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The Effectiveness of Using Artificial Intelligence in Advancing the Level of Biomechanical Analysis of Gymnastics Skills

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Abstract: *The research aims to identify the effectiveness of using artificial intelligence in advancing the level of biomechanical analysis of gymnastics skills by examining (the analytical efficiency of artificial intelligence in biomechanical measurement, temporal effectiveness and speed of data processing, objectivity and support of training decision-making, and the contribution of intelligent analysis to improving skill performance). The researcher used the descriptive method due to its suitability to the nature of the research. The researcher selected a random sample of (60) gymnastics coaches and relied on a questionnaire form to collect data. Among the most important conclusions was that the use of artificial intelligence in the biomechanical analysis of gymnastics skills demonstrates a high degree of efficiency and accuracy, contributes to reducing time and effort, enhances objectivity in evaluation, and supports the improvement of skill performance, which confirms its effectiveness as a modern scientific tool that can be employed to develop the training process in gymnastics. Among the most important recommendations was the necessity of expanding the use of artificial intelligence technologies in analyzing gymnastics skills within clubs and sports institutions, and integrating intelligent biomechanical analysis systems into daily training programs due to their role in improving evaluation accuracy and accelerating the analysis process.*

Keywords: *Artificial Intelligence, Biomechanical Analysis, Gymnastics*

Introduction

The current era is witnessing rapid development in digital technology applications, especially in the fields of artificial intelligence and big data analysis, which has clearly been reflected in various aspects of life, including the sports field. Despite the relentless global competition over sports achievement, relying on modern scientific methods has been an absolute necessity of improving the athletic performance levels and increasing training program efficiency.

A sport high in motor complexity is likely to be characterized as gymnastics since it relies on the required fine technical performance and neuromuscular coordination, and associated with the constraints of biomechanical variables like joint angles, angular velocities, center of gravity path, and dynamic balance. Thus, any small error in technique will impact the performance and judging assessment directly, while even increasing the risk of injury. (Al-Laithi, 2022: 63)

Biomechanical analysis is one of the mainstays of motor performance in gymnastics because it allows movement to be studied from the mechanical laws by which they are governed, through kinematic variables (displacement, velocity, acceleration angles) and kinetic variables (forces, torques). Such analysis helps in understanding the strengths and weaknesses, providing explanation for tech errors and suggesting appropriate corrective measures. (Abdelhamid, Abdelwahab, 2015: 28)

Biomechanical analysis plays an important role, but traditional methods based on visual observation and manual video-based analysis may have some drawbacks such as being time- and effort-consuming, prone to personal bias, or how to obtain precise measurements at real-time. Here, the role of artificial intelligence technologies forwarded, especially computer vision and deep learning techniques that can take body points tracking from point coordinates, extract joint angles in no time at all and analyze movement trajectories automatically and accurately. (Hajji, 2023: 17)

Using machine learning in biomechanical analysis of gymnastics skills offers sophisticated capabilities like:

1. Immediate analysis of motor performance.
2. Providing precise feedback based on digital data.
3. Comparing performance with ideal standards.
4. Predicting potential errors or injury risks.
5. Supporting training decisions based on objective quantitative indicators.

Integrating these technologies within the training environment also contributes to developing teaching and training methods and enhances the coach's ability to plan scientifically based on data, rather than relying entirely on personal experience or self-estimation. (David, 2023: 47)

Based on this, the significance of the present study can be found in trying to investigate a machine learning approach to enhance the quality of individual biomechanical analysis in gymnastics skills and examine its extent towards raising levels of accuracy, objectivity and reducing the time needed for movement analysis while aiding motor performance development. The study also aims to provide a scientific framework for the systematic use of such technologies within the sports field.

The researcher hopes that the results of this study will contribute to enriching the theoretical aspect related to artificial intelligence applications in the sports field, in addition to providing practical recommendations that can be utilized in developing training and motion analysis programs for gymnastics.

Research Problem

Gymnastics is one of the sports that fundamentally depends on high technical precision, neuromuscular coordination, and control of body positions during performance in the different phases of movement (preparatory phase – takeoff – flight – landing). Accordingly, the success of skill performance does not depend solely on strength or flexibility, but is largely related to the degree of adherence to precise biomechanical requirements such as appropriate joint angles, movement sequencing, angular velocity, the trajectory of the center of gravity, and achieving balance during transitions between performance phases.

