, and 27.8% at L4.

Discussion

The study aimed to investigate and assess the impact of dancesport elements on the development of segmental coordination in children aged 6 to 8 years. The examination of segmental coordination and the differences between difficulty levels at both initial and final testing (Tables 1 and 2) revealed an increase in mean Lap times between Levels 1 and 2 (24.5%) during the final testing, and between Levels 2 and 3 (53.8%) and Levels 3 and 4 (24.6%) during the initial testing. Similarly, the total time taken showed increases between Levels 1 and 2 (23.9%) at the final testing, and between Levels 2 and 3 (52.8%) and Levels 3 and 4 (24.5%) at the initial testing. These significant differences in Lap means underscore an elevation in the difficulty of the levels examined at the final testing and illustrate the effect of dancesport elements on segmental coordination in 6-8-year-old children. The analysis of the results, as depicted in Figure 1, further emphasizes the positive influence of dancesport elements on the development of segmental coordination in this age group.

When comparing the average difficulty levels between tests, changes in visual reaction time were noted: a reduction of 0.04 seconds at Level (L) 1, an increase of 0.03 seconds at L2, a reduction of 0.08 seconds at L3, and a significant reduction of 0.19 seconds at L4. These reductions in visual reaction time among children aged 6 to 8 years suggest an enhancement in segmental coordination, attributable to the engagement with dancesport elements. Regarding the comparative analysis of segmental coordination between tests for each difficulty level in children aged 6 to 8 (Table 3), significant differences were observed: 5.6% at $p < 0.05$ and 22.2% at $p < 0.01$. Moreover, improvements in performance, as indicated by negative differences, were seen between tests, with a 33.3% improvement at L1, 55.5% at L2, 38.9% at L3, and 27.8% at L4. These findings underscore the beneficial impact of dancesport on the development of segmental coordination in young children.

Numerous studies underscore the critical role of psychomotricity in children's development, emphasizing the integration of physical movement with mental processes. An evaluation of psychomotor

development and cognitive-adaptive functions in relation to sports activities among primary school students demonstrated a pronounced correlation between engagement in sports and advancements in both psychomotor and cognitive development [15, 16]. Such an integrated approach is deemed essential in early education, fostering holistic growth across motor skills, cognitive functions, and socio-affective dimensions. Psychomotricity promotes the comprehensive development of various psychomotor domains, including gross and fine motor coordination, laterality, balance, spatial and temporal orientation, rhythm, and body schema [5, 17, 18]. Reflecting the importance of these skills, the Italian national guidelines for the primary school curriculum, issued in 2012, place a significant emphasis on motor skills development. These guidelines mandate achieving specific goals in balance and motor coordination as critical objectives for students by the end of their primary education [19].

The relationship between the quality of dance performance and coordination as a motor skill was evaluated using five different measurement tools. The data revealed statistically significant correlations between dance performance quality and levels of motor coordination [20]. Furthermore, a study aimed to demonstrate the impact of educational dance on children's motor development compared the motor skills of children engaged in educational dance with those who did not participate in dance activities, based on assessments conducted over a 6-8 month period [21]. Experts have emphasized the critical importance of developing coordination skills at an early age, particularly in selecting 6-7-year-old children for advanced stages of sports training and rehabilitation. It was found that enhancing balance skills during this pivotal developmental stage lays the groundwork for the acquisition of future motor skills and competencies [22].

An analysis of segmental coordination and postural control during complex multi-joint dance movements, such as the 'développé arabesque,' illustrates the profound effects of prolonged practice on the intricate coordination of limbs and posture. The study identified essential motor control parameters necessary for managing sequential movements of the trunk and extremities [23]. Considering that children who are slim and physically fit exhibit higher levels of coordination, physical education programs should prioritize enhancing physical fitness. Key focus areas include muscle strength, speed, agility, aerobic capacity, and nutritional education aimed at reducing fat mass [24]. To explore the development of various coordination components in children, aspects such as general coordination, rhythm, balance, and spatial-temporal orientation were examined. Specific tests designed for these components were

administered, accompanied by initial and final assessments to gauge progress [25].

Dance holds a pivotal role in cultivating a well-rounded educational experience for young children, serving as a critical component of early childhood arts education [26]. A comprehensive study delved into the mental state and neurodynamic and cognitive traits of young dancers, categorizing them by their proficiency in choreographic skills. The findings suggest a strong correlation between success in dance and various cognitive attributes, including attention, speed of visual perception, and levels of operative and logical thinking. Notably, the study identified that in the realm of dancesport, the most crucial cognitive trait is the verbal domain of information perception and processing [13].

Proprioceptive training within dancesport is generally acknowledged to positively impact agility skills enhancement. Consequently, this form of training is recommended for incorporation into regular dance classes, owing to its potential to significantly improve agility [27]. Similarly, engaging in recreational physical activities also plays a crucial role in fostering the development of key skills that facilitate effective performance in both daily tasks and sports activities. The effects of contemporary dance as a recreational activity on static balance and attention levels were specifically investigated in girls aged 6 to 9. Results indicated that participating in this training twice a week over a period of six months could positively affect attention span and postural control [28].

The studies outlined above underscore the critical roles that psychomotricity and physical activities, including dance, play in the holistic development of children. These activities impact far beyond mere motor skills, extending to cognitive and socio-affective dimensions. The implementation of educational programs and interventions that incorporate these elements could have a significant and positive effect on children's overall development. Furthermore, such approaches could contribute to the nurturing of mentally and physically healthy, well-balanced adults.

