

Review

A Comprehensive Technical Review of Instruments for Vertical Jump Height Measurement in Sports Science

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Abstract: Vertical jump height is a fundamental measure of neuromuscular power in sports science. A diverse array of measurement instruments is available, yet selecting the appropriate technology requires a nuanced understanding of the trade-offs between accuracy, cost, and practicality. This comprehensive technical review synthesizes the current state of vertical jump instrumentation. We systematically analyze four primary methodologies: direct measurement, motion capture (kinematic), force platform (kinetic), and flight time-based systems. The underlying technical principles, error sources, and practical limitations of each are detailed. Our analysis reveals a clear hierarchy: force platforms and motion capture systems provide gold-standard accuracy (e.g., ± 0.3 cm for force platforms) but are constrained by high cost and laboratory environments. Conversely, flight time-based systems and smartphone applications offer excellent portability and accessibility but are subject to systematic errors (1-4 cm overestimation) and lower temporal resolution. Furthermore, we examine how emerging technologies, including artificial intelligence and wearable sensors, are poised to bridge the gap between laboratory-grade accuracy and field-based utility. This review provides engineers and sports scientists with a consolidated framework to guide instrument selection, data interpretation, and future innovation in athletic performance assessment.

Keywords: jump height measurement; force platforms; motion capture; flight time; instrumentation validation



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1 Introduction

Vertical jump height assessment represents a cornerstone evaluation method in sports science, serving as a fundamental indicator of neuromuscular power, athletic performance capacity, and training adaptation. The ability to generate rapid, forceful vertical displacement reflects the integrated function of the neuromuscular system, making jump height measurement invaluable for talent identification, performance monitoring, and injury prevention protocols across diverse athletic populations^[1]. From a biomechanical perspective, vertical jumping requires coordinated

activation of lower extremity muscle groups, optimal force-velocity relationships, and efficient energy transfer through the kinetic chain, establishing it as a comprehensive assessment of athletic function^[2-4].

The technical challenges inherent in accurate jump height measurement have driven the development of numerous instrumentation approaches, each employing distinct physical principles and measurement methodologies. Traditional methods such as jump-and-reach tests provide simplistic height estimation but fail to capture the true center of mass displacement. Contemporary instrumentation systems range from sophisticated force platforms and three-dimensional motion capture systems requiring laboratory

environments, to portable jump mats and smartphone applications enabling field-based assessments. This diversity in measurement approaches reflects the ongoing challenge of balancing measurement accuracy with practical implementation constraints across varied sporting contexts^[1,5-7].

Engineering considerations for jump height measurement systems encompass several critical factors that directly impact measurement validity and reliability. Sensor sensitivity and sampling frequency requirements vary significantly based on the rapid temporal dynamics of jumping movements, where critical events such as takeoff and landing occur within millisecond timeframes. Signal processing algorithms must accommodate noise interference, sensor drift, and environmental conditions while maintaining measurement precision across diverse user populations and jumping techniques. Additionally, calibration procedures, data synchronization between multiple sensors, and real-time processing capabilities present ongoing technical challenges for instrument designers^[8-11].

The biomechanical definition of jump height itself presents fundamental considerations for instrument design^[1]. True jump height represents the maximum vertical displacement of the body's center of mass from takeoff to peak height during the flight phase. This definition requires instruments to either directly track the center of mass trajectory or employ validated mathematical relationships between measurable parameters (such as flight time or takeoff velocity) and actual center of mass displacement^[9]. The rigid body model assumption for human movement during jumping provides the theoretical foundation for these calculations, though real-world applications must account for segmental movement variations and postural changes during jump execution^[12-15].

Contemporary instrumentation approaches can be systematically categorized based on their fundamental measurement principles and technical implementation strategies. Direct measurement systems employ physical markers or manual techniques to assess vertical displacement, while motion capture systems utilize optical tracking and computational algorithms to reconstruct three-dimensional movement patterns^[6]. Force platform systems measure ground reaction forces and calculate jump height through biomechanical principles, whereas flight time-based systems determine height from temporal measurements of airborne duration^[7]. Emerging artificial intelligence and computer vision technologies integrate multiple sensor modalities with machine learning algorithms to enhance measurement accuracy and automation capabilities^[11,12,16,17].

While numerous studies have compared the validity of two or three different systems, a comprehensive technical review that synthesizes the underlying physical principles, error sources, and practical implementation challenges across all major categories of instrumentation

is currently lacking. This review aims to fill that critical gap, providing engineers, researchers, and sports scientists with a consolidated and detailed analysis to inform instrument selection, data interpretation, and future development efforts in this rapidly evolving field. Our systematic examination of measurement methodologies, validation studies, and emerging technologies aims to inform instrument selection decisions and guide future development efforts in this rapidly evolving field.

2 Foundations of Jump Height Measurement Instrumentation

The diverse array of instruments available for measuring vertical jump height can be systematically categorized according to their fundamental physical principle of operation. These principles range from simple anthropometric estimates to complex kinetic and kinematic analyses, with each method possessing a unique set of advantages, limitations, and underlying assumptions that are critical for an engineering audience to understand. The choice of instrument often represents a trade-off between accuracy, portability, cost, and the specific data required by the practitioner. A vast body of literature is dedicated to comparing these systems to determine their concurrent validity and reliability, often using laboratory-grade systems as the criterion measure.

2.1 Biomechanical Principles and the Rigid Body Model

The theoretical foundation for vertical jump height measurement rests upon the rigid body model of human movement, which assumes that the body's center of mass (COM) follows predictable trajectory patterns during jumping^[9]. This model simplifies the complex multi-segmental nature of human anatomy into a single point mass, enabling mathematical calculations of jump height based on fundamental physics principles.

The rigid body assumption is particularly valid during the flight phase of vertical jumping, when external forces are limited to gravitational acceleration and the body maintains a relatively constant configuration^[14,15]. However, this assumption is a simplification, as in-flight movements of the arms and legs can alter the body's center of mass trajectory relative to its constituent segments. This is a potential source of error, particularly for flight time-based methods, which assume a perfectly parabolic trajectory determined solely by takeoff velocity.

Center of mass displacement during vertical jumping represents the true measure of jump performance, as it reflects the total energy conversion from muscular work to gravitational potential energy. This biomechanical process is illustrated in Figure 1. The location of the

human body's center of mass varies with anthropometric characteristics and segmental positioning, typically residing approximately at the level of the second sacral vertebra in anatomical standing position^[4,9]. During countermovement jumping, center of mass displacement occurs in two distinct phases: the propulsive phase where muscular forces accelerate the body upward, and the flight phase where gravitational forces decelerate the ascending center of mass until peak height is achieved^[13,15].