Despite the development witnessed in sports sciences, the process of evaluating motor performance in many training environments still largely depends on visual observation and the coach's experience, or on traditional manual video analysis, which may result in a number of issues, most notably:

- Difficulty in detecting precise technical errors that occur in fractions of a second, especially in flight and rotation skills.
- Time and effort consuming processes of manual measuring or analyzing
- Differences in the way coaches or analysts makes things cooler makes it hard to be objective because they have different perspectives, angles and methods of observation.
- Limited ability to extract accurate quantitative indicators (such as angular velocity, phase time, and deviation of the center of gravity trajectory) continuously and regularly within the training environment.

In contrast, recent years have witnessed a clear expansion in the use of artificial intelligence techniques in the field of sports motion analysis, especially with regard to computer vision and deep learning techniques that allow tracking body points, extracting joint angles, and determining movement trajectories almost instantaneously, with the possibility of providing accurate and numerically supported feedback. However, the reality of employing these technologies in the field of gymnastics within training institutions still faces scientific and practical questions related to:

- The accuracy and reliability of AI-based analysis in highly complex gymnastics skills
- The ability of these technologies to improve the quality of biomechanical analysis compared to commonly used traditional practices.
- The applicability of these systems within the training environment and the possibility of integrating them into the daily programs of coaches and athletes.
- The extent to which AI-based analysis contributes to supporting training decisions and guiding the correction of skill errors more objectively.

Through the researcher's review of the reality of training and field practice, and what some preliminary observations have shown regarding heavy reliance on personal estimation and a clear lack of the use of digital tools that provide accurate and immediate biomechanical data, the need has emerged for a scientific study that describes and analyzes the effectiveness of using artificial intelligence in advancing the level of biomechanical analysis of gymnastics skills, in a way that contributes to bridging the gap between modern technological development and practical application within sports training.

Accordingly, the research problem is defined in the following main question: What is the effectiveness of using artificial intelligence techniques in advancing the level of biomechanical analysis of gymnastics skills in terms of accuracy, speed, objectivity, and applicability within the training environment?

Research Objectives

The research aims to identify the effectiveness of using artificial intelligence in advancing the level of biomechanical analysis of gymnastics skills by identifying:

- The analytical efficiency of artificial intelligence in biomechanical measurement.

- Temporal effectiveness and speed of data processing.
- Objectivity and support of training decision-making.
- The contribution of intelligent analysis to improving skill performance.

Research Questions

- What is the analytical efficiency of artificial intelligence in biomechanical measurement?
- What is the temporal effectiveness and speed of data processing?
- What is the level of objectivity and support for training decision-making?
- What is the degree of contribution of intelligent analysis to improving skill performance?

Research Procedures

Research Method:

The researcher used the descriptive method, due to its suitability to the nature of the research.

Research Population and Sample:

The researcher selected a random sample of (60) gymnastics coaches.

The researcher divided the research sample as follows:

- **Pilot study sample:** Consisted of (17) individuals for the purpose of standardizing the questionnaire form from the original research population and outside the basic study sample.
- **Basic study sample:** Consisted of (43) individuals for the purpose of applying the questionnaire form for the research, as shown in Table (1).

Table (1). Numerical distribution of the research population and sample

Basic Sample		Pilot Sample		Research Sample	Categories of Research Sample
%	(n)	%	(n)		
%71.67	43	%28.33	17	60	Gymnastics coaches
%71.67	43	%28.33	17	60	Total

Data Collection Tools

The researcher designed a questionnaire form for the individuals and categories of the research population shown in Table (1) as a primary tool for data collection, with the aim of identifying the effectiveness of using artificial intelligence in advancing the level of biomechanical analysis of gymnastics skills, through a reference survey and the results of previous studies related to the research topic.

Through the previous steps, the researcher established four (4) axes for the questionnaire form, represented as follows:

- The first axis: Analytical efficiency of artificial intelligence in biomechanical measurement.
- The second axis: Temporal effectiveness and speed of data processing.
- The third axis: Objectivity and support for training decision-making.

- The fourth axis: The contribution of intelligent analysis to improving skill performance.

Scientific Coefficients of the Questionnaire Form:
Validity:

To establish the validity of the questionnaire form, the researcher relied on:

Content validity (experts' validity):

The researcher presented the axes to a group of specialized experts in the field of gymnastics training who meet the requirement of holding a doctoral degree, numbering (7) experts, Appendix No. (1), to survey their opinions regarding the suitability of the proposed axes and to express their views on their appropriateness for achieving the research objectives.