Conclusions

The results show a notable increase in average lap times across difficulty levels L1-2, L2-3, and

L3-4 during the final testing phase. This progression underscores the improvement in performance among 6-8-year-old children throughout the testing period, indicating that the children were capable of engaging with and surmounting higher levels of difficulty by the time of the final testing.

Further analysis of the results underscores the beneficial impact of dancesport elements on the development of segmental coordination in children aged 6 to 8 years. A comparative analysis of the average difficulty levels between tests reveals a significant enhancement in visual reaction times. This observed improvement affirms that participation in dancesport practices can play a crucial role in advancing segmental coordination skills within this age group.

A comparative analysis of segmental visual reaction times between tests across each difficulty level highlighted significant distinctions between levels L3 and L4. This variation underscores that different difficulty levels can notably affect children's segmental coordination performance. Recognizing these disparities is crucial for the development and customization of training programs.

Furthermore, an improvement in performance, as indicated by negative differences, was noted at the lower difficulty levels (L1 and L2) between the initial and final tests. These findings suggest that over the course of the testing period, children managed to enhance their performance at these foundational levels. Such progress is likely attributed to the consolidation and refinement of basic segmental coordination skills.

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Conflict of interest

There are no conflicts of interest to declare.

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The contribution of plyometric exercises assisted by sensory technology on vertical jump parameters in U15 female volleyball players

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Abstract

Background and Study Aim Volleyball requires high vertical jump skills for crucial actions like attacking and blocking, making jump training a focus for players, especially in youth categories. The main goal of the study was to highlight (with some specific data) the strengths and weaknesses of integrating sensory technology into the physical training program, during the entire competitive period.

Material and Methods The study included both an experimental and a control group, each consisting of 16 female athletes from the volleyball section of the Cetate Sports High School in Deva. During the competitive season of 2022/2023, both groups underwent daily training sessions from Monday to Saturday, totaling 120 minutes per day. The BlazePod Flash Reflex Training system was employed in this research. It integrates cognitive training to enhance thinking speed and clarity with physical exercises aimed at maximizing motor skills. Performance evaluations of the athletes utilized eight predefined tests from the OptoJump Next optical measuring system and the Myotest accelerometric system. To analyze the data, paired (dependent) sample t-tests were conducted to compare average parameters between matched samples. Repeated measures ANOVA was utilized to compare the average outcomes, ensuring the participants were consistent across the evaluated conditions.

Results The experimental group showed significant improvements in the height reached from the center of gravity and flight time for the following tests: Countermovement Jump, Countermovement Jump with Arm Swing, Squat Jump, Squat Jump with Arm Swing, and Drop Jump from 30 cm. All improvements reached statistical significance: $p < 0.05$. Significant enhancements were also observed in average jump height, jump power, force of jumps, and ascensional speed, demonstrating statistical significance ($p < 0.05$). Furthermore, the use of an arm swing during jumps notably improved performance compared to when jumps were performed with hands on hips. This indicates that an arm swing can significantly increase the height of the vertical jump ($p < 0.05$).

Conclusions The study confirms that the integration of sensory technology into the training programs for junior volleyball teams is effective in enhancing training outcomes. This approach not only improves the vertical jump capabilities of young athletes but also positively affects their ability to perform technical moves that require elevation from the ground. It underscores the potential of innovative training methods in advancing athletic performance in youth sports.

Keywords: volleyball, plyometrics, sensory technology, vertical jump

Introduction

Volleyball, a dynamic and complex sport, is rooted in natural human movements and carries significant instructional and educational values. Its popularity has surged globally, especially among younger athletes, marking it as one of the world's most favored sports [1]. With its explosive growth, the sport presents unique challenges and opportunities for athletic development.

The success in volleyball is heavily dependent on the athlete's physical capabilities, particularly in performing vertical jumps that are crucial for executing key actions like attacking, setting, serving, and blocking [2, 3]. These skills highlight

the importance of specialized physical training within the sport's competitive framework [4, 5]. This emphasis on athleticism bridges to the sport's physiological demands.

Traditionally considered a high-power, predominantly anaerobic activity, volleyball requires athletes to engage in intense bursts of activity with short recovery periods between points [6,7,8]. This structure of play necessitates a comprehensive physical conditioning program that balances both aerobic and anaerobic capacities for sustained performance [9, 10]. The integration of such conditioning within training regimens poses a challenge yet is critical for reaching peak performance levels.

While the significance of physical training in

enhancing athletic performance is universally acknowledged [11], achieving excellence in volleyball is particularly challenging due to the need for a harmonious blend of physical training with other training components [12]. However, there is often a gap in applying a scientific basis to physical training, especially at the youth level, which can limit athletes' potential [13]. Addressing this gap requires a detailed understanding of the sport's demands and the strategic application of training methodologies.

Against this backdrop, the introduction of sensory technology into volleyball training presents a promising avenue for enhancing physical training outcomes. The study by Vuorinen [14] systematically incorporates sensory technology into the training regimen to explore its potential in optimizing vertical jump performance and related skills. This approach not only aims to elevate the athletes' physical capabilities but also integrates innovative training methods that support their overall development in the sport.

This strategic incorporation is expected to significantly improve vertical jump capabilities and the performance of skills requiring ground detachment, thereby illustrating the tangible benefits of incorporating advanced sensory technologies into sports training.

The main goal of the study was to highlight (with some specific data) the strengths and weaknesses of integrating sensory technology into the physical training program, during the entire competitive period.

