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Concurrent Validity and Reliability of MediaPipe Pose Estimation for Kinematic Analysis of the Clean Lift in Physical Education Students

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ABSTRACT
The aim of this research was to evaluate how well the MediaPipe performs in comparison to Kinovea in analyzing key kinematic parameters in the clean lift movement for physical education students, and how reliable the MediaPipe is in doing so. The research design used in this study was descriptive, combined with both comparative and correlational research approaches. The researchers recruited 30 first-year physical education students at the College of Physical Education and Sports Sciences and conducted an experiment on their clean lift movement, captured by high-speed cameras and analyzed using both the MediaPipe and Kinovea. The data analyzed included the knee, hip, and ankle joint angles, and barbell movement, such as vertical velocity, vertical displacement, and bar path. The data analysis involved the use of descriptive statistics, Pearson correlation, intraclass correlation, root mean square error, paired t-test, and Bland-Altman plots. The findings showed that the MediaPipe and Kinovea are highly comparable, particularly in analyzing the velocity of the barbell, where the correlation coefficient between the two tools was 0.96, showing high concurrent validity. There were no significant differences between the two methods. The reliability of the MediaPipe in analyzing the kinematics of the clean lift movement was high, as the correlation coefficient ranged between 0.85 and 0.91, showing high stability in the measurements. The analysis of the bar path movement showed high comparability between the two methods. The conclusion drawn from the research is that the MediaPipe is an effective and affordable tool for analyzing the kinematics of the clean lift movement and thus can be used in both educational and research settings.

Keywords: MediaPipe; Kinematic Analysis; Clean lift; Concurrent Validity; Sports Biomechanics.

ABSTRAK
Tujuan dari penelitian ini adalah untuk mengevaluasi seberapa baik kinerja MediaPipe dibandingkan dengan Kinovea dalam menganalisis parameter kinematik utama dalam gerakan clean lift untuk siswa pendidikan jasmani, dan seberapa andal MediaPipe dalam melakukannya. Desain penelitian yang digunakan dalam penelitian ini bersifat deskriptif,

dikombinasikan dengan pendekatan penelitian komparatif dan korelasional. Para peneliti merekrut 30 mahasiswa pendidikan jasmani tahun pertama di College of Physical Education and Sports Sciences dan melakukan percobaan pada gerakan pengangkatan bersih mereka, yang ditangkap oleh kamera berkecepatan tinggi dan dianalisis menggunakan MediaPipe dan Kinovea. Data yang dianalisis meliputi sudut sendi lutut, pinggul, dan pergelangan kaki, dan gerakan barbel, seperti kecepatan vertikal, perpindahan vertikal, dan jalur batang. Analisis data melibatkan penggunaan statistik deskriptif, korelasi Pearson, korelasi intrakelas, kesalahan kuadrat rata-rata akar, uji-t berpasangan, dan plot Bland-Altman. Temuan menunjukkan bahwa MediaPipe dan Kinovea sangat sebanding, terutama dalam menganalisis kecepatan barbel, di mana koefisien korelasi antara kedua alat adalah 0,96, menunjukkan validitas bersamaan yang tinggi. Tidak ada perbedaan yang signifikan antara kedua metode tersebut. Keandalan MediaPipe dalam menganalisis kinematika gerakan clean lift tinggi, karena koefisien korelasi berkisar antara 0,85 dan 0,91, menunjukkan stabilitas tinggi dalam pengukuran. Analisis pergerakan jalur batang menunjukkan komparabilitas yang tinggi antara kedua metode tersebut. Kesimpulan yang ditarik dari penelitian ini adalah bahwa MediaPipe adalah alat yang efektif dan terjangkau untuk menganalisis kinematika gerakan pengangkatan bersih dan dengan demikian dapat digunakan dalam pengaturan pendidikan dan penelitian.

Kata Kunci: Pipe Media; Analisis Kinematik; Angkat beban; Validitas Bersamaan; Biomekanik Olahraga.

INTRODUCTION

The Clean lift is a sophisticated motor skill that requires coordination, muscular strength, and proficiency. In physical education, proficiency in executing the lift is crucial for students to attain explosive strength and pedagogical proficiency. Biomechanical examination helps in quantifying the angles, barbell movements, and velocities, which are critical for lifting efficiency (Werner et al., 2020).