Table (2). Frequency and percentage of experts' opinions regarding the axes of the questionnaire form

n = 7 experts

Experts Agreeing		Axes
Percentage	Frequency	
%100	7	**First axis: Analytical efficiency of artificial intelligence in biomechanical measurement**
%100	7	**Second axis: Temporal effectiveness and speed of data processing**
%85.71	6	**Third axis: Objectivity and support for training decision-making**
%100	7	**Fourth axis: The contribution of intelligent analysis to improving skill performance**

It is evident from Table (2) that the opinions of the experts agreed on the suitability of the axes established by the researcher, with percentages ranging between (85.71%: 100%).

The researcher then formulated the appropriate statements for each axis. Subsequently, the axes and statements of the questionnaire form in its initial version, Appendix (1), were presented to the experts. The form was personally delivered to the experts by the researcher to obtain their opinions regarding:

- The extent to which each statement is appropriate to the axis to which it belongs in achieving its objective.
- The correctness of the linguistic formulation of each statement.
- The deletion, merging, transfer, or modification of what they deemed appropriate.

Table (3) shows the frequencies and percentages of the experts' opinions regarding each statement of the questionnaire form.

Table (3). Frequencies and percentages of the experts' opinions regarding each statement of the questionnaire form

n = 7 experts

Percentage	Frequency	Statement .No	Percentage	Frequency	Statement .No	Percentage	Frequency	Statement .No	Percentage	Frequency	Statement .No
%100	7	21	%100	7	14	%100	7	8	%100	7	**1**

%85.71	6	22	%100	7	15	%100	7	9	%100	7	**2**
%28.57	2	23	%100	7	16	%100	7	10	%100	7	**3**
%100	7	24	%100	7	17	%85.71	6	11	%100	7	**4**
%100	7	25	%85.71	6	18	%100	7	12	%85.71	6	**5**
%85.71	6	26	%100	7	19	%100	7	13	%100	7	**6**
%100	7	27	%42.86	3	20				%100	7	**7**

It is evident from Table (3) that the experts agreed on the initial version of the questionnaire form, as the percentage of agreement ranged between (25%: 100%), with a suggestion to delete some statements. The researcher made the necessary modifications, as shown in the following Table No. (4).

Table (4). Modifications made to the questionnaire form

Statement after modification	Type of modification	Statement before modification	Statement .No	Axis
-------------	Deletion	The artificial intelligence system is characterized by ease of use in the .training environment	**20**	**Third**
-------------	Deletion	The artificial intelligence system is characterized by ease of use in the .training environment	**23**	**Fourth**

Based on the experts' modifications made to the questionnaire form, including the deletion of some statements, the questionnaire form became finalized in its final version before application, Appendix No. (2).

Internal Consistency Validity:

The validity of the questionnaire statements was verified by calculating the correlation coefficient between the score of each statement and the total score of the questionnaire form, as shown in Table (5).

Table (5). Correlation coefficient between the score of each statement and the total score of the questionnaire form

n = 17

Correlation Coefficient		Statement .No	Correlation Coefficient		Statement .No	Correlation Coefficient		Statement .No	Correlation Coefficient		Statement .No
With Questionnaire	With Axis		With Questionnaire	With Axis		With Questionnaire	With Axis		With Questionnaire	With Axis	
*0.893	0.69 *4	20	*0.875	0.63 *5	14	*0.886	0.79 *9	8	*0.659	0.62 *1	**1**
*0.723	0.87 *4	21	*0.562	0.77 *5	15	*0.594	0.64 *3	9	*0.641	0.72 *8	**2**
*0.792	0.85 *9	22	*0.908	0.50 *6	16	*0.579	0.85 *2	10	*0.727	0.69 *9	**3**
*0.685	0.62 *2	23	*0.512	0.74 *1	17	*0.884	0.85 *3	11	*0.673	0.57 *4	**4**
*0.787	0.60 *2	24	*0.878	0.79 *0	18	*0.669	0.65 *6	12	*0.638	0.80 *2	**5**

*0.783	0.81 *7	25	*0.799	0.90 *7	19	*0.708	0.60 *0	13	*0.769	0.67 *8	**6**
									*0.670	0.70 *1	**7**

*Statistically significant at 0.05(tabulated Pearson correlation coefficient = (0.468

It is evident from Table (5) that the correlation coefficients between each statement and the total score of the questionnaire form are statistically significant at the significance level (0.05).