Materials and Methods

Participants

The study involved two groups: an experimental group and a control group, each consisting of 16 female athletes from the volleyball section of Cetate Sports High School in Deva. The composition of each group was evenly divided between athletes: 8 athletes were 15 years old (born in 2009), and the other 8 were 14 years old (born in 2010). Detailed characteristics of the athletes are provided in Table 1.

Prior to the commencement of the study, informed consent was obtained from the parents of all participating athletes. Additionally, the study protocol was thoroughly reviewed and approved by the Ethics Committee of the University.

Research Design

During the competitive season of 2022/2023, both the experimental and control groups engaged in daily training sessions from Monday to Saturday, each lasting 120 minutes. The evaluation of the athletes involved eight predefined tests. These assessments were facilitated by two distinct systems: the optical measuring system, OptoJump Next (Table 2), and the accelerometric system, Myotest (Table 3).

Additionally, the study utilized the BlazePod Flash Reflex Training system. This innovative equipment combines cognitive exercises aimed at enhancing mental processing speed with physical training activities designed to maximize motor skills (Table 4).

Table 1. Characteristics of the athletes.

Characteristics	EG		CG	
	14.11.2022	15.05.2023	14.11.2022	15.05.2023
Height (cm)	1.67 ± 0.04	1.69 ± 0.05	1.68 ± 0.03	1.70 ± 0.03
Weight (kg)	53.68 ± 3.15	55.12 ± 3.22	54.87 ± 3.11	55.93 ± 2.88

Values are expressed as means ± standard deviations. EG = experimental group, CG = control group.

Table 2. Tests performed with the Optojump optical measurement system.

Test	Purpose	Measured parameters
Countermovement jump with arm swing (CMJAS)	Evaluation of explosive force of lower limbs	Flight time (FT), height reached from center of gravity (JH)
Squat jump with arm swing (SJAS)	Evaluation of explosive force of lower limbs	Flight time (FT), height reached from center of gravity (JH)
Successive vertical jumps for 10 seconds (10 s)	Analysis of anaerobic power	Average: contact time (AVCT), flight time (AVFT), height of jumps (AVJH), power of each jump (AVP)
Countermovement jump (CMJ)	Evaluation of explosive force of lower limbs	Flight time (FT), height reached from center of gravity (JH)
Squat jump (SJ)	Evaluation of explosive force of lower limbs	Flight time (FT), height reached from center of gravity (JH)
Drop jump 30 cm (DJ30)	Evaluation of explosive force of lower limbs	Contact time (CT), flight time (FT), height reached from center of gravity (JH), power of each jump (P)

During the competitive season of 2022/2023, both the experimental and control groups engaged in daily training sessions from Monday to Saturday, each lasting 120 minutes. The athletes were evaluated using eight predefined tests, facilitated by two distinct systems: the optical measuring system, OptoJump Next (Table 2), and the accelerometric system, Myotest (Table 3).

Additionally, the BlazePod Flash Reflex Training system was utilized in this study. This cutting-edge equipment merges cognitive exercises, designed to enhance mental processing speed, with physical training activities aimed at optimizing motor skills (Table 4).

Throughout the competition period, from November 2022 to May 2023, physical training sessions were conducted weekly from Monday to Thursday. Exercises targeting the development of muscles in the lower and upper limbs, shoulders, chest, and back were exclusively performed using elastic cords/tubes. Both groups participated in the same exercises for the duration of the study.

Blazepod: Plyo Box

Placement of Light Capsules: Three light capsules are positioned atop three plyometric boxes of different heights: 20 cm, 30 cm, and 40 cm. These boxes are aligned in a straight line.

Table 3. Tests performed with the Myotest accelerometric system.

Test	Purpose	Measured parameters
3 consecutive countermovement jumps (My-CMJ)	Evaluation of explosive force of lower limbs	Average: jump height (AVJH), jump power (AVP), force of jumps (AVF), ascensional speed (AVS)
3 consecutive squat jumps (My-SJ)	Evaluation of static dynamic explosiveness of the lower limbs	Average: jump height (AVJH), jump power (AVP), force of jumps (AVF), ascensional speed (AVS) Maximum power (PMAX)

Table 4. Intervention program.

Day	Type of training	Training content EG	Training content CG
Monday	Aerobic	Blazepod: Run pacer drill 6 min/km	Run at 2/4 tempo around the hall or the length of it for 6 minutes
Tuesday	Anaerobic	1. Blazepod cognitive agility - 2 rep.	1. 6 x 15/18 m (Intensity 100%)
		2. Blazepod speed trap - 2 rep.	2. 6 x 10/12 m
		3. Blazepod speed competition - 2 rep.	3. 6 x 5/8 m
	Plyometric	1. Blazepod: Plyo box - 1 set	1. Plyo box jumps (30 cm) x 10 rep.
		2. Blazepod: Lateral jumps over hurdles + 3-step spike approach - 1 set	2. Lateral jumps over hurdles + 3-step spike approach x 6 rep.
		3. Blazepod: Lateral hurdle jumps - 1 set	3. Lateral hurdle jumps 45 s
		4. Blazepod: Block jumps with added steps- 1 set	4. Side step block jumps 30 s
		5. Blazepod: Plyo codes - 1 set	5. Plyo jumps 30 s
Wednesday	Aerobic	Blazepod: Run pacer drill 6 min/km	Run at 2/4 tempo around the hall or the length of it for 6 minutes
Thursday	Anaerobic	1. Blazepod cognitive agility 2 rep.	1. 6 x 15/18 m (Intensity 100%)
		2. Agility star 2 rep.	2. 6 x 10/12 m
		3. Blazepod speed box 2 rep.	3. 6 x 5/8 m
	Plyometric	1. Blazepod: Plyo box - 1 set	1. Plyo box jumps (30 cm) x 10 rep.
		2. Blazepod: Lateral jumps over hurdles + 3-step spike approach - 1 set	2. Lateral jumps over hurdles + 3-step spike approach x 6 rep.
		3. Blazepod: Lateral hurdle jumps - 1 set	3. Lateral hurdle jumps 45 s
		4. Blazepod: Block jumps with crossed steps - 1 set	4. Cross step block jumps 30 s
		5. Blazepod: Plyo codes - 1 set	5. Plyo jumps 30 s