The conventional kinematic analysis technique relies on marker-based motion capture technology; whereby reflective markers are attached to the anatomical points of interest. While the technique provides accurate results, it requires complex designs and entails significant costs, thus limiting its application in the training room and sport settings (Sandau et al., 2021).

The development of computer vision technology and machine learning, especially deep learning technology, has enabled markerless pose estimation technology to emerge. Among all markerless pose estimation technologies, MediaPipe has received significant attention because of its real-time motion capture and mobile device compatibility (Jyothi et al., 2024).

Despite the promising capabilities of MediaPipe, the accuracy of the MediaPipe pose estimation technique in capturing high acceleration movements such as the Clean lift in sports movements is an area that requires investigation.While previous research has indicated high accuracy in capturing upper limb movements with an accuracy of 0.28 pixels, the application of MediaPipe for the fast movements in the Clean lift requires rigorous validation against reference standards (Jyothi et al., 2024).

Consequently, the current study focuses on physical education students to investigate whether MediaPipe can be an effective pedagogical and research tool for correcting the technique and monitoring physical education performances.

The research problem derives its origin from a technological and practical disparity between the need for accurate biomechanical analysis of the Clean Lift movement and the resources available within the field settings of colleges of physical education. Marker-based motion capture technology, such as Vicon, has been considered the gold standard for biomechanical analysis. However, its high cost and complex setup process are major limitations for its use within training settings and academic evaluation of physical education students (Sandau et al., 2021).

The emergence of artificial intelligence and the use of markerless pose estimation tools such as MediaPipe pose critical concerns regarding the accuracy and reliability of such tools for the biomechanical analysis of high-speed and high-acceleration sports movements. Recent research has suggested that such tools may result in an accuracy error of up to 13.6° when determining joint angles for complex weightlifting movements (Thiele et al., 2024).

In addition, the literature does not include any direct empirical studies that examine the validity and reliability of the MediaPipe pose estimation in determining the accuracy of the analysis of the key phases of the Clean Lift movement, such as the first pull, transition, second pull, and catch, for physical education students. Therefore, it is essential to conduct a scientific study to examine the reliability and accuracy of the MediaPipe pose estimation model as an effective instrument.

The objectives of the present research study are as follows:

1. Quantification of certain kinematic parameters in the phases of the Clean lift using the MediaPipe method for the sample of physical education students.
2. Quantification of the kinematic parameters of the Clean lift, i.e., the joint angles, velocity of the barbell, and the trajectory of the barbell, using the manual digitization method (reference method) for the sample of physical education students.
3. Evaluation of the concurrent validity of the MediaPipe method by comparing the results with the results of the manual digitization method in the analysis of the phases of the Clean lift.
4. Evaluation of the reliability of the MediaPipe method in the quantification of the kinematic parameters of the Clean lift.
5. Determination of the measurement errors of the MediaPipe method in the various analyses.

Based on the research problem and objectives, the study seeks to answer the following research questions:

1. To what extent is the MediaPipe technique valid for analyzing the kinematic variables of the Clean lift phases among physical education students when compared with manual digitization using Kinovea?
2. What is the degree of correlation between the kinematic measurements obtained using MediaPipe and those obtained using Kinovea in analyzing the phases of the Clean lift?
3. What is the level of measurement reliability of the MediaPipe technique when the kinematic analysis of the Clean lift is repeated?

4. Does the measurement accuracy of the MediaPipe technique differ across the different phases of the Clean lift (first pull, transition, second pull, and catch)

Human Scope

The human subjects of the research were 30 students of the College of Physical Education and Sports Sciences. Inclusion Criteria: The subjects of the experiment must not have musculoskeletal injuries for the three months preceding the experiment. The period of the experiment was 10 weeks, and the experiment began on 25 March 2025 and ended on 10 June 2025. The experiment took place in the weightlifting hall of the College of Physical Education and Sports Sciences.

MediaPipe is an open-source technology that is developed by Google and is heavily used in the fields of computer vision and artificial intelligence. The technology helps in tracking the joints of the human body and identifying the spatial and temporal coordinates of the images and video recordings, making it an effective and accurate way of analyzing human movement. The technology is unique in that it is easy to use, real-time, and available on multiple mobile and computing platforms. It is also effective in analyzing multiple human and sports movements, making it an effective tool for both academic and professional use (Olubayode, 2025).