Table (6). Internal consistency of the questionnaire axes

(n = 17)

Pearson Correlation Coefficient with Total Questionnaire Score	Axes
*0.784	**First axis: Analytical efficiency of artificial intelligence in biomechanical measurement**
*0.694	**Second axis: Temporal effectiveness and speed of data processing**
*0.624	**Third axis: Objectivity and support for training decision-making**
*0.862	**Fourth axis: The contribution of intelligent analysis to improving skill performance**

*Statistically significant at 0.05(tabulated Pearson correlation coefficient = (0.468

It is evident from Table (6) that the values of the correlation coefficients among the questionnaire axes and between them and the total score of the questionnaire are statistically significant at the significance level (0.05), which indicates the validity of the questionnaire form and that it measures what it was designed to measure.

Reliability:

Reliability was verified using Cronbach's Alpha coefficient to determine the reliability of the questionnaire statements and the reliability of the questionnaire axes, as shown in Table (7).

Table (7). Reliability of the Questionnaire Using Cronbach's Alpha Method

(n = 17)

Reliability Coefficient if Statement Deleted		**Statement .No**	**Reliability Coefficient if Statement Deleted**		**Statement .No**	**Reliability Coefficient if Statement Deleted**		**Statement .No**	**Reliability Coefficient if Statement Deleted**		**Statement .No**
For Questionnaire	**For Axis**		**For Questionnaire**	**For Axis**		**For Questionnaire**	**For Axis**		**For Questionnaire**	**For Axis**	
0.865	0.794	20	0.869	0.857	14	0.893	0.853	8	0.879	0.861	**1**
0.865	0.798	21	0.869	0.862	15	0.893	0.872	9	0.879	0.853	**2**
0.865	0.854	22	0.869	0.868	16	0.893	0.863	10	0.879	0.862	**3**
0.865	0.848	23	0.869	0.839	17	0.893	0.861	11	0.879	0.859	**4**

0.865	0.764	24	0.869	0.859	18	0.893	0.861	12	0.879	0.863	**5**
0.865	0.801	25	0.869	0.860	19	0.893	0.864	13	0.879	0.869	**6**
									0.879	0.859	**7**

Table (8). Cronbach's Alpha values for the questionnaire axes

Cronbach's Alpha Coefficient		**Questionnaire Axes**
For the questionnaire as a whole	**For the axis as a whole**	
0.901	**0.882**	**First axis: Analytical efficiency of artificial intelligence in biomechanical measurement**
	0.896	**Second axis: Temporal effectiveness and speed of data processing**
	0.877	**Third axis: Objectivity and support for training decision-making**
	0.873	**Fourth axis: The contribution of intelligent analysis to improving skill performance**

It is evident from Table (8), which presents the reliability coefficients of the questionnaire axes using Cronbach's Alpha, that the reliability coefficients for the axes with the questionnaire ranged between (0.873 – 0.896). The reliability coefficients for the statements with the questionnaire as a whole reached (0.901). All of them are statistically significant at the significance level (0.05), which indicates the reliability of the questionnaire form.

Application of the Questionnaire Form:

- **Human Scope:** The application was conducted on the members of the research sample, numbering (43) gymnastics coaches.
- **Spatial Scope:** The research was conducted in the clubs of Diyala Governorate.
- **Time Scope:** The questionnaire form for the research was applied during the period from 17/11/2025 to 25/12/2025.

Method of Scoring the Questionnaire Form:

The researcher relied on a three-point scale in determining the responses to the questionnaire form, represented by (Agree – To some extent – Disagree). The responses were assigned scores of (3, 2, 1).

Statistical Treatments Used in the Research:

The statistical treatments were conducted using SPSS version 2020 as follows:

- Percentage (%) to calculate the frequencies of experts' opinions on the statements and axes of the questionnaire.
- Pearson correlation coefficient to calculate the internal consistency validity between the questionnaire statements.
- Cronbach's Alpha reliability coefficient to calculate the reliability of the questionnaire form.

- Chi-square (χ^2) to calculate the differences between the responses of the research sample.
- Predominant trend to determine the direction of the sample members' responses.
- Approval percentage to determine the percentage of agreement of the research sample's opinions on the questionnaire statements.