Distance: There is a 1-meter gap between each of the plyometric boxes to ensure adequate space for movement.

Starting Position: Participants begin standing one meter behind the middle plyometric box. They are required to observe and react to the capsule that illuminates.

Exercise Structure: Upon illumination of a light capsule on a box, the participant swiftly moves to the indicated box and performs a jump onto it with an arm swing. After landing on the box, they jump back down to the ground and prepare to react to the next capsule lighting up, thus continuing the jumping sequence. Movement between the boxes involves either added steps or cross steps to maintain agility and coordination.

Accessories Required: Three plyometric boxes are utilized in this exercise setup.

Duration: The exercise consists of making 10 contacts with the luminous capsules, with participants responding to the lights by performing jumps onto the corresponding boxes.

Blazepod: Lateral jumps over hurdles + 3-step spike approach

Placement of Light Capsules: Two small hurdles, each 15 cm in height, are positioned in a straight line on the ground. Light capsules are placed at the end of this line.

Distance: There is a 1-meter gap between the hurdles and the capsules.

Starting Position: Participants begin the exercise standing midway between the hurdles and the capsules.

Exercise Structure: Participants execute a lateral jump from a two-footed stance over the hurdle towards the end where the light capsule illuminates. They then return to the starting position by performing a lateral jump from two feet. After completing 3 jumps over the hurdles and returning to the starting position, the subject performs a 3-step spike approach toward the net, concluding with a landing on mats or a plyometric box.

Duration: Participants are required to perform 6 complete jumping cycles. There is a 20-second rest period between each cycle to allow for recovery.

Accessories Required: Two hurdles, each 15 centimeters in height, are used in this exercise.

Blazepod: Lateral Hurdle Jumps

Placement of Light Capsules: Five hurdles, each 25 centimeters high, are aligned in a row on the ground. Four light capsules are positioned between these hurdles.

Distance: There is a 50-centimeter gap between each of the hurdles. The light capsules are situated 50 centimeters in front of the line of hurdles.

Starting Position: Participants start the exercise positioned equidistantly between two hurdles, facing the direction of the light capsules.

Exercise Structure: Upon the activation of a light capsule, the participant executes lateral jumps over the hurdles towards the illuminated capsule. Upon reaching it, the participant touches the capsule, then visually locates the next lighting capsule and repeats the jumping process towards it, continuing until the end of the activity sequence.

Duration: Each touch triggers a change in capsule color, with the total duration of the activity set at 45 seconds.

Accessories Required: Five hurdles, each 25 centimeters in height, are used for this exercise.

Blazepod: Plyo Codes

Placement of Light Capsules: Four light capsules are positioned on the ground in a single row.

Distance: A 20 cm gap is maintained between each of the light capsules.

Starting Position: Participants begin the exercise standing 2 meters behind the row of light capsules, centrally within a square delineated by 15 cm hurdles.

Exercise Structure: Upon the illumination of a capsule, the participant undertakes the exercise designated for that specific color, continuing with that activity until the next capsule lights up. The designated exercises are as follows:

- First Color:** The participant executes two-legged jumps forwards or backwards over the hurdle located at the front or back of the square.
- Second Color:** The participant performs lateral two-legged jumps to the left or right, going over the hurdle on the respective side.
- Third Color:** Engaging in bouncing movements on two legs, akin to a ball, within the center of the square.

Duration: Capsule color changes occur every 4-6 seconds, with the overall activity lasting for 30 seconds.

Blazepod: Block Jumps with Side or Cross Step

Placement of Light Capsules: Two light capsules are positioned at an elevated level.

Distance: The capsules are affixed to the volleyball net, set at a height tailored to the athlete performing the exercise, ranging from 2.24 to 2.60 meters. They are spaced 3 to 4 meters apart.

Starting Position: Participants start positioned equidistantly between the two capsules, standing wide apart.

Exercise Structure: Upon the activation of one capsule, the participant advances towards it using side steps or cross steps, makes contact with the capsule, and then lands securely on both feet. Following the landing, the participant awaits the lighting of the opposite capsule before moving towards it, again utilizing side steps, cross steps, or huddled steps for movement.

Duration: The exercise is performed continuously for 30 seconds, focusing on the dynamic transition

between capsules.

Statistical Analysis

Statistical processing of the research data was carried out using IBM SPSS Statistics for Windows, Version 26.0 (IBM Corp., Armonk, NY). Continuous variables were expressed as mean values and standard deviations, while categorical variables were presented in terms of absolute frequencies and percentages. Paired (dependent) sample t-tests were employed to compare mean values between paired samples. For comparing the means across groups, where participants remained the same in each group, repeated measures ANOVA was utilized. To assess mean differences according to dichotomous variables within the study, the t-test for independent samples was applied. A p-value of less than 0.05 was considered to indicate statistical significance.