METHOD

Research Design

The present study followed a descriptive research design, incorporating comparative and correlational approaches, as deemed more appropriate for the nature and objectives of the present investigation.

Population and Sample

The population for the present study included all the students enrolled at the College of Physical Education and Sports Sciences of the university. Due to the impracticality of surveying the population, a representative sample of the population was selected for the purpose of the present investigation. A sample of 30 participants was selected, identified according to predetermined criteria to ensure their suitability for the movements to be performed and the absence of injuries.

The descriptive characteristics of the study sample are presented in the following table:

Table 1. Descriptive characteristics of the study sample.

N = 30			
SD	Mean	Unit of Measurement	Variables
1.2	21.4	Years	Age
5.4	176.8	cm	Height
6.2	78.5	kg	Body Mass
12.4	65.0	kg	Clean Lift 1RM

Table 1 shows the descriptive sample characteristics of the study sample, where the sample consists of first-year students in the College of Physical Education and Sports Sciences. The results showed that the mean age of the sample is 21.4 ± 1.2 years, mean height is 176.8 ± 5.4 cm, and mean body mass is 78.5 ± 6.2 kg. Furthermore, the mean one-repetition maximum (1RM) for the Clean lift is 65.0 ± 12.4 kg.

Instruments, Tools, and Equipment Used for Data Collection

Research Sources
1. International scientific references and studies.
2. Online databases and internet resources.

Data Collection Tools
1. An open-source artificial intelligence–based pose estimation framework (MediaPipe) used for markerless joint tracking.
2. Kinovea motion analysis software.
3. Data recording forms used for documenting the extracted measurements.

Field Research Equipment
1. Two smartphones (Poco X4 GT) equipped with cameras recording at 120 frames per second (fps).
2. Two tripod stands for stabilizing the cameras during recording.
3. Measuring tape.
4. A 1-m calibration scale used to convert pixel measurements into real-world units.
5. Standard weightlifting equipment, including a barbell, weight plates, and tight sportswear to facilitate motion tracking.

Determination of Tests and Measurements

Selection of the Research Test

The researcher identified the tests and measurements that are being utilized in the present study. The main measurement involved the determination of the maximum load that could be lifted in the Clean lift using the one-repetition maximum (1RM) test. This test is recognized as the standard test for measuring the maximum strength of an athlete and for determining the training load intensity (Haff & Triplett, 2016; Stone et al., 2007).

Determination of Biomechanical Variables

In the process of kinematic analysis of the barbell, the following biomechanical variables were examined:
1. The maximum vertical velocity of the barbell
2. The maximum vertical displacement of the barbell
3. The maximum height attained by the barbell during the entire process of lifting it
4. The trajectory of the barbell (Bar Path) during the phases of lifting

An analysis of the barbell's trajectory can be used to determine the efficiency of the technical process in the performance of weightlifting, which can be used to determine the patterns of the vertical and horizontal movements of the barbell during the process (Häkkinen, 1984; Sandau et al., 2021). In addition to this, the phases of lifting were delineated to include the first pull, transition, second pull, and catch phases. An analysis of this process is significant to determine the mechanisms of performance in the Clean lift, including the changes in the movements that are performed during the process (Werner et al., 2020).

Pilot Study

A pilot study design was used with a sample of five students who were not part of the general population under consideration. A pilot study is used as a preliminary test to validate the efficacy of the used equipment and the feasibility of the procedures. In this case, the pilot study sought to:
1. Evaluate the quality of recorded images and the precision of the video recording process with the use of high-speed cameras.

2. Establish the optimal camera positions and the recording angles.
3. Establish the optimal distance between the cameras and the performance area, which was established at 5 meters.
4. Establish the efficacy of the visibility of the markers placed on the anatomical joints as the student performed the motion.
5. Evaluate the efficacy of the motion data extraction process with the use of the MediaPipe technique and the Kinovea software.

The pilot study established the feasibility of the procedures with the required precision, thus paving the way for the next stages.

Main Experiment

The performance area was prepared inside the weightlifting hall of the College of Physical Education and Sports Sciences. Two high-speed cameras (120 frames per second) were installed to record the movement performance during the Clean lift.
The cameras were positioned as follows:
Camera 1: Positioned in the sagittal plane to analyze lateral movement during the lift. Camera 2 was set up in the frontal plane for documentation purposes and to ensure that the movement for the lift was correctly aligned, as well as to ensure that there was no lateral movement during the execution of the lift.