Presentation and Discussion of Results

Presentation and Discussion of the Results of the First Axis: Analytical Efficiency of Artificial Intelligence in Biomechanical Measurement

Table (9). Frequencies, percentages, and statistical significance of the statements of the first axis (Analytical efficiency of artificial intelligence in biomechanical measurement) (n = 43)

Appro % val	Overall Response Likert	Mean	Significance Level	Chi-Square	Disagree		To Some Extent		Agree		Statement Content	N.o
					%	n	%	n	%	n		
%90.70	Yes	2.813953	.000	50.000	2.33 %	1	13.95 %	6	83.72 %	36	The artificial intelligence system contributes to measuring joint angles with high accuracy during skill performance.	1
%94.19	Yes	2.884	.000	25.326	0.00 %	0	11.63 %	5	88.37 %	38	AI-based analysis is characterized by consistency and stability in results.	2
%75.58	Yes	2.5116	.000	18.047	11.63 %	5	25.58 %	11	62.79 %	27	The system helps identify subtle differences in the stages of motor performance.	3
%77.91	Yes	2.558	.000	25.721	13.95 %	6	16.28 %	7	69.77 %	30	Artificial intelligence provides accurate quantitative indicators of the trajectory of the center of gravity.	4
%88.37	Yes	2.7674	.000	42.186	2.33	1	18.60	8	79.07	3	The system	5

					%		%		%	4	allows clear and objective analysis of linear and angular velocities.	
%82.56	Yes	2.651	.000	30.326	6.98 %	3	20.93 %	9	72.09 %	31	The error rate in measurement decreases when using artificial intelligence techniques.	6
%86.05	Yes	2.7209	.000	35.488	2.33 %	1	23.26 %	10	74.42 %	32	The results of intelligent analysis can be relied upon as a basis for biomechanical evaluation.	7

Chi-square is significant at the 0.05 level, where the significance level ≤ 0.05 at degree of freedom 2 = 5.99, degree of freedom 1 = 3.84.

Likert Scale: Weighted mean ranges: 1.00–1.66 (Disagree), 1.67–2.33 (To some extent), 2.34–3.00 (Agree).

It is evident from Table (9), which presents the frequencies, percentages, and statistical significance of the statements of the first axis (Analytical efficiency of artificial intelligence in biomechanical measurement), that there are statistically significant differences between the responses. For all statements, the chi-square values are significant to 0.05 level (approval percent: 75.58% - >94.19%).

These results are consistent with the findings of the study by Dindorf (2024), which confirmed that computer vision and deep learning techniques contribute to improving the accuracy of biomechanical measurements compared to traditional methods. The study demonstrated that digital joint-tracking systems are capable of extracting movement angles and angular velocities with a high degree of consistency and stability, thereby reducing human error resulting from visual estimation. The results of the study by Mohi El-Din Al-Laithi (2022) also indicated that the use of artificial intelligence in motion analysis provides accurate quantitative indicators of the trajectory of the center of gravity and the sequencing of movement phases, which enhances the objectivity of analysis and increases the efficiency of technical evaluation. This is consistent with the high approval percentages for the statements related to measurement accuracy and the analysis of linear and angular velocities.

These results are also consistent with the findings of the study by Somaya Jamil Al-Sarayreh (2019), which indicated that intelligent systems allow performance to be reanalyzed multiple times with the same level of accuracy without being affected by human factors, thereby enhancing the statistical reliability of measurements. The study further noted that reliance on digital analysis contributes to detecting subtle differences that are difficult to observe with the naked eye, especially in high-speed skills such as gymnastics skills. This explains why the statements related to reducing error rates and the possibility of relying on results as a basis for biomechanical evaluation achieved high approval percentages exceeding (80%).

The researcher believes that the high approval percentages and mean scores in this axis reflect the sample members' awareness of the importance of shifting toward digital analysis supported by artificial intelligence, particularly in a sport characterized by precision and motor complexity such as gymnastics. It furthermore reflects a professional belief that intelligent analysis is no longer just an ancillary technical assistance, but such that if it was applied as a laboratory formal method we could further promote better quality of biomechanical measurement parameters due to reduction of bias and also make evaluation more objective.

