

E-BOOK



# A PRACTICAL GUIDE TO **3-AXIS** FORCE PLATES

# 3D DELTAS



ASSESSING COMPLEX  
ATHLETIC MOVEMENTS FOR  
SPORTS AND RETURN TO PLAY

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# OVERVIEW OF THE TECHNOLOGY

# 3D DELTAS



# Introduction

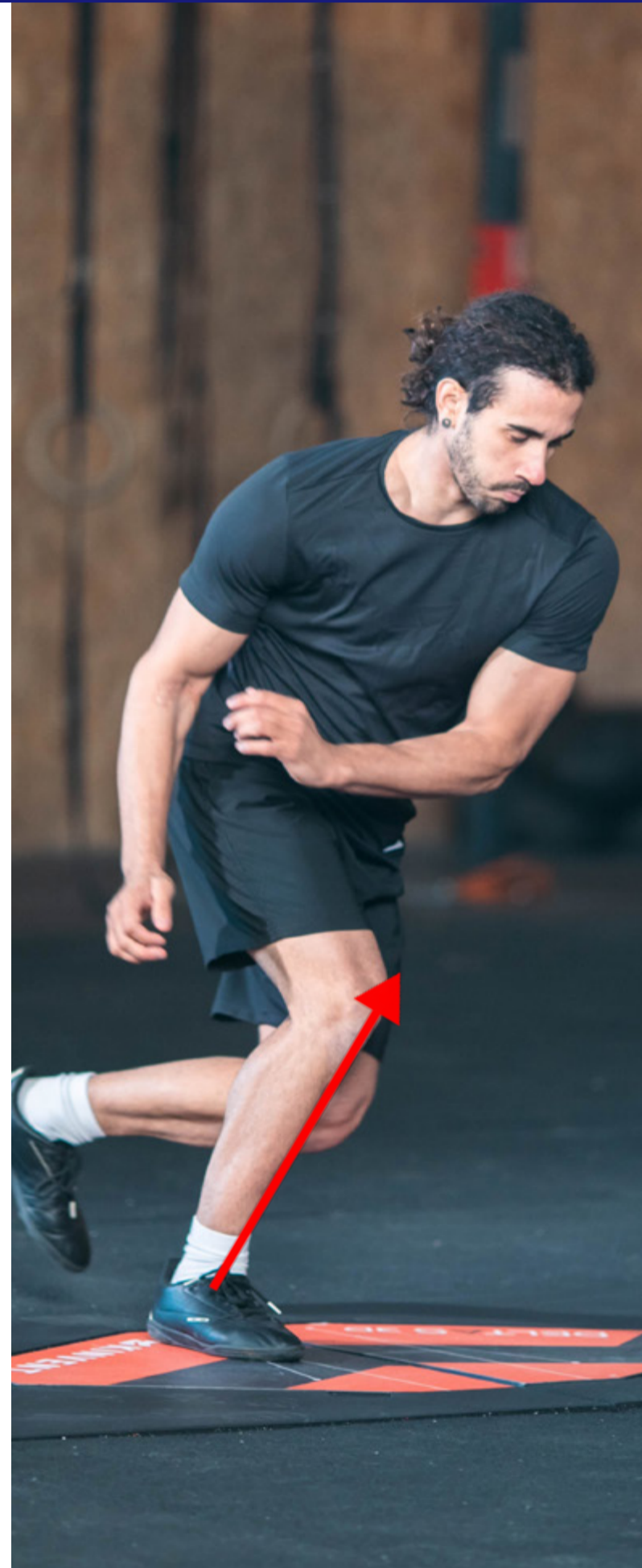
## Overview of the Ebook's Purpose

Human movement is a complex interplay of internal and external forces, joint rotations, and muscle actions. For athletes, coaches, and clinicians, accurately analyzing these movements can be the difference between peak and suboptimal performance or between remaining injury-free and sustaining an injury. This ebook aims to introduce you to 3D force plate technology - a powerful tool that captures detailed information on how forces act on the body. By the end, you will understand how 3D force plates work, why they are essential, and how you can apply their data to improve athletic performance and rehabilitative outcomes.