Both cameras were set up 5 meters away from the performance area and at a height that was approximately equivalent to the hip joint to ensure an appropriate field of view for the capture of the movement for the lift (Figure 1).

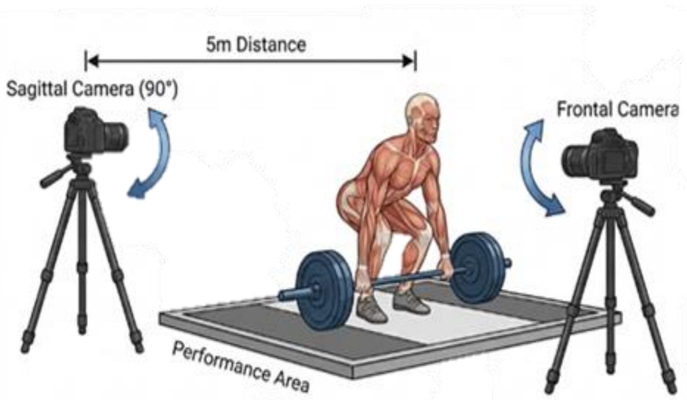

Figure 1. Experimental setup and camera placement for the recording of Clean lift performance

Procedural framework:
1. The participants underwent a warm-up process, which lasted for 15 minutes and involved both general and specific warm-up exercises.
2. The one-repetition maximum (1RM) of the Clean lift was determined for each participant.
3. Colored markers were attached to the primary anatomical landmarks of the hip, knee, and ankle of the participants.
4. The performance was recorded using high-speed cameras with the inclusion of a calibration scale in the frame of the recording.
5. Three successful attempts of the Clean lift at 70% of the participant's determined 1RM were performed.

6. The best successful attempt was chosen for further kinematic analysis.best successful attempt was selected for the kinematic analysis.

Data Processing: The motion data were processed using two different methods to examine the validity of the measurements.

1. MediaPipe Technique

The MediaPipe BlazePose library was implemented within the Python environment to extract the (X, Y) coordinates of 33 anatomical landmarks of the human body. Subsequently, the kinematic joint angles of the main lower-limb joints (knee, hip, and ankle) were calculated using joint-angle computation algorithms based on the extracted coordinates.

2. Kinovea Software

The Kinovea software was used to perform manual digitization of the joint points in each frame of the recorded video. The extracted coordinates were then converted into metric units using a calibration factor derived from the reference scale included in the video recording. After that, the kinematic variables were calculated and compared with those obtained using the MediaPipe technique.

Statistical Analysis

The statistical analysis of the data was carried out using the SPSS statistical program and Microsoft Excel. The statistical techniques used in the analysis of the collected data are as follows: Mean, Standard Deviation (SD), Pearson Correlation Coefficient (r), Intraclass Correlation Coefficient (ICC), Root Mean Square Error (RMSE), Paired Samples t-test, Bland-Altman method for assessing agreement.

RESEARCH RESULTS

Concurrent Validity of the Mediapipe Technique

The following table shows the complete results of the concurrent validity of the Mediapipe technique.

Table 2. Concurrent Validity of the Mediapipe Technique for Analyzing the Movement Performance of the Athlete

N= 30			
Variables	Correlation Coefficient (r)	RMSE	Significance Level
Knee angle (First Pull)	0.94	2.1°	0.001*
Hip angle (Second Pull)	0.91	3.4°	0.001*
Ankle angle (Catch Phase)	0.78	5.8°	0.01*
Peak vertical barbell velocity	0.96	0.04 m/s	0.001*
Maximum vertical barbell displacement	0.93	1.2 cm	0.001*
Peak barbell height	0.94	1.4 cm	0.001*
Barbell trajectory	0.92	1.6 cm	0.001*

Statistically Significant at $p \le 0.05$

Table 2 shows a strong correlation between the values measured by the Mediapipe technique and the values measured by the Kinovea software for the various kinematic parameters of the movement. However, the highest value of the correlation coefficient was found for the velocity of the barbell (0.96), followed by the angle of the knee joint (0.94). On the other hand, the lowest value of the correlation coefficient for the angle of the ankle joint during the catch phase of the movement was found to be 0.78. This might have resulted from the presence of the visual occlusion effect, as the movement of the barbell occurs close to the body.