Results

In the Countermovement Jump (CMJ), the experimental group showed an increase in Jump Height (JH) of 27.37% ($p < 0.05$) and Flight Time (FT) of 12.92% ($p < 0.05$). The control group also exhibited an upward trend in both parameters: a 24.1% increase in JH and an 11.26% rise in FT (Table 5).

Significant improvements were observed in the Countermovement Jump with Arm Swing (CMJAS) during the experimental program. The average JH increased by 28.25% ($p < 0.05$), and the FT by 13.7% ($p < 0.05$). Similarly, the control group demonstrated notable advancements in this test; FT increased from an average of 0.444 seconds to 0.496 seconds, marking a 12.73% increase in the final test compared to the initial one. An approximate 25% increase in the average JH was observed in the control group during the competitive period of the annual training plan.

For the Squat Jump (SJ), specific training proved crucial, leading to an increase in Jump Height (JH) of 25.18% ($p < 0.05$) in the experimental group and 21.77% in the control group. The Flight Time (FT) improvements were approximately half of those observed for JH: 11.86% ($p < 0.05$) in the experimental group and 10.72% in the control group.

The Squat Jump with Arm Swing (SJAS) yielded similar outcomes to the previous test. Specifically, JH and FT increased by 29.43% ($p < 0.05$) and 13.79% in the experimental group, respectively, and by 25.26% ($p < 0.05$) and 11.85% in the control group.

Employing an arm swing enabled the athletes to perform significantly better than in similar tests conducted with hands on hips. These results suggest that the use of an arm swing can contribute to an approximate 4% increase ($p < 0.05$) in the height of the vertical jump, as opposed to jumps executed with the subject's hands on their hips (Table 6, Table 7).

The Drop Jump from 30 cm (DJ30) report included four parameters: jump height (JH), flight time (FT), power (P in W/kg), and contact time (CT

in seconds). In the DJ30, the experimental group exhibited an average increase in JH of 26.44% ($p < 0.05$), while the control group showed a slightly lower improvement, at 8.23% less than the DJ30 results. FT enhancements were observed at about 11.65% ($p < 0.05$) for the experimental group and approximately 9% for the control group. Notably, power (P) measured during the DJ30 increased by 44% in both groups. Additionally, the experimental group demonstrated a significant reduction in CT by 27.79% during the DJ30, with the control group also showing a notable decrease of 33.33% in this parameter.

In the Myotest device's 3 consecutive Countermovement Jumps (My-CMJ), the experimental group demonstrated substantial improvements from the initial to the final testing, with an 18.12% ($p < 0.05$) increase in Average Jump Height (AVJH), a 25.49% rise in Average Jump Power (AVP), a 6.34% ($p < 0.05$) enhancement in Average Force (AVF), and an 11.82% ($p < 0.05$) uplift in Average Ascensional Speed (AVS). The control group also noted improvements, with an 11.25% increase in AVJH, a 25.49% rise in AVP, an 8.82% increase in AVF, and a 7.96% enhancement in AVS.

The assessment of the lower limbs' static-dynamic explosiveness utilized the Myotest device, wherein participants were required to execute three successive squat jumps (My-SJ). The outcomes of this particular test indicated a discernible advantage for the experimental group, with an improvement margin of 2-4% over the control group.

A consistent parameter across all conducted tests was jump height. Analyzing the outcomes associated with this parameter reveals that, by the conclusion of the 26-week competitive period, the experimental group demonstrated enhancements ranging from 3% to 7% in comparison to the control group, as detailed in Figure 1.

Discussion

Is Plyometric Training Safe for Children?

This question is paramount in performance sports, especially considering the associated risks of injury, potential muscle soreness, overtraining, or even frustration when involving young athletes [15].

Faigenbaum and Yap [16] argue that plyometrics are inherently part of many natural movements, as demonstrated by the variety of jumps seen in children's play activities. Even walking, a fundamental voluntary motor action, embodies a form of plyometric exercise since each step initiates a stretch-shortening cycle in the quadriceps.

To mitigate the potential negative outcomes of plyometric training, it is imperative for coaches to have a thorough understanding of the neurophysiological, musculoskeletal, and mechanical principles underpinning plyometric

Table 5. Results & Corelations.