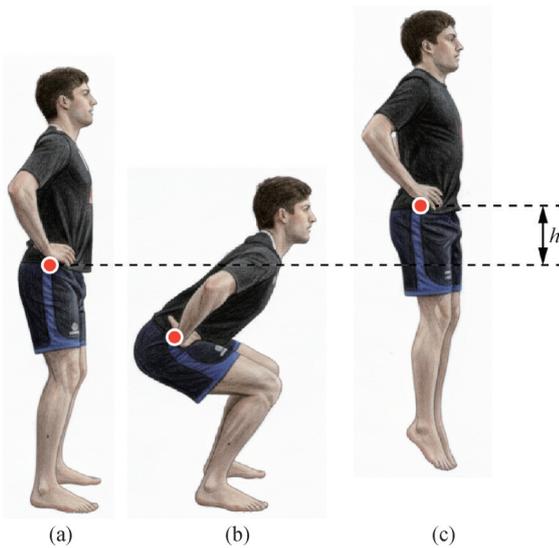


Fig.1 Biomechanical representation of the countermovement jump (CMJ). The phases include: (a) initial standing, (b) the lowest point of the countermovement phase, and (c) peak flight. The red dot represents the body's center of mass, and h is the peak vertical displacement of the center of mass from its initial standing position.

Mathematical representation of jump height follows from conservation of energy principles, where kinetic energy at takeoff converts to potential energy at peak height according to:

$$\frac{1}{2}mv_{to}^2 = mgh$$

where v_{to} represents takeoff velocity, g is gravitational acceleration (9.81 m/s^2), and h is jump height. This fundamental relationship establishes the theoretical basis for multiple measurement approaches, whether through direct velocity measurement, flight time calculations, or force integration methods^[9,13].

2.2 Mathematical Relationships for Jump Height Calculation

The flight time method represents the most widely implemented approach for jump height calculation, utilizing the kinematic equation for uniformly accelerated motion under gravitational influence. The relationship between flight time and jump height derives from the parabolic trajectory of the center of mass displacement during the airborne phase^[6,12]:

$$h = \frac{gt_{flight}^2}{8}$$

where t_{flight} represents total airborne duration. This equation assumes symmetric ascent and descent phases, with peak height occurring at exactly half the flight time. The constant 1.226 frequently referenced in literature ($h = 1.226 \times t^2$) represents a simplified version of this relationship using specific unit conversions^[1,12,18].

Alternative formulations for flight time calculations include the impulse-momentum approach, which determines takeoff velocity from force platform measurements and subsequently calculates height through energy conservation. The impulse-momentum method utilizes numerical integration of ground reaction forces during the propulsive phase^[9,19]:

$$\int_{t_1}^{t_2} (F_{GRF} - mg)dt = mv_{to}$$

where F_{GRF} represents ground reaction force, m is body mass, and the integration limits span the propulsive phase duration. This approach provides superior accuracy compared to flight time methods as it eliminates assumptions about landing configuration and directly measures the forces generating upward acceleration^[9,20].

The takeoff velocity method calculates jump height directly from measured or calculated velocity at the instant of ground departure:

$$h = \frac{v_{to}^2}{2g}$$

This relationship follows directly from energy conservation principles and provides high accuracy when velocity measurements are precise. Implementation requires either direct velocity measurement through motion capture systems or calculation from force platform data through numerical integration of acceleration profiles^[7,13]. These primary calculation models are summarized in Table 1.

Table 1 Summary of Jump Height Calculation Models

Calculation Method	Governing Principle	Core Equation	Key Variables
Flight Time	Kinematics	$h = \frac{gt_{flight}^2}{8}$	t_{flight} : total airborne time; g : gravity
Impulse-Momentum	Newton's Second Law	$v_{to} = \frac{1}{m} \int (F_{GRF} - mg)dt$	F_{GRF} : ground reaction force; m : mass; t : propulsive phase time
Takeoff Velocity	Energy Conservation	$h = \frac{v_{to}^2}{2g}$	v_{to} : takeoff velocity; g : gravity

2.3 Error Sources and Measurement Limitations

Systematic errors in jump height measurement arise from several fundamental sources related to the assumptions underlying each calculation method. Flight time-based calculations assume symmetric takeoff and landing configurations, an assumption frequently violated when subjects modify knee and ankle positioning during descent. This asymmetry typically results in an overestimation of jump height by 1-4 cm compared to methods that directly measure center of mass displacement^[1,6,8].

Force platform measurements encounter errors from several technical sources, including sensor calibration drift, sampling frequency limitations, and signal noise interference. Numerical integration procedures required for velocity and displacement calculations are susceptible to accumulated errors, particularly when integration time intervals are extended. Additionally, the rigid body assumption may be violated when significant trunk rotation or limb movement occurs during jumping, introducing kinematic errors into height calculations^[9,19,20].

Motion capture systems face accuracy limitations

related to marker placement, camera calibration, and three-dimensional reconstruction algorithms. The Direct Linear Transformation (DLT) algorithm commonly employed for coordinate reconstruction introduces computational errors that can affect final height measurements. Environmental factors such as lighting conditions, marker occlusion, and camera positioning further influence measurement precision in motion capture applications^[16,17].

Anthropometric factors contribute to measurement variability across different calculation methods. Foot length, leg length, and trunk dimensions affect the relationship between flight time and actual center of mass displacement, particularly when comparing jump mat measurements to motion capture results. These anthropometric influences underscore the importance of method-specific normalization procedures and population-specific validation studies [6, 10, 13]. Having established the fundamental biomechanical principles, mathematical models, and general error sources, the following sections will provide a detailed technical review of the primary instrumentation categories. These distinct approaches—kinetic, kinematic, and flight-time based—are visually summarized in Figure 2.

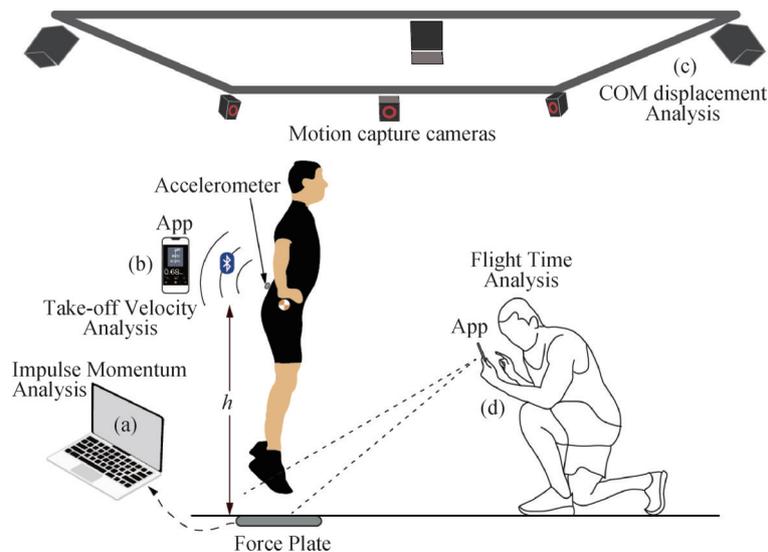


Fig.2 Schematic of the different methods used to measure vertical jump height: (a) Impulse-Momentum analysis from a force plate, (b) Take-off Velocity analysis from an accelerometer, (c) Center of Mass (COM) displacement analysis from motion capture cameras, and (d) Flight Time analysis from a mobile application.