The low value of the RMSE (2.1 - 3.4) indicates the presence of a minor measurement error, as the value falls well within the range of the acceptable values for the measurement of the angles of the joints.

Differences Between MediaPipe and Kinovea

The table below illustrates the summary of the comparison outcome between the two measurement techniques:

Table 3. Comparison between MediaPipe and Kinovea

Variables	MediaPipe (M ± SD)	Kinovea (M ± SD)	t-value	Significance Level
Knee angle (First Pull)	122.4 ± 6.3	121.8 ± 6.1	0.41	0.68
Hip angle (Second Pull)	168.2 ± 5.7	167.6 ± 5.5	0.36	0.71
Ankle angle (Catch Phase)	96.5 ± 4.8	94.9 ± 4.6	1.27	0.21
Peak vertical barbell velocity	1.72 ± 0.18	1.70 ± 0.17	0.29	0.77

The outcome in Table 3 indicates that there are no statistically significant differences between the measurements obtained by the MediaPipe technique and those obtained by the Kinovea software. This implies that there is a high level of agreement between the two techniques in the analysis of the kinematics involved in the Clean lift.

Measurement Reliability of the MediaPipe Technique

The table below shows the results for the intraclass correlation coefficient (ICC) using the ICC (3,1) model, as suggested by Koo & Li (2016):

Table 4. Measurement Reliability of the MediaPipe Technique

N= 30			
Variables	ICC	95% Confidence Interval	Interpretation
Joint angles	0.88	0.82 – 0.93	High reliability
Barbell velocity	0.91	0.85 – 0.95	Excellent reliability
Lift phase timing	0.85	0.79 – 0.90	High reliability

The results in Table 4 show that the MediaPipe technique has a high level of reliability, as the ICC results range from 0.85 to 0.91.

Agreement Analysis Between the Two Methods

The above figure illustrates the Bland-Altman plot used to analyze the agreement between the results obtained from the two methods used in this research.

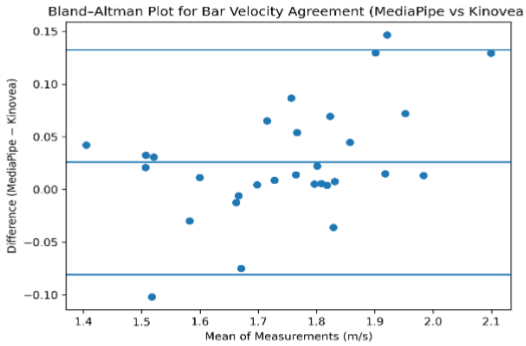

Figure 2. Bland-Altman plot illustrating the agreement between measurements of barbell velocity.

Figure 2 above illustrates a Bland-Altman plot used to analyze the agreement between the results obtained from the MediaPipe method and those obtained from Kinovea software in measuring peak vertical barbell velocity in the Clean lift. The above figure illustrates that a greater number of data points are within the region of agreement, thus illustrating a satisfactory level of agreement between the results obtained from the two methods in measuring peak vertical barbell velocity in the Clean lift.

Comparison of Barbell Trajectory

The above figure illustrates a comparison of the barbell trajectory obtained from both methods used in this research.

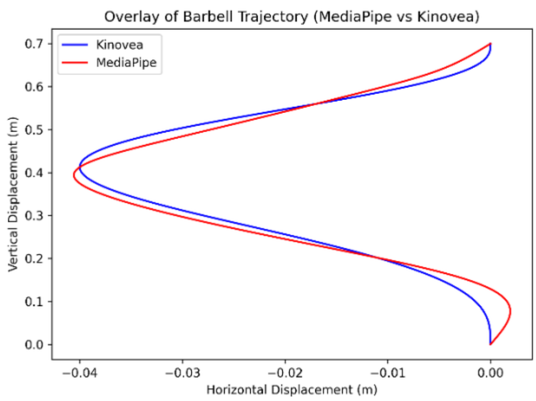

Figure 3. Overlay of barbell trajectory obtained from MediaPipe and Kinovea software.

Figure 3 above illustrates a comparison of the barbell trajectory obtained from both MediaPipe and Kinovea software in the execution of a Clean lift. The above figure illustrates a high level of similarity in the trajectories obtained from both methods used in this research.