Presentation and Discussion of the Results of the Second Axis: Temporal Effectiveness and Speed of Data Processing

Table (10). Frequencies, percentages, and statistical significance of the statements of the second axis (Temporal effectiveness and speed of data processing)

(n = 43)

Appro % val	Overall Response Likert	Mean	Significance Level	Chi-Square	Disagree		To Some Extent		Agree		Statement Content	م
					%	n	%	n	%	n		
%91.86	Yes	2.8372	.000	19.558	0.00 %	0	16.28 %	7	83.72 %	36	The use of artificial intelligence reduces the time required to analyze skill performance.	**8**
%59.30	To Some Extent	2.186047	.105	4.512	18.60 %	8	44.19 %	19	37.21 %	16	The system provides immediate feedback after skill execution.	9
%77.91	Yes	2.55814	.000	23.070	11.63 %	5	20.93 %	9	67.44 %	29	It contributes to accelerating the process of comparing performance between different attempts.	**10**
%91.86	Yes	2.837209	.000	19.558	0.00 %	0	16.28 %	7	83.72 %	36	It helps organize data and present it in a fast and easily	**11**

											understandable manner.	
%97.67	Yes	2.953488	.000	35.372	0.00 %	0	4.65 %	2	95.35 %	41	It reduces the time and effort expended in traditional manual analysis.	**12**
%91.86	Yes	2.837209	.000	54.326	2.33 %	1	11.63 %	5	86.05 %	37	It shortens the technical procedures associated with the biomechanical analysis process.	**13**

Chi-square is significant at the 0.05 level, where the significance level ≤ 0.05 at degree of freedom 2 = 5.99, degree of freedom 1 = 3.84.

Likert Scale: Weighted mean ranges: 1.00–1.66 (Disagree), 1.67–2.33 (To some extent), 2.34–3.00 (Agree).

The clear from Table (10) that provides frequencies and percentages Statements of the second axis: Temporal effectiveness and speed of processing data). The Chi-square revealed statistically significant differences at the 0.05 level for all judicial statements except statement number (9), and the approval percentages therefore were (59.30% to 97.671%).

These results are in agreement with what Bakri, 2013 study found, confirming that AI systems have evidently shortened the time needed for data processing compared to traditional analysis dependent on manual frameworks or non-automated software. Moreover, the result of this study revealed that automated motion-tracking techniques could extract multiple biomechanical indicators within a short timeframe while they can be stored, organized, and directly displayed in the data that shortens the associated technical procedures with the analysis process. This is consistent with the high approval rates for statements regarding saving time and effort as well as data organization.

Also, the results of Odeh (2009) study showed that digital processing speed is one of AI systems' essential advantages in the sports domain compared to other attempts or athletes as intelligent systems allow to view instantaneous comparisons depending on accurate digital data. However, some other works have reported that immediate feedback could be influenced by technical parameters as the speed of the device, connection quality and software performance used; which may explain lower approval percentage for this statement regarding immediate feedback when compared with other statements, where high percentages were achieved.

This can be attributed to the perception and awareness of members of the sample on the time-saving aspect achieved by artificial intelligence in biomechanical analysis, particularly with regards to minimizing effort within a relatively short period that they spend conducting manual analysis, which marks a qualitative orientation in the sports training environment. As for immediate feedback, the differences in responses may indicate discrepancies between participants' nominal level of experience with intelligent systems and their actual level of experience with intelligent systems or inconsistencies in the technical solutions afforded to them.

Presentation and Discussion of the Results of the Third Axis: Objectivity and Support for Training Decision-Making

Table (11). Frequencies, percentages, and statistical significance of the statements of the third axis (Objectivity and support for training decision-making)

(n = 43)

Appro % val	Overall Response Likert	Mean	Significance Level	Chi-Square	Disagree		To Some Extent		Agree		Statement Content	م
					%	n	%	n	%	n		
%81.40	Yes	2.627907	.000	29.628	9.30 %	4	18.60 %	8	72.09 %	31	Artificial intelligence enhances the objectivity of motor performance evaluation.	**14**
%86.05	Yes	2.72093	.000	40.791	6.98 %	3	13.95 %	6	79.07 %	34	It reduces personal bias in judging the athlete's level.	15
%70.93	Yes	2.418605	.000	20.419	23.26 %	10	11.63 %	5	65.12 %	28	It supports training decision-making based on accurate digital data.	**16**
%82.56	Yes	2.651163	.000	32.977	9.30 %	4	16.28 %	7	74.42 %	32	It provides measurable indicators that help identify strengths and weaknesses.	**17**
%60.47	To Some Extent	2.209302	.120	4.233	18.60 %	8	41.86 %	18	39.53 %	17	It contributes to unifying evaluation standards among coaches.	**18**
%59.30	To Some Extent	2.186047	.032	6.884	16.28 %	7	48.84 %	21	34.88 %	15	It helps in building training plans based on	**19**

											objective analysis results.	