3 Motion Capture Systems

3.1 Technical Principles and Implementation

Motion capture systems for vertical jump analysis employ sophisticated optical tracking technology to reconstruct three-dimensional movement patterns with high temporal and spatial resolution. These systems utilize multiple synchronized cameras positioned at strategic angles around the measurement volume to capture the trajectory of retroreflective markers placed on

anatomical landmarks of the jumper. The fundamental principle relies on triangulation algorithms that calculate three-dimensional coordinates from two-dimensional projections recorded by each camera, enabling precise tracking of body segment movements throughout the jump sequence^[16,17].

The Direct Linear Transformation (DLT) algorithm, first published by Abdel-Aziz and Karara in 1971, serves as the mathematical foundation for coordinate reconstruction in motion capture applications. This algorithm establishes a direct linear relationship between

two-dimensional camera coordinates and three-dimensional object space coordinates without requiring explicit knowledge of camera internal parameters or orientation. The DLT approach utilizes eleven transformation parameters per camera, determined through calibration procedures using known control points within the measurement volume^[16].

Implementation of motion capture for jump height measurement requires careful consideration of marker placement strategies to accurately represent the center of mass movement. Three distinct approaches are commonly employed: comprehensive full-body marker sets that enable calculation of total body center of mass through segmental analysis, reduced marker sets focusing on hip and pelvis landmarks as center of mass approximations, and single marker placement on the lower back region (typically L5 vertebra) as a simplified center of mass indicator. Each approach presents trade-offs between accuracy and practical implementation complexity^[7,15,17].

Camera configuration and calibration procedures critically influence measurement accuracy in motion capture applications. Optimal camera positioning requires consideration of measurement volume coverage, marker visibility throughout the jump trajectory, and geometric strength for triangulation calculations. Typical configurations employ 6-12 cameras arranged in a circular or semi-circular pattern around the jumping area, with sampling frequencies ranging from 100-1000 Hz depending on the specific application requirements^[12,16].

3.2 Accuracy and Validation Studies

Validation studies of motion capture systems for jump height measurement demonstrate excellent accuracy when compared to theoretical calculations and alternative measurement methods. Research by Cronin et al. (2024) reported root mean square errors of 0.01 m for center of mass height calculations with intraclass correlation coefficients exceeding 0.95, indicating high precision and reliability. The accuracy of three-dimensional reconstruction, measured as a percentage of total pixels in the image, typically remains below 1% for properly calibrated systems^[17].

Comparative studies examining motion capture against force platform measurements reveal systematic differences attributable to the distinct parameters measured by each system^[1]. Motion capture systems measure absolute center of mass displacement from standing position to peak height, while force platforms typically calculate displacement from takeoff instant to peak height. This fundamental difference results in motion capture measurements consistently exceeding force platform values by approximately 13-14 cm, primarily due to center of mass elevation during the countermovement phase^[6,10].

The influence of marker placement on measurement accuracy has been extensively investigated, with results indicating significant variations based on anatomical

landmark selection^[7]. Full-body marker sets provide the most accurate center of mass calculations through segmental mass distribution models, achieving errors below 1 cm in controlled laboratory conditions. Reduced marker sets utilizing hip and pelvis landmarks demonstrate slightly higher variability but maintain clinical acceptability for most applications. Single marker placement on the lower back shows increased error potential, particularly when trunk movement occurs during jumping^[17].

Environmental factors significantly impact motion capture accuracy, with lighting conditions, marker occlusion, and camera positioning serving as primary sources of measurement error. Automated markerless systems utilizing computer vision algorithms show promise for reducing setup complexity while maintaining acceptable accuracy levels. Recent developments in markerless motion capture report correlation coefficients ranging from 0.84 to 0.99 when validated against traditional marker-based systems^[17].

3.3 Practical Considerations and Limitations

Implementation of motion capture systems for routine jump height assessment faces several practical challenges that limit widespread adoption outside research environments. System complexity requires specialized technical expertise for camera calibration, marker placement, data collection, and post-processing analysis. Setup time for typical motion capture sessions ranges from 30-60 minutes, significantly longer than alternative measurement methods^[17].

Cost considerations represent a substantial barrier to motion capture implementation, with complete systems ranging from \$50,000- \$500,000 depending on camera quantity, resolution, and software capabilities. Additionally, dedicated laboratory space with controlled lighting conditions and minimal environmental interference is typically required for optimal system performance. These requirements restrict motion capture applications primarily to research institutions and high-performance training centers^[17].

Data processing complexity presents ongoing challenges for the routine implementation of motion capture technology. Raw coordinate data requires extensive post-processing including gap filling, trajectory smoothing, filtering, and biomechanical model application to generate meaningful jump height measurements. Processing time for a single jump trial typically ranges from 15-30 minutes with experienced operators, limiting real-time feedback capabilities^[17].

Recent technological advances aim to address these limitations through the development of simplified motion capture approaches^[5]. Single-camera markerless systems utilizing smartphone technology demonstrate potential for field-based applications, though accuracy remains inferior to laboratory-based multi-camera systems. Integration of artificial intelligence and computer vision

algorithms shows promise for automating data processing and reducing technical expertise requirements^[11,17].

A significant development in this area is the use of markerless motion capture systems, which leverage deep learning-based pose estimation algorithms (e. g., OpenPose, as explored in the reference) to identify and track anatomical landmarks from standard video. The primary advantage of this technology is its potential to democratize motion analysis by removing the need for physical markers and dedicated laboratory spaces. However, current implementations face challenges in accuracy, particularly when reconstructing 3D coordinates from single-camera 2D video. Errors in pose estimation can propagate and become magnified during biomechanical calculations, leading to significant discrepancies when compared to gold-standard marker-based systems. Continued advancements in neural network architectures and multi-view integration are expected to improve the accuracy and viability of these promising systems.

4 Force Platform Systems

4.1 Technical Specifications and Operating Principles

Force platforms represent the current gold standard for vertical jump height measurement in research and high-performance athletics, employing sophisticated load cell technology to measure tri-axial ground reaction forces with exceptional precision^[9]. Modern force platforms utilize strain gauge, piezoelectric, or piezo-resistive sensing elements arranged in multiple force transducers positioned at the corners of a rigid mounting plate. These transducers convert mechanical forces into electrical signals that are amplified, filtered, and digitized at sampling frequencies typically ranging from 1000-2000 Hz^[19-21].