Test & parameter	Experimental group		Control group		Correlations between EG & CG			
	Pre test	Post test	Pre test	Post test	Pre test	Post test	Pre test	Post test
					t	t	Sig. (2-tailed)	Sig. (2-tailed)
CMJ - JH (cm)	24.86 ± 2.3	31.64 ± 3.05	23.24 ± 2.47	28.84 ± 2.01	1.9	3.6	0.066	0.005
CMJ - FT (s)	0.45 ± 0.02	0.51 ± 0.03	0.44 ± 0.03	0.48 ± 0.02	1.9	2.99	0.067	0.006
CMJAS - JH (cm)	26.26 ± 2.5	33.73 ± 3.71	24.24 ± 2.53	30.23 ± 1.96	2.28	3.32	0.030	0.002
CMJAS - FT (s)	0.46 ± 0.02	0.44 ± 0.01	0.52 ± 0.02	0.49 ± 0.01	2.15	3.26	0.390	0.003
SJ - JH (cm)	24.62 ± 2.22	30.82 ± 2.91	22.69 ± 2.31	27.63 ± 1.64	2.4	3.81	0.022	0.001
SJ - FT (s)	0.44 ± 0.02	0.5 ± 0.02	0.42 ± 0.02	0.47 ± 0.01	2.4	3.75	0.023	0.001
SJAS - JH (cm)	25.69 ± 2.36	33.25 ± 3.54	23.67 ± 2.32	29.65 ± 1.97	2.43	3.54	0.021	0.001
SJAS - FT (s)	0.45 ± 0.02	0.52 ± 0.02	0.43 ± 0.02	0.49 ± 0.01	2.42	3.47	0.021	0.002
DJ30 - JH (cm)	25.95 ± 2.73	32.81 ± 4.20	24.22 ± 28.63	28.63 ± 1.76	2.02	3.66	0.052	0.001
DJ30 - P (W/kg)	24.53 ± 3.29	35.41 ± 4.60	23.59 ± 3.48	34.16 ± 3.9	0.785	0.829	0.439	0.414
DJ 30 - FT (s)	0.45 ± 0.02	0.51 ± 0.03	0.44 ± 0.01	0.48 ± 0.01	1.96	3.67	0.059	0.001
DJ30 - CT (s)	0.38 ± 0.04	0.27 ± 0.03	0.39 ± 0.07	0.26 ± 0.04	-0.215	1.36	0.831	0.182
10 s - AVJH (cm)	24.20 ± 2.68	27.21 ± 4.15	22.95 ± 2.41	24.63 ± 2.37	1.38	2.15	0.177	0.039
10 s - AVCT (s)	0.37 ± 0.07	0.23 ± 0.05	0.33 ± 0.05	0.25 ± 0.03	1.67	-1.18	0.105	0.244
10 s - AVFT (s)	0.44 ± 0.02	0.46 ± 0.03	0.43 ± 0.02	0.44 ± 0.02	1.37	2.14	0.179	0.040
10 s - AVP (W/kg)	24.86 ± 5.19	35.33 ± 6.91	23.91 ± 2.96	30.75 ± 4.29	0.635	2.25	0.530	0.032
MY-CMJ AVJH (cm)	24.83 ± 2.53	29.33 ± 3.57	24.35 ± 1.8	27.09 ± 1.46	0.618	2.32	0.541	0.027
MY-CMJ AVP (W/kg)	34.36 ± 4.78	41.99 ± 5.37	33.39 ± 2.71	36 ± 3.9	0.704	0.487	0.487	0.001
MY-CMJ AVF (N/kg)	21.75 ± 2.37	23.13 ± 2.71	22.21 ± 2.02	22.83 ± 2.56	-0.601	0.321	0.552	0.750
MY-CMJ AVS (cm/s)	202.75 ± 15.6	227.13 ± 16.6	201.19 ± 6.1	216.88 ± 7.46	0.372	2.24	0.712	0.032
MY-SJ AVJH (cm)	24.41 ± 2.47	28.17 ± 3.10	23.78 ± 1.91	26.54 ± 1.37	0.806	1.924	0.426	0.064
MY-SJ AVP (W/kg)	36.15 ± 2.53	39.36 ± 4.11	35.53 ± 2.43	38 ± 2.59	0.697	1.121	0.491	0.271
MY-SJ PMax (W/kg)	37.73 ± 2.82	40.62 ± 4.16	36.75 ± 2.01	38.72 ± 2.83	1.14	1.509	0.271	0.263
MY-SJ AVF (N/kg)	22.30 ± 2.02	23.82 ± 1.92	23.02 ± 2.27	23.88 ± 3.08	-0.951	-0.062	0.349	0.951
MY-SJ AVS (cm/s)	207.38 ± 13.6	223.13 ± 11.4	209.13 ± 21.3	219.69 ± 6.6	-0.276	1.04	0.784	0.305

EG = experimental group, CG = control group, CMJ = countermovement jump, CMJAS = countermovement jump with arm swing, SJ = squat jump, SJAS = squat jump with arm swing, 10 s = successive vertical jumps for 10 seconds, DJ30 = drop jump 30 cm, MY-CMJ = 3 consecutive countermovement jumps, MY-SJ = 3 consecutive squat jumps, FT = flight time, JH = height reached from center of gravity, AVCT = average contact time, AVFT = average flight time, AVJH = average height of jumps, AVP = average power of each jump CT = contact time, P = power of each jump, AVF = average force of jumps, AVS = average ascensional speed, PMAX = maximum power.

Table 6. Statistical indicators of CMJ & CMJAS.

Group	Pair	t	p (2-tailed)
EG	1 CMJ JH (cm) IT - CMJAS JH (cm) - IT	-5.144	0.000
	2 CMJ FT(s) IT - CMJAS FT (s) - IT	-4.145	0.001
	3 CMJ JH (cm) FT – CMJAS JH (cm) FT	-6.883	0.000
	4 CMJ FT (s) FT - CMJAS FT (s) FT	-7.297	0.000
CG	1 CMJ JH (cm) IT - CMJAS JH (cm) - IT	-10.651	0.000
	2 CMJ FT(s) IT - CMJAS FT (s) - IT	-10.787	0.000
	3 CMJ JH (cm) FT – CMJAS JH (cm) FT	-10.377	0.000
	4 CMJ FT (s) FT - CMJAS FT (s) FT	-10.233	0.000

EG = experimental group, CG = control group, CMJ= countermovement jump, JH= height reached from center of gravity, FT= flight time, IT= initial test, FT= final test.

Table 7. Statistical indicators of SJ & SJAS.