Chi-square is significant at the 0.05 level, where the significance level ≤ 0.05 at degree of freedom 2 = 5.99, degree of freedom 1 = 3.84.

Likert Scale: Weighted mean ranges: 1.00–1.66 (Disagree), 1.67–2.33 (To some extent), 2.34–3.00 (Agree).

The table (11), it is clear the frequencies, percentages, and significance of the statements for third axis (requirements objectivity and support in decision training) there are statistically significance differences between responses. The Chi-square value at the 0.05 level is significant for all statements but statement No-18, with approval levels between (59.30% to 86.05%)

This comes in consonance with the results of a study that proved using AI helps to improve objectivity in performance evaluation because it is based on measurable quantitative data and minimizes personal influences and subjective opinions in judging performance. Mohi El-Din Al-Laithi (2022) further suggested that backing training decisions with the correct digital indicators allows the coach to better identify strengths and weaknesses than through conventional visual appraisal. This aligns with the high rates of approval for the statements regarding reducing bias and offering measurable indicators.

Inversely, Sanders's (2000) results prescribed that a full adaptation towards converging evaluation standards and constructing training plans from scratch using solely digital analysis might take time, practice adoption and coaching professional culture adjustments. This could be the reason why statements about unifying standards and constructing training plans received fairly moderate approval rates. This does not only depend on the accuracy of the system for decision-making process but this is more affected by how much user accepting it, technical experience of users and supportive infrastructure.

The researcher believes that this data indicates a significant awareness of the impact of artificial intelligence on achieving objectivity in assessment and within evaluation, reducing human impact which is an important step towards creating methods of training decision-making in gymnastics. From the effective role of digital indicators and databases as supportive source (which should continue) in forming training plans, quantifying standards among coaches; there should be some qualification, training and awareness of the importance of quantitative analysis. The researcher maintains that in this light making objective and efficient decisions by training decision-makers, no matter how intelligent they may be, ultimately remains the best model.

Presentation and Discussion of the Results of the Fourth Axis: The Contribution of Intelligent Analysis to Improving Skill Performance

Table (12). Frequencies, percentages, and statistical significance of the statements of the fourth axis (The contribution of intelligent analysis to improving skill performance)

(n = 43)

Appro % val	Overall Response Likert	Mean	Significance Level	Chi-Square	Disagree		To Some Extent		Agree		Statement Content	م
					%	n	%	n	%	n		
%79.07	Yes	2.581395	.000	22.372	6.98 %	3	27.91 %	12	65.12 %	28	AI-based analysis contributes to improving the level of technical performance.	**20**
%76.74	Yes	2.534884	.000	19.023	9.30 %	4	27.91 %	12	62.79 %	27	It helps correct motor errors more accurately.	21
%58.14	To Some Extent	2.162791	.079	5.070	18.60 %	8	46.51 %	20	34.88 %	15	It contributes to developing the different phases of skill performance.	**22**
%70.93	Yes	2.418605	.001	14.279	18.60 %	8	20.93 %	9	60.47 %	26	It supports the motor learning process among athletes.	**23**
%65.12	To Some Extent	2.302326	.045	6.186	16.28 %	7	37.21 %	16	46.51 %	20	It reduces the repetition of technical errors during training.	**24**
%83.72	Yes	2.674419	.000	31.302	4.65 %	2	23.26 %	10	72.09 %	31	It contributes to raising performance efficiency in official competitions.	**25**

Chi-square is significant at the 0.05 level, where the significance level ≤ 0.05 at degree of freedom 2 = 5.99, degree of freedom 1 = 3.84.

Likert Scale: Weighted mean ranges: 1.00–1.66 (Disagree), 1.67–2.33 (To some extent), 2.34–3.00 (Agree).

It is evident from Table (12), which presents the frequencies, percentages, and statistical significance of the statements of the fourth axis (The contribution of intelligent analysis to improving skill performance), that there are statistically significant differences between the responses. The Chi-square values are significant at the 0.05 level for all statements except statement No. (22), with approval percentages ranging from (58.14% to 83.72%).