The fundamental principle underlying force platform measurement involves Newton's second law of motion, where the net force acting on the body equals the product of mass and acceleration.

$$F_{\text{net}} = ma$$

During vertical jumping, the ground reaction force,

$$F_{\text{GRF}}$$

Measured by the platform, combined with the known body weight mg , enables calculation of the net accelerating force according to^[9,20]:

$$F_{\text{net}} = F_{\text{GRF}} - mg = ma$$

This net force, when integrated over time, provides the change in momentum and subsequently the takeoff velocity required for jump height calculations^[19].

Load cell configurations in force platforms vary based on intended applications and accuracy requirements. High-end laboratory force platforms employ multiple independent load cells (typically 4-8) to measure forces and moments in all six degrees of

freedom, enabling calculation of the center of pressure trajectory and force vector orientations. Portable force platforms designed for field applications may utilize fewer sensors with reduced accuracy but enhanced portability and cost-effectiveness^[19-22].

Signal conditioning and data acquisition systems in force platforms must accommodate the rapid force changes characteristic of jumping movements while maintaining high accuracy across the full measurement range. Typical force platforms measure forces ranging from 0-10,000 N with resolution better than 0.1% of full scale and linearity within $\pm 0.5\%$. Anti-aliasing filters prevent signal distortion from high-frequency noise, while amplification systems provide sufficient signal-to-noise ratios for accurate measurement of small force variations^[9,20-22].

4.2 Calculation Methods and Accuracy Assessment

Force platform systems employ two primary calculation methods for jump height determination: the impulse-momentum approach and the takeoff velocity method, both providing superior accuracy compared to flight time-based alternatives. The impulse-momentum method integrates the net force over the propulsive phase duration to determine the change in momentum, subsequently calculating takeoff velocity and jump height^[9,19,20]:

$$\Delta p = \int_{t_1}^{t_2} F_{\text{net}} dt = mv_{to}$$

where Δp represents momentum change, t_1 and t_2 define the propulsive phase boundaries, and v_{to} is the calculated takeoff velocity. This approach eliminates assumptions about landing configuration and directly measures the forces responsible for upward acceleration^[9].

The takeoff velocity method calculates velocity through numerical integration of the acceleration-time curve derived from force measurements. This approach requires double integration to obtain displacement, introducing potential accumulated errors but providing detailed kinematic analysis throughout the movement. Integration procedures typically employ trapezoidal or Simpson's rule algorithms with appropriate boundary conditions to minimize computational errors^[9, 13, 14, 21].

Comparative validation studies consistently demonstrate superior accuracy of force platform methods over flight time alternatives. Research by Xu et al. (2023) reported that impulse-momentum calculations provide the most accurate representation of jump height from takeoff instant to peak elevation, with measurement errors typically below 1 cm. The systematic overestimation characteristic of flight time methods (ranging from 0.6-4.1 cm) is eliminated through force-based calculations that directly measure the accelerating forces^[1,9].

Reliability assessment of force platform measurements demonstrates excellent consistency across repeated trials and different operators. Intraclass

correlation coefficients for jump height measurements consistently exceed 0.90, with coefficients of variation below 5% for experienced users. The typical error of measurement for force platforms ranges from 0.3 to 1.0 cm depending on the specific system and calculation method employed^[9,20,21].

4.3 Portable and Emerging Force Platform Technologies

Development of portable force platform systems addresses the limitations of traditional laboratory-based equipment by providing accurate force measurement capabilities in field environments. These systems maintain measurement accuracy comparable to laboratory platforms while offering enhanced portability, reduced cost, and simplified setup procedures. Validation studies of portable force platforms demonstrate correlation coefficients exceeding 0.94 when compared to laboratory-grade equipment^[20,21].

Recent innovations in portable force platform design include wireless data transmission, integrated battery power systems, and ruggedized construction suitable for outdoor use. Portable force platforms demonstrate excellent validity with over 94% of measurements falling within acceptable limits of agreement when compared to laboratory standards. Similarly, research-grade portable systems maintain high accuracy with correlation coefficients exceeding 0.94 for jump height measurements^[19,20].

Technical considerations for portable force platform implementation include sampling frequency optimization, wireless data transmission reliability, and battery life management. Many portable systems reduce sampling frequencies to 500-1000 Hz compared to laboratory systems operating at 2000+ Hz, though validation studies indicate minimal impact on jump height measurement accuracy. Wireless transmission systems must maintain data integrity while providing real-time feedback capabilities for practical field applications^[20-22].

Emerging force platform technologies incorporate advanced signal processing algorithms, cloud-based data management, and integration with other monitoring systems. Future developments focus on further miniaturization, cost reduction, and integration with wearable sensor technologies to provide comprehensive movement analysis capabilities^[7,20].

5 Flight Time-Based Systems

5.1 Contact Mat Technologies and Operating Principles

Contact mat systems represent the most widely implemented approach for practical jump height measurement, utilizing pressure-sensitive switching mechanisms to detect takeoff and landing events during vertical jumping. These systems operate on the

fundamental principle that jump height can be calculated from flight time duration using the kinematic equation

$$h = gt_{\text{flight}}^2 / 8$$

Requiring only accurate temporal measurement of the airborne phase. The simplicity of this approach, combined with relatively low cost and high portability, has established contact mats as standard equipment in sports science applications^[6,8,10,12].

Traditional contact mat designs employ mechanical switching circuits that open when pressure is removed from the mat surface and close upon contact^[10]. These systems utilize spring-loaded contacts, pressure-sensitive resistors, or piezoelectric elements to detect force application. Modern implementations incorporate matrix arrays of force-sensitive resistors (FSR) distributed across the mat surface, providing higher resolution and accuracy compared to simple switch-based designs. Advanced systems may employ up to 256 individual sensors arranged in 16×16 grids, significantly improving spatial resolution and reducing sensitivity to foot placement variations^[18].

The Chronojump system, developed as an open-source alternative to proprietary jump mats, has undergone extensive validation studies demonstrating excellent reliability and accuracy. Research by Pueo et al. (2020) reported intraclass correlation coefficients of 0.999-1.000 when comparing Chronojump measurements to established commercial systems, with mean differences of only 0.03 ± 0.21 cm. The open-source nature of this system enables customization and cost-effective implementation while maintaining research-grade accuracy^[10].

Commercial contact mat systems such as the Optojump photoelectric system employ infrared light barriers rather than pressure-sensitive surfaces, detecting interruption of light beams to determine takeoff and landing timing. These optical systems eliminate mechanical wear issues associated with pressure-based mats while providing precise temporal resolution. Validation studies comparing optical and pressure-based systems demonstrate comparable accuracy for jump height measurement applications^[10].