Group	Pair	t	p (2-tailed)
EG	1 SJ JH (cm) IT - SJAS JH (cm) - IT	-6.467	0.000
	2 SJ FT(s) IT - SJAS FT (s) - IT	-6.357	0.000
	3 SJ JH (cm) FT – SJAS JH (cm) FT	-8.979	0.000
	4 SJ FT (s) FT - SJAS FT (s) FT	-9.446	0.000
CG	1 SJ JH (cm) IT - SJAS JH (cm) - IT	-5.435	0.000
	2 SJ FT(s) IT - SJAS FT (s) - IT	-5.436	0.000
	3 SJ JH (cm) FT – SJAS JH (cm) FT	-7.875	0.000
	4 SJ FT (s) FT - SJAS FT (s) FT	-7.832	0.000

EG = experimental group, CG = control group, SJ= squat jump, JH= height reached from center of gravity, FT= flight time, IT= initial test, FT= final test.

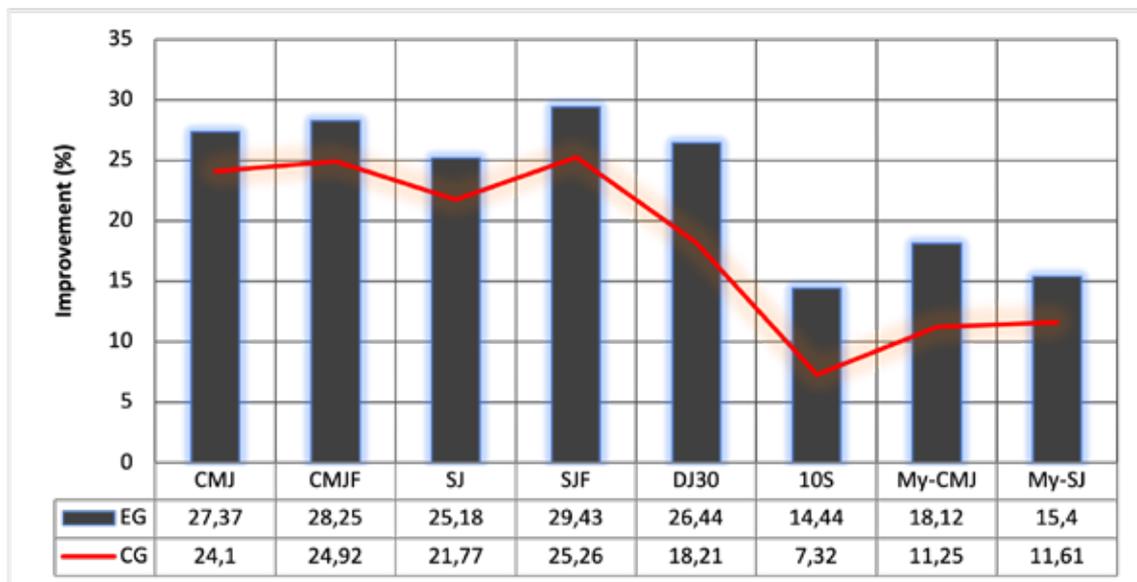


Figure 1. Jump height improvements. EG = experimental group, CG = control group.

exercises [17]. Properly structured plyometric training, developed with careful consideration, can enhance the contractile characteristics of children’s muscles and augment the neural mechanisms involved in muscle contraction [18].

Strength Training in the Youth Sector

Historically, performance sports specialists were

hesitant to endorse strength training for young athletes, citing concerns over potential damage to children’s growing bones. However, this viewpoint has evolved significantly, thanks in large part to research showing that properly designed and supervised strength training programs do not cause cracks or fractures in cartilage growth plates.

Over the last three decades, extensive research has underscored the benefits of strength training for children, provided that such training is carefully supervised and involves lifting appropriate weights [19, 20, 21]. The Department of Pediatrics at Stanford University School of Medicine in the USA [22] has endorsed strength training for young athletes, highlighting its correct application's numerous advantages. When executed properly, strength training can increase muscle strength, enhance bone density, strengthen ligaments and tendons, boost athletic performance, and potentially prevent injuries among youth athletes.

Stanford specialists advocate that children engaged in strength training can utilize a variety of methods, including free weights, body weight exercises, fitness machines, and other apparatus like elastic bands. Reflecting on this guidance, our research has similarly embraced the use of exercises with elastic tubes/bands. The beneficial outcomes of such training modalities have been well-documented across multiple studies [23, 24, 25].

The Validity of the Testing Equipment

In our research, assessments were conducted using the OptoJump Next optical measurement system and the Myotest system. The OptoJump Next is adept at facilitating movement tests requiring precise time measurements, while the Myotest system employs three-dimensional accelerometry to accurately measure specific athletic parameters.

The reliability and validity of the OptoJump system, based on its photocell technology, have been well-established over time. Numerous studies have validated its significant utility in sports science research, especially for analyzing various athletic skills in scenarios where a force plate is not accessible [26, 27, 28].

Similarly, the Myotest system's effectiveness in capturing various parameters through three-dimensional accelerometry has been rigorously evaluated. The findings from multiple studies confirm that Myotest delivers valid and highly reproducible data. It stands out as a reliable method for assessing vertical jumps, validating its use in field evaluations [29, 30, 31].

The Effects of Plyometrics on the Vertical Jump

The 26-week training program significantly enhanced the metrics assessed across all nine tests administered to the participants. When comparing the groups—specifically in the Countermovement Jump (CMJ), Drop Jump from 30 cm (DJ30), 10-second test (10 s), and Myotest CMJ (My-CMJ)—the findings suggest that the specialized physical training program, designed to maximize and develop vertical jump capabilities, was more effective than a conventional training regimen, with a statistical significance threshold of $p < 0.05$.