These results are consistent with the findings of Dindorf (2024), which indicated that AI-supported digital feedback contributes to improving technical performance by providing the athlete with accurate and immediate information about motor errors, thereby helping to correct them more efficiently. The study also clarified that the use of quantitative biomechanical indicators enhances motor control and reduces the gap between actual performance and the ideal model, which is positively reflected in achievement levels during official competitions. This aligns with the high approval percentages for statements (20) and (25).

On the other hand, the findings of Souaifi (2025) indicated that the comprehensive development of all phases of skill performance may require a longer period and continuous repetition of feedback, in addition to the integration of physical and psychological factors alongside technical analysis. This may explain the lack of statistical significance for statement (22) and its classification within the “To Some Extent” category. Furthermore, reducing the repetition of technical errors depends not only on the availability of digital analysis, but also on the athlete’s understanding of the feedback and their ability to apply it practically during training.

The researcher believes that the results indicate a clear positive effect of intelligent analysis in improving skill performance, especially in aspects related to technical precision and competitive achievement. Nevertheless, such enhancements must be generalized overall performance phases by putting biomechanical analysis into practice, through planned training programs and systematic repeated use of intelligent systems. This at the same time does not work separately from the rest of the parts of training process, but should be used within a complete system in order to gain as much benefit as possibly possible.

Conclusions

In light of the research results, the following conclusions were reached:

Analytical Efficiency of Artificial Intelligence in Biomechanical Measurement shows AI is well trained as aligned to biomechanics manufactures, with an accuracy of obtaining biomechanical variables important for gymnastics skills, High accuracy, consistency and stability in analysis results is achieved with the help of intelligent system, Artificial intelligence lowers the measurement error rate relative to other methods, Directly probes the data from a single AHRS sensor and produces precise numerical metrics for the center of gravity trajectory, joint angles, and angular velocities, The results of intelligent analysis can be relied upon as a scientific basis for biomechanical evaluation, The results confirmed a high level of analytical efficiency of artificial intelligence in biomechanical measurement, which enhances the objectivity and accuracy of motor performance analysis in gymnastics.
Temporal Effectiveness and Speed of Data Processing shows Artificial intelligence contributes to significantly reducing the time required to analyze skill performance,It reduces the time and effort expended in traditional manual analysis, It helps organize and present data in a fast and easily understandable manner, It shortens the technical procedures associated with the biomechanical analysis process, The element of immediate feedback still requires further technical development to ensure full benefit from it, Artificial intelligence achieved high temporal effectiveness in data processing and performance analysis, with a need to enhance the aspect of immediate feedback.

Objectivity and Support for Training Decision-Making shows Artificial intelligence enhances the objectivity of motor performance evaluation, It reduces personal bias in judging players' levels, It supports training decision-making through accurate and measurable digital data, It helps identify strengths and weaknesses more clearly, Unifying evaluation standards and building training plans based entirely on intelligent analysis still require further activation and training, Artificial intelligence effectively contributes to supporting objectivity in evaluation and training decision-making; however, its full integration into training planning requires further professional qualification.

Contribution of Intelligent Analysis to Improving Skill Performance, Intelligent analysis contributes to improving the technical performance level of gymnastics players, It helps correct motor errors more accurately and efficiently, It supports the motor learning process and enhances training quality, It contributes to raising performance efficiency in official competitions,Comprehensive development of all phases of skill performance requires integrating intelligent analysis with carefully planned training programs, AI-based analysis is an efficient resource for skill performance enhancement; nonetheless, to leverage its full potential it must be embedded in a holistic training system, Artificial intelligence in the biomechanical analysis of gymnastics skills are more efficient and accurate, save time and effort, increase evaluation objectivity, and promote skill performance. It proves this tool effectiveness as a modern scientific device to be used for formation of the training process in gymnastics.

Recommendations

In light of the research findings, it is recommended to integrate artificial intelligence–based biomechanical analysis systems into regular gymnastics training programs to enhance the accuracy and speed of skill evaluation. Sports clubs and associations should utilize digital performance indicators generated through intelligent analysis to design effective training plans and systematically correct technical errors. It is also important to provide the necessary technical infrastructure, including high-resolution cameras, specialized motion analysis software, and high-performance computers, to maximize the benefits of these technologies. Furthermore, implementing real-time feedback systems during training can significantly support the motor learning process. Finally, organizing practical training workshops for coaches and promoting collaboration between sports scientists and artificial intelligence specialists will contribute to developing more accurate and efficient analysis systems for gymnastics performance.

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