5.2 Smartphone Applications and Video Analysis

Smartphone applications have emerged as highly accessible alternatives to dedicated jump measurement equipment, utilizing the ubiquitous availability of high-resolution cameras and sophisticated processing capabilities. These applications employ video analysis techniques to manually or automatically identify takeoff and landing frames, calculating flight time and subsequently jump height. The My Jump application series represents the most extensively validated smartphone-based measurement tool, with numerous studies confirming its accuracy and reliability across diverse populations^[8,23].

The fundamental approach employed by smartphone

applications involves recording jump execution at standard video frame rates (typically 120-240 fps) and analyzing the recorded footage to identify critical temporal events. Manual analysis requires user selection of takeoff and landing frames, while automated systems employ computer vision algorithms to detect these events. The accuracy of smartphone-based measurements depends critically on camera positioning, frame rate selection, and the precision of event identification^[5,11,23].

Validation studies of the My Jump application demonstrate strong correlations with force platform measurements, with intraclass correlation coefficients typically ranging from 0.90-0.99. However, systematic biases are frequently observed, with smartphone applications generally underestimating jump height by 1-4 cm compared to force platform measurements. This underestimation primarily results from the lower temporal resolution of video recording compared to force platform sampling frequencies.

Recent developments in smartphone-based jump measurement incorporate artificial intelligence algorithms to improve automated event detection and reduce measurement errors. Applications utilizing machine learning techniques to identify takeoff and landing events show reduced dependency on manual frame selection. However, validation studies indicate that AI-enhanced applications may overestimate jump height by 2-5 cm compared to force platform measurements, suggesting ongoing challenges in automated event detection algorithms^[11,28].

5.3 Audio-Based Measurement Systems

Audio-based jump height measurement represents an innovative approach that utilizes sound detection algorithms to identify takeoff and landing events during vertical jumping. This methodology employs the acoustic signatures generated by foot contact with the ground surface, processing these audio signals through specialized algorithms to extract flight time measurements. Research by Pueo et al. (2019) first demonstrated the feasibility of audio-based measurement, achieving accuracies comparable to traditional contact mat systems^[11].

The technical implementation of audio-based systems requires sophisticated signal processing algorithms capable of distinguishing genuine takeoff and landing sounds from environmental noise. Initial approaches employed classical signal processing techniques including frequency domain analysis and threshold-based detection methods. However, these methods demonstrated sensitivity to background noise and acoustic interference, limiting their applicability in typical sports environments.

Recent advances incorporate deep neural networks trained specifically for jump sound recognition, significantly improving robustness and accuracy in challenging acoustic environments. The system demonstrates particular promise for field-based

applications where traditional measurement equipment may be impractical^[28].

Validation studies comparing audio-based systems to contact mat references report measurement errors of approximately 4 cm, with accuracy varying based on environmental acoustic conditions. The primary advantage of audio-based measurement lies in its non-contact nature and potential for smartphone integration, enabling widespread accessibility without requiring specialized equipment. Future developments focus on improving noise immunity and expanding the training database to encompass diverse jumping techniques and environmental conditions^[11,28].

5.4 Accuracy Limitations and Systematic Errors

Flight time-based measurement systems exhibit characteristic systematic errors that result in a consistent overestimation of jump height compared to methods that directly measure center of mass displacement. The primary source of error stems from the assumption that ascent and descent phases are temporally symmetric, requiring identical knee and ankle configurations at takeoff and landing. In practice, subjects frequently modify lower limb positioning during descent, extending the measured flight time and artificially inflating calculated jump height^[1,6,12].

Research examining the magnitude of flight time overestimation reports systematic differences ranging from 0.6 to 4.1 cm compared to impulse-momentum calculations from force platforms. The extent of overestimation correlates with the degree of limb flexion during landing, with greater knee and ankle flexion producing larger measurement errors. This variability introduces uncertainty when comparing results across different subjects or testing sessions, particularly with inexperienced jumpers who may exhibit inconsistent landing techniques^[1,6].

Additional error sources in flight time measurements include sensor sensitivity limitations, particularly in contact mat systems that require minimum activation forces. Research comparing contact mats to alternative measurement methods indicates that minimum force requirements can delay detection of ground contact, artificially extending measured flight time. Similarly, the finite temporal resolution of video-based smartphone applications introduces quantization errors that affect measurement precision^[5, 6, 10].

Environmental factors further influence flight time measurement accuracy, including surface compliance, temperature effects on sensor performance, and electromagnetic interference in electronic systems. The portability advantage of flight time systems often requires operation in varied environmental conditions that may not be optimal for sensor performance, introducing additional measurement variability. Despite these limitations, flight time-based systems remain valuable tools for practical jump assessment when measurement

errors are acknowledged and accounted for in data interpretation^[6,10,18].

6 Artificial Intelligence and Computer Vision Systems

6.1 Machine Learning Applications in Jump Measurement

Artificial intelligence applications for jump height measurement have evolved rapidly, addressing fundamental limitations of traditional measurement approaches through sophisticated pattern recognition and predictive modeling techniques. Machine learning algorithms demonstrate particular efficacy in smartphone-based applications, where they compensate for hardware limitations and sensor noise that typically degrade measurement accuracy. Feature selection typically encompasses both biomechanically relevant parameters (such as peak acceleration and movement duration) and signal characteristics that may compensate for measurement artifacts^[7,24].

Validation studies of machine learning-enhanced measurement systems demonstrate promising accuracy improvements, particularly for low-cost sensor implementations. However, these improvements require extensive training datasets and may not generalize effectively across diverse populations or jumping techniques without retraining procedures. Cross-population validation represents a critical challenge for AI-based measurement systems, as training datasets may not adequately represent diverse athletic populations or jumping techniques^[7].

The integration of multiple sensor modalities with automated analysis pipelines provides comprehensive jump assessment capabilities. These systems combine inertial measurement units, force sensors, and computer vision to cross-validate measurements and enhance overall accuracy. The multi-sensor approach enables detection and correction of individual sensor limitations while providing rich biomechanical feedback beyond simple jump height measurements^[24].

Real-time processing capabilities represent a critical advancement in AI-enhanced jump measurement systems, enabling immediate feedback during training sessions. The audio-based system with deep neural networks achieves real-time jump detection and height calculation, providing instantaneous results comparable to traditional contact mat systems. Similarly, smartphone applications incorporating AI algorithms can process jump recordings within seconds of completion, maintaining practical usability for field applications^[7,11,23].