DISCUSSION

This study revealed that there are high levels of correlation between the results obtained using the proposed MediaPipe technique and those obtained using the Kinovea software in measuring the kinematic variables for the Clean lift. In this study, the correlation coefficient was found to be 0.96 for the kinematics of the barbell, which indicated that the proposed technique has high levels of concurrent validity in measuring the performance of movements.

These findings are consistent with the study conducted by Sandau et al. (2021) that revealed that video motion analysis can accurately measure movement variables in weightlifting, especially with respect to the movement of the barbell. In addition, the findings are consistent with the study conducted by Jyothi et al. (2024) that revealed that machine learning-based pose estimation techniques can accurately measure the movement of the joints and the body with satisfactory levels of accuracy.

In this study, it was also revealed that the proposed technique has lower levels of accuracy in measuring the ankle joint angle during the catch phase, with the correlation coefficient being 0.78 and the measurement error being 5.8 degrees. It is believed that this could be since this phase occurs when the barbell is moving near the body, which may cause occlusion. It has been established that occlusion can be a major challenge in computer vision-based motion tracking systems. Thiele et al. (2024) revealed that markerless motion tracking systems may face difficulties in detecting certain joints due to the occlusion between the body segments or objects such as the barbell.

Regarding the reliability of the measurements, the results from the ICC calculation showed that the reliability was high, as indicated by the ICC results ranging from 0.85 to 0.91. These results show the reliability of the measurements from the MediaPipe method, as the results were consistent even when the measurements were repeated. Measurement reliability is an important aspect in research that focuses on the consistency of the measurements from the tools used in the biomechanical analysis.

In addition, the results from the comparison of the barbell movement trajectories from the MediaPipe method and the results from the Kinovea software showed that there was a significant similarity in the movement patterns, as suggested by the overlapping trajectories in the motion analysis figure. This shows that the MediaPipe method is valid in analyzing the kinematic movements in the Clean lift, as it was able to track the barbell movement trajectories.

The results from this study show that the MediaPipe method can function as an effective tool in analyzing the movement performance in educational and physical settings, as it allows for the examination of the kinematic movements using simpler technology compared to other motion analysis tools.

In the current study, the reference method for motion analysis was the Kinovea software, as it is widely used in research related to sports biomechanics. Even though the marker-based motion capture system, Vicon, is considered the "gold standard" for motion analysis, it is not feasible in many educational settings due to the high cost and complexity of the system.

Although the Kinovea software was used as the reference tool in evaluating the concurrent validity of the MediaPipe method, it should be noted that the marker-based motion capture system, Vicon, is still considered the gold standard in motion analysis in biomechanics. However, the results from this study show that the MediaPipe method can function as an alternative in educational settings where access to motion analysis tools is limited. Furthermore, the MediaPipe method can also function as an effective tool in assessing the technical performance of students in physical education programs.

CONCLUSIONS AND RECOMMENDATIONS

Based on the findings of the present study, the following conclusions may be drawn:

1. The application of the MediaPipe technique revealed a high level of concurrent validity for the measurement of the kinematic variables during the Clean lift phases, particularly for the first pull and second pull stages of the lift movement.
2. The results revealed a strong level of correlation between the measurements taken using the MediaPipe technique and the measurements taken using the Kinovea software, indicating the reliability of the application of the MediaPipe technique for the measurement of movement in the field setting.
3. The reliability of the measurements taken using the MediaPipe technique for repeated analyses indicates the application of the technique for the measurement of movement performance, particularly for the educational setting.
4. The results revealed a greater level of measurement errors for the measurement of the variables during the catch phase, which could be attributed to the effects of the visual occlusion phenomenon as the barbell passes closely to the body during the movement.

Based on the findings of the current research, the following recommendations may be offered:

1. MediaPipe technique may be used as a supplementary educational tool for the instruction of weightlifting skills in physical education and sport sciences.
2. MediaPipe technique may be used to facilitate the provision of feedback to the students and the athletes to improve the technical performance of the Clean lift.
3. High-speed cameras and a suitable recording area should be used to improve the precision of the motion analysis.
4. Future research should be conducted to use the MediaPipe technique to analyze the technical performance of the Snatch lift.
5. Further research should be conducted to use the three-dimensional motion analysis systems to improve the precision of the kinematic variables.

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