This observation is consistent with the

conclusions of prior research, which have underscored the beneficial effects of plyometric training on vertical jump performance among adolescent athletes [32, 33, 34]. By the conclusion of the competition period, the experimental group, which underwent our targeted intervention program, exhibited improvements in performance parameters ranging from 12% to 29%.

Comparatively, literature reviews indicate that plyometric training can enhance vertical jump height by 5% to 35% in untrained individuals and by 6% to 13% in those who are already trained [35, 36, 37].

The Effects of Sensory Technology

The utilization of reactive training lights in performance sports has a long history, yet recent advancements, such as BlazePod, have made this technology accessible to a broader audience. BlazePod's "flash reflex" light capsules illuminate in various colors, providing visual stimuli for exercises aimed at enhancing an athlete's reaction time, coordination, balance, and strength.

Hoffmann [38] discusses the application of sensory technology in training, highlighting its efficacy in improving hand-eye coordination, agility, speed, stability, and strength. Despite the recognized benefits of reactive training lights, there remains a gap in the literature concerning the integration of plyometrics with sensory technology. Thus, our research pioneers a novel approach, merging these two methodologies to potentially revolutionize the physical training landscape for athletes.

The Arm Swing Effects

Volleyball players frequently employ a comprehensive arm swing technique, where arms are initially drawn back and then propelled forward with elbows fully extended during the counter-movement vertical jump [39]. This technique is crucial in volleyball for executing jump serves, passes, blocks, and attacks, contributing to increased vertical jump height by enhancing hip joint muscle activity [40]. The arm swing is particularly effective in augmenting the height of the counter-movement vertical jump, a pivotal element in volleyball [41].

The vigorous upward acceleration of the arms generates a counteractive downward force on the body, consequently amplifying the vertical force exerted on the ground. It has been theorized that this downward force results in a pre-loading effect on the lower limbs, which moderates the velocity of knee extension. This moderation allows for an increased force output by the quadriceps muscles, in accordance with the force-velocity relationship [42].

Harman et al. [43] argue that the optimal method to maximize standing jump height includes incorporating a counter-movement with a controlled arm swing. This approach underscores the importance of the arm swing in enhancing

vertical jump efficiency.

In a study focusing on eighteen high-performance volleyball players from the Czech first league, Vaverka et al. [44] discovered that the counter-movement jump with an arm swing resulted in an average vertical jump height that was 0.143 meters (37.7%) higher than the counter-movement jump without the arm swing. Utilizing force platforms, Payne et al. [45] observed a 5% increase in vertical jump height attributable to the arm swing. Additionally, Ramey [46] reported increases in maximal force generation from 2.5 times the body weight without an arm swing to 3.7 times the body weight with an arm swing, suggesting the arm swing's contribution to vertical jump height ranges from 0 to 40%. Shetty and Etnyre [47] found that the arm swing contributed to increases in peak force (6%), power (15%), and breakaway speed (6%), while also aiding in the reduction of peak landing force by 12%.

In an examination of eleven Canadian national female volleyball players' vertical jumps, Coutts [48] affirmed that the arm swing enhances jump performance, noting a 10% increase in vertical breakaway speed due to the arm swing [49]. After implementing the intervention program on female athletes in the experimental group at the end of the competitive period, significant differences were observed. The performances in tests allowing the use of an arm swing reached the threshold of statistical significance ($p < 0.05$), with increases ranging between 3 and 16% in tests comparing the impact of the arm swing.

While this study has elucidated the considerable impact of arm swing on vertical jump performance, it is important to note its limitations. Specifically, the research was confined to a sample size of 32 female athletes from the volleyball section of Cetate Sports High School in Deva, which may affect the generalizability of the findings. This focus underscores the necessity for expanded research encompassing diverse age groups, genders, and competitive levels to comprehensively understand the arm swing's implications across a broader spectrum of athletes. Future investigations could delve into the biomechanical intricacies driving the enhancements in jump efficacy, adopting varied methodologies or longitudinal frameworks to gauge the sustained impact of combined plyometric and sensory technology-enhanced training

regimens. Such explorations are crucial not only for corroborating these initial findings but also for advancing grasp of effective training methodologies for volleyball enthusiasts and athletes across other disciplines.

Conclusions

The implementation of a meticulously structured training regimen for junior volleyball players has proven to be a catalyst in strengthening technical-tactical skills related to vertical jumps. The duration of this intervention was well-suited to the developmental needs of this age group, allowing for the accumulation of the requisite motor skills.

The experimental intervention's methodologies were both effective and diverse, tailored to the proficiency levels of the participants. Over the course of the training, the athletes showcased significant motor potential, positioning them for enhanced tactical and technical performance.

The rapid advancement of modern technology in the realm of performance sports has introduced valuable tools for training enhancement. The incorporation of sensory technology in junior volleyball training aligns with the contemporary push for diversified and engaging motor activities, proving to be a pivotal element in elevating training efficacy.

Supported by robust statistical analysis, it is evident that utilizing a systematic approach incorporating sensory technology significantly boosts vertical jump capabilities and the execution of movements requiring ground detachment.

The intervention was well-received by the participants, with no injuries reported, underscoring the program's safety. Despite the perceived financial constraints associated with cutting-edge technology, its adoption is crucial for refining training programs and elevating the athletic prowess of junior volleyball players, emphasizing the necessity for coaches and sports administrators to invest in technologies that substantiate and augment training outcomes.

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