6.2 Computer Vision and Markerless Motion Analysis

Computer vision applications for jump height

measurement aim to combine the accuracy of motion capture systems with the accessibility and simplicity of smartphone-based solutions. These systems employ advanced image processing algorithms to track body landmarks without requiring physical markers, potentially eliminating setup complexity while maintaining acceptable measurement precision. Pose estimation frameworks enable real-time pose estimation from single-camera recordings, facilitating practical implementation in diverse settings^[17].

The technical implementation of markerless motion capture relies on deep neural networks trained to identify anatomical landmarks from two-dimensional images. These algorithms estimate joint positions and subsequently calculate the center of mass trajectory using biomechanical models. The accuracy of markerless systems depends critically on camera positioning, image quality, and the sophistication of the underlying pose estimation algorithms.

Validation studies comparing markerless computer vision to traditional motion capture reveal significant accuracy limitations in current implementations. Research by Cronin et al. (2024) reported poor agreement between markerless tracking and manual digitization, with large discrepancies resulting from pose estimation errors that propagate through biomechanical calculations. These large discrepancies result from pose estimation errors that propagate through biomechanical calculations, producing unrealistic kinematic values^[17].

Recent developments focus on improving pose estimation accuracy through enhanced neural network architectures and domain-specific training procedures. The integration of multiple camera views and temporal constraints shows promise for reducing pose estimation errors, though computational requirements remain substantial. Future implementations may benefit from edge computing capabilities in modern smartphones, enabling real-time processing without requiring cloud-based computation^[11,17].

6.3 Validation Challenges and Future Directions

Validation of AI-enhanced jump measurement systems presents unique challenges related to algorithm transparency, generalizability, and reference standard selection. Traditional validation approaches comparing AI systems to force platform measurements may be insufficient, as these systems often attempt to estimate parameters that differ from force platform outputs. The "black box" nature of many machine learning algorithms, where the internal decision-making process is not transparent, complicates the diagnosis of specific error sources and limits scientific confidence in novel measurement scenarios^[24].

The temporal stability of AI-enhanced measurement systems requires ongoing assessment, as algorithm performance may degrade over time due to hardware changes, software updates, or population drift in user

characteristics. Unlike traditional measurement equipment that maintains consistent calibration over extended periods, AI systems may require periodic retraining or validation to ensure continued accuracy^[28].

Standardization challenges for AI-enhanced measurement systems include the lack of established protocols for algorithm validation, uncertainty quantification, and quality assurance procedures. The absence of regulatory frameworks for AI-based measurement devices complicates implementation in clinical and research settings where measurement

traceability and uncertainty assessment are essential. Future developments require the establishment of standardized validation protocols and uncertainty assessment methods specific to AI-enhanced measurement systems^[24]. To consolidate the information presented in the preceding sections, a comprehensive comparison of the key characteristics across the different vertical jump measurement technologies is provided. This summary highlights the trade-offs between accuracy, cost, portability, and ease of use for each category. For a direct comparison of these methodologies, refer to Table 2.

Table 2 Comparison of Vertical Jump Measurement Technologies

Technology Category	Primary Instruments	Typical Accuracy	Approx. Cost	Portability & Ease of Use	Key Limitations
Kinetic	Force Platforms	Gold Standard (± 0.3 cm)	High (\$10k - \$500k+)	Low (Lab-bound) Requires technical expertise.	High cost, lack of portability, complex setup.
Kinematic	Motion Capture Systems	Gold Standard (Direct CM measurement)	Very High (\$50k - \$500k)	Low (Lab-bound) Time-consuming setup & processing.	Highest cost, facility requirements, technical expertise needed.
Temporal (Flight Time)	Contact Mats, Optical Systems (e.g., Optojump)	Good (Overestimates by 1-4 cm)	Low to Medium (< \$1,000)	High Simple to use, immediate feedback.	Systematic overestimation due to landing technique; sensitive to surface.
Video/App-Based	Smartphone Applications (e.g., My Jump)	Fair to Good (± 4 cm, can underestimate)	Very Low (<\$20)	Very High Extremely accessible.	Accuracy dependent on video frame rate and precision of event marking.
AI / Novel Sensing	Wearable IMUs, Audio-based systems	Variable (Emerging) (Promising, but requires validation)	Low to Medium	High	"Black box" algorithms; may require large training datasets; generalizability can be a concern.

7 Future Directions and Emerging Technologies

7.1 Miniaturized Sensor Technologies and Wearable Systems

The evolution toward miniaturized sensor technologies promises to revolutionize jump height measurement through ultra-compact, wearable devices that maintain research-grade accuracy while eliminating environmental constraints. Advanced microelectromechanical systems (MEMS) accelerometers and gyroscopes now achieve measurement precision previously available only in laboratory-grade equipment, enabling accurate inertial measurement unit (IMU) implementations in devices smaller than conventional contact mats. These miniaturized sensors demonstrate sampling rates exceeding 1000 Hz with resolution sufficient for precise kinematic analysis during rapid jumping movements.

Emerging wearable sensor configurations optimize placement strategies to maximize measurement accuracy while minimizing user interference. Research indicates that hip-mounted sensors provide optimal balance between accuracy and practical implementation,

achieving correlation coefficients of 0.87-0.95 when compared to reference measurements. Advanced algorithms compensate for trunk rotation and postural variations that previously limited wearable sensor accuracy, enabling reliable measurement across diverse jumping techniques and user populations^[7,24].

Integration of multiple sensor modalities within a single wearable device enhances measurement robustness and provides comprehensive biomechanical analysis capabilities. Contemporary developments combine tri-axial accelerometers, gyroscopes, magnetometers, and barometric pressure sensors to create comprehensive inertial measurement platforms. These multi-sensor approaches enable cross-validation of measurements and detection of sensor malfunctions that might compromise measurement accuracy^[7].

Wireless communication capabilities in miniaturized sensors facilitate real-time data transmission and cloud-based processing, enabling sophisticated analysis without compromising device portability. Low-power wireless protocols such as Bluetooth Low Energy provide extended battery life while maintaining reliable data transmission for field applications. Future implementations may incorporate energy harvesting

technologies to achieve indefinite operation without battery replacement requirements^[24].

7.2 Standardization and Validation Protocols

The development of comprehensive standardization protocols for emerging jump measurement technologies represents a critical requirement for widespread adoption in research and clinical applications. Current validation approaches lack consistency across different measurement modalities, complicating the comparison of results and limiting confidence in novel technologies. Establishment of standardized reference methods, uncertainty assessment procedures, and calibration protocols will facilitate objective evaluation of emerging measurement systems^[25, 26].

International standards organizations increasingly recognize the need for measurement device standards specific to sports science applications, with preliminary frameworks emerging for jump measurement systems. These standards address calibration procedures, uncertainty quantification, environmental operating conditions, and validation methodology requirements. Implementation of standardized protocols will enable objective comparison of different measurement technologies and facilitate regulatory approval for clinical applications.

Validation protocol development must address the unique challenges presented by AI-enhanced and computer vision-based measurement systems, including algorithm transparency, training dataset adequacy, and generalizability assessment. Traditional measurement validation approaches may be insufficient for AI-based systems that employ non-transparent algorithms and require extensive training data. New validation frameworks must incorporate assessment of algorithm robustness, bias detection, and uncertainty quantification specific to machine learning applications^[24].

Collaborative efforts between research institutions, commercial developers, and standards organizations aim to establish consensus validation protocols that balance innovation encouragement with measurement quality assurance. These collaborative approaches recognize the rapid pace of technological development while ensuring that new measurement systems meet established accuracy and reliability requirements. Future standardization efforts may incorporate automated validation procedures and continuous monitoring protocols to maintain measurement quality throughout device lifecycles^[1].

7.3 Integration with Comprehensive Monitoring Platforms

Future jump measurement systems will increasingly integrate with comprehensive athlete monitoring platforms that combine multiple performance metrics, injury risk indicators, and training load assessments. These integrated platforms utilize jump height measurements as one component of holistic athlete

evaluation systems that provide coaches and athletes with comprehensive performance insights. Cloud-based data integration enables longitudinal tracking and population-based comparisons that extend beyond individual measurement sessions.

Artificial intelligence applications within integrated monitoring platforms can identify patterns and relationships between jump performance and other physiological or biomechanical parameters. Machine learning algorithms analyze trends across multiple assessment modalities to provide predictive insights regarding performance optimization and injury prevention. These capabilities represent a substantial advancement over traditional single-parameter assessments that provide limited contextual information^[26].

Interoperability requirements for integrated monitoring platforms necessitate standardized data formats and communication protocols that enable seamless integration of measurements from diverse sensor technologies. Open-source data standards and application programming interfaces facilitate integration of third-party measurement devices and analysis algorithms. These standardization efforts prevent vendor lock-in scenarios while promoting innovation through collaborative development approaches.

Privacy and data security considerations become increasingly important as jump measurement systems integrate with comprehensive monitoring platforms that may contain sensitive athlete information. Robust security protocols, data encryption, and user consent mechanisms must be implemented to protect athlete privacy while enabling beneficial data sharing for research and performance optimization. Future platforms may incorporate blockchain technologies to provide transparent and secure data sharing capabilities.

8 Discussion

8.1 Comparative Analysis of Measurement Methodologies

The comparative analysis of measurement methodologies, summarized in Table 2, reveals that no single instrument provides an optimal solution for all applications. Instead, a clear trade-off exists along a continuum from laboratory-grade precision to field-based practicality. At one end, force platform systems represent the kinetic gold standard, offering unparalleled accuracy. However, their substantial financial and technical requirements effectively restrict their use to foundational research and elite performance diagnostics. At the opposite end, flight time-based systems democratize jump assessment through exceptional portability and low cost, but at the expense of accuracy, introducing a well-documented systematic overestimation due to landing technique variations^[1, 6, 9, 10, 19].

Occupying a unique position, motion capture

systems provide the richest biomechanical data, allowing for detailed kinematic analysis beyond simple jump height. While also considered a gold standard for measuring direct center of mass displacement, their implementation complexity and cost are prohibitive for routine monitoring. It is critical to note that the systematic difference of 13-14 cm often observed between motion capture and force platform data is not an issue of accuracy, but rather a fundamental distinction in the measured parameter: motion capture measures total displacement from standing, while force platforms calculate displacement from the instant of takeoff. This highlights the necessity of understanding the core principles of a system when interpreting its results^[6, 10, 17].

Emerging smartphone applications and AI-enhanced systems demonstrate promise for democratizing jump height assessment, with validation studies indicating measurement errors of 2-5 cm when properly implemented. These systems offer unprecedented accessibility and user convenience, though measurement accuracy remains inferior to laboratory-grade equipment. The rapid development pace in smartphone-based measurement suggests potential for continued accuracy improvements through algorithmic refinements and hardware advances^[5, 11, 23].

The selection of appropriate measurement methodology must consider the specific application requirements, including accuracy needs, cost constraints, portability requirements, and user expertise levels. High-performance athletics and research applications may justify the cost and complexity of force platform or motion capture systems, while routine training monitoring may benefit from the practicality of flight time-based or smartphone systems. Understanding the systematic errors and limitations of each approach enables appropriate interpretation of results across different measurement contexts^[1, 6, 10].

8.2 Technical Challenges and Implementation Considerations

Current jump height measurement technologies face several common technical challenges that influence measurement accuracy and practical implementation. Temporal resolution requirements for accurate event detection represent a fundamental constraint, particularly for flight time-based systems where millisecond-level precision directly affects measurement accuracy. Advanced systems typically require sampling frequencies exceeding 1000 Hz to achieve optimal temporal resolution, though portable systems often compromise sampling rates to extend battery life and reduce computational requirements^[6, 7, 9, 12, 20, 24].

Calibration and standardization procedures vary significantly across different measurement technologies, complicating direct comparison of results from different systems. Force platforms require regular calibration against known weights and forces, while contact mats

may need adjustment for different surface conditions and user weights. Smartphone applications depend on camera calibration and frame rate verification, though these procedures are typically transparent to end users. Standardization of calibration protocols across different measurement modalities remains an ongoing challenge^[5, 6, 9, 25, 26].

Environmental influences affect measurement accuracy across all system types, though specific sensitivities vary based on the underlying measurement principles. Force platforms demonstrate excellent stability in controlled environments but may be sensitive to vibration and temperature variations in field applications. Contact mats can be affected by surface compliance and moisture conditions, while optical systems require adequate lighting and may be sensitive to shadows or reflective surfaces. Understanding and controlling these environmental factors is essential for maintaining measurement quality^[8, 10, 17, 19, 20].

User technique variations represent a significant source of measurement variability affecting all measurement systems, though their influence varies by specific methodology. Flight time-based systems demonstrate particular sensitivity to landing technique consistency, while force platform systems may be influenced by countermovement depth and timing variations. Standardization of jumping protocols and user instruction procedures can minimize technique-related variability, though individual differences in movement patterns remain challenging to eliminate entirely^[1, 6, 9].

8.3 Validation Methodology and Quality Assurance

The diversity of jump height measurement technologies necessitates equally diverse validation approaches that account for the specific principles and limitations of each system. Traditional validation protocols comparing new systems to force platform references may be inadequate for technologies that measure fundamentally different parameters or employ AI-based algorithms with limited transparency. The development of validation frameworks that acknowledge systematic differences while assessing measurement quality represents an ongoing challenge in the field^[1, 7, 9, 25].

Reference standard selection presents particular challenges when validating emerging measurement technologies, as different systems may provide accurate measurements of different biomechanical parameters. Motion capture systems measure absolute center of mass displacement from standing position, while force platforms typically calculate displacement from takeoff instant. Flight time-based systems estimate height based on temporal measurements that may not correspond exactly to either motion capture or force platform parameters. Recognition of these fundamental differences is essential for appropriate validation study design and

result interpretation^[1,6,9,12].

Statistical approaches for validation assessment must account for both systematic and random errors that characterize different measurement systems. Traditional correlation analysis may be insufficient for detecting systematic biases that affect clinical or practical interpretation of results. Bland-Altman analysis provides a superior assessment of measurement agreement, though interpretation requires understanding of acceptable error limits for specific applications. Validation studies should incorporate assessment of both accuracy (systematic error) and precision (random error) to provide a comprehensive evaluation of measurement quality^[1,6,20,25].

Longitudinal validation requirements for emerging technologies, particularly AI-enhanced systems, present unique challenges not encountered with traditional measurement equipment. Machine learning algorithms may exhibit performance degradation over time due to population drift or hardware changes, necessitating ongoing validation throughout the device lifecycle. Additionally, algorithm updates and software modifications may alter measurement characteristics, requiring revalidation to ensure continued accuracy. Development of automated validation procedures and continuous monitoring protocols may be necessary to maintain quality assurance for evolving measurement systems^[7,25,28].

8.4 Clinical and Practical Applications

The practical implementation of jump height measurement systems must consider the specific requirements and constraints of different application contexts, ranging from elite sports performance monitoring to clinical rehabilitation assessment. High-performance athletics applications may justify substantial investment in force platform or motion capture systems to achieve maximum measurement accuracy and comprehensive biomechanical analysis. These applications benefit from the enhanced precision and detailed feedback available from laboratory-grade equipment, supporting sophisticated training optimization and performance monitoring protocols^[3,9,17,19,20,25].

Clinical applications in rehabilitation and injury prevention contexts typically require different performance characteristics, emphasizing reliability, ease of use, and patient safety over maximum measurement precision. Portable force platforms or flight time-based systems may provide optimal balance between measurement quality and practical implementation in clinical environments. The ability to conduct assessments in natural movement environments, rather than laboratory settings, may provide more relevant information for clinical decision-making^[3,10,20,22,25].

Educational and recreational applications benefit from the accessibility and low cost of smartphone-based measurement systems, despite their inferior accuracy compared to research-grade equipment. These systems

enable widespread access to jump height assessment and may encourage participation in physical fitness activities through gamification and social sharing features. The educational value of immediate feedback and longitudinal tracking may outweigh the measurement precision limitations for non-elite applications^[5,11,23].

Future application development must address the growing demand for remote monitoring and telehealth capabilities. Smartphone and AI-enhanced measurement systems provide potential solutions for remote athlete monitoring and home-based rehabilitation assessment. However, implementation requires careful consideration of data security, user instruction protocols, and quality assurance procedures to maintain measurement validity outside supervised environments.

Ultimately, the selection of an appropriate measurement methodology should be guided by the specific context and goals of the assessment. For foundational biomechanics research or elite athletic diagnostics where maximal accuracy and detailed kinetic data are paramount, force platforms and motion capture systems remain the undisputed standard. For practitioners in field-based settings, such as team sports coaches or strength and conditioning specialists conducting routine monitoring, the trade-off in accuracy for the portability and efficiency of flight time-based systems or validated smartphone applications is often justified. In clinical rehabilitation, where ease of use and reliability are critical, portable and simple systems are preferable. By understanding the distinct advantages and inherent limitations of each technology, users can make informed decisions to ensure the data they collect is both valid and appropriate for its intended purpose.

9 Conclusions

This comprehensive review has systematically examined the current state of instrumentation systems for vertical jump height measurement, revealing a diverse landscape of technologies with distinct capabilities, limitations, and application niches. Force platform systems maintain their position as the gold standard for accuracy, providing measurement uncertainties below 1 cm through sophisticated impulse-momentum calculations, though their high cost and complexity limit widespread adoption outside research environments. Flight time-based systems, including traditional contact mats and smartphone applications, offer excellent portability and accessibility while accepting systematic overestimation errors of 1-4 cm that result from landing technique variations and temporal resolution limitations.

Motion capture systems provide the most comprehensive biomechanical analysis capabilities but require substantial technical expertise and dedicated laboratory facilities that restrict their practical implementation. The 13-14 cm systematic difference between motion capture and force platform

measurements reflects fundamental differences in measured parameters rather than accuracy limitations, emphasizing the importance of understanding system-specific characteristics when interpreting results. Emerging artificial intelligence and computer vision technologies demonstrate promising potential for improving measurement accuracy while maintaining practical accessibility, though current implementations require further validation and standardization.

The selection of appropriate measurement methodology must carefully balance accuracy requirements against practical constraints including cost, portability, user expertise, and environmental conditions. High-performance athletics and research applications may justify sophisticated force platforms or motion capture systems, while routine monitoring applications benefit from the practicality of flight time-based systems despite their accuracy limitations. Smartphone-based systems offer unprecedented accessibility for educational and recreational applications, potentially democratizing access to jump height assessment across diverse populations.

Technical challenges common across all measurement modalities include temporal resolution requirements for accurate event detection, calibration and standardization procedures, environmental influence mitigation, and user technique standardization. Future developments must address these challenges while advancing toward increased automation, improved accuracy, and seamless integration with comprehensive monitoring platforms. The emergence of miniaturized sensor technologies and AI-enhanced algorithms promises continued advancement in measurement accuracy and practical applicability.

Standardization efforts represent a critical need for the continued development and adoption of jump height measurement technologies. Current validation approaches lack consistency across different measurement modalities, complicating result comparison and limiting confidence in emerging technologies. Development of comprehensive validation protocols, uncertainty assessment procedures, and calibration standards will facilitate objective evaluation of new measurement systems while ensuring quality assurance for clinical and research applications.

The future of jump height measurement lies in the integration of multiple technologies to combine the accuracy advantages of laboratory systems with the accessibility of portable devices. Sensor fusion approaches, AI-enhanced algorithms, and cloud-based analysis platforms enable sophisticated measurement capabilities while maintaining practical usability. However, successful implementation requires continued attention to validation methodology, standardization protocols, and user education to ensure appropriate interpretation and application of measurement results.

As jump height measurement continues to evolve,

the emphasis must remain on matching measurement capabilities to application requirements while acknowledging the limitations and appropriate use contexts for each technology. The diversity of available systems enables customized solutions for different applications, from elite performance monitoring to routine fitness assessment, provided that users understand the capabilities and limitations of their chosen measurement approach. This understanding, combined with continued technological advancement and standardization, will ensure that vertical jump measurement remains a vital and insightful tool for quantifying human neuromuscular performance across all applications and populations.

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