# Importance of Accurate 3D Human Movement Assessment with 3D force plates

## Accurate assessment of 3D human movement is vital for:

- **Performance Optimization:** Pinpointing inefficiencies in movement across all three dimensions—forward/backward, side-to-side, and rotational—provides a comprehensive understanding of how forces are applied and absorbed. By measuring in 3D, we gain insights into subtle imbalances or inefficiencies that might go unnoticed with traditional 1D analysis. Addressing these issues can lead to faster times, higher jumps, and overall more efficient and effective movement, as training can be tailored to refine technique and maximize performance in all planes of motion.
- **Injury Prevention:** Exposes hidden vulnerabilities by analyzing force distribution in 3D. For example, uneven landing forces can reveal excessive torque on the knee, increasing ACL injury risk.
- **Rehabilitation:** Recovery isn't just about movement - it's about moving the right way. Tracking force application and compensatory patterns post-injury, such as favoring one plane during gait or in a direction change. This helps therapists correct dysfunctional movement, measure progress, and ensure safe return-to-play through data-driven interventions.
- **Research:** Portable 3D systems enable data collection in real-world settings like courts and gyms. This delivers context-specific insights into biomechanics during athletic or daily activities, advancing evidence-based practice and functional training approaches.
- **Motion Capture Integration:** Combines joint kinematics and force vectors to analyze tasks like direction changes. Reveals inefficient force application and improper joint alignment, aiding physical therapists in refining mechanics and reducing injury risk.



# Introduction to the 3D Force Plate System

A 3D force plate is a sophisticated device that measures ground reaction forces (GRFs) in three dimensions, providing a comprehensive view of how forces interact with the body during movement. To appreciate its significance, it's essential to compare it with a 1D force plate and explore the mechanics behind how a 3D system works.



## Comparison: 3D vs. 1D Force Plates



### 1D Force Plates

1D force plates measure forces along a single axis, typically the vertical (z-axis). This data is useful for understanding basic movements, such as assessing the vertical ground reaction force during standing, jumping, or running. While valuable for straightforward assessments, 1D force plates are limited because they ignore lateral (x-axis) and anterior-posterior (y-axis) forces, which are crucial in dynamic and multidirectional tasks.

For example:

- **Jumping:** A 1D plate can provide the peak vertical force but cannot assess how balanced the landing was or if forces were unevenly distributed laterally.
- **Gait:** It can measure the vertical force of each step but misses details about propulsion (y-axis) or medial-lateral sway (x-axis).

### 3D Force Plates

3D force plates capture forces along three axes:

- **Vertical (z-axis):** Measures the upward/downward forces, as in a jump or landing.
- **Anterior-Posterior (y-axis):** Captures forces during forward or backward movements, such as acceleration or deceleration in running.
- **Medial-Lateral (x-axis):** Detects forces during side-to-side movements, such as cutting, lateral dribble in basketball or other balancing tasks.

# 3D DELTAS



This multidimensional measurement provides a comprehensive understanding of the forces acting on the body. For instance:

- **Jumping:** In addition to peak vertical force, 3D plates can reveal if the landing mechanics are symmetrical not only in the vertical force but also if excessive and asymmetrical lateral forces are produced which could indicate poor technique or potential injury risk. Additionally now lateral or forward jumps can be assessed in terms of performance which is crucial for real life assessments.
- **Gait and Running:** A 3D plate can track propulsion forces, braking forces, and lateral sway, offering a complete biomechanical profile.
- **Complex Movements:** A 3D system is indispensable for analyzing advanced multidirectional movements such as cutting, pivoting, or performing rotational movement. Key assessments include:
  - **Cutting Mechanics:** Evaluate the eccentric ( $F_x$ ) and concentric ( $F_y$ ) components during direction changes. Quantify the entry and exit speed to determine the efficiency and safety of the movement. Additionally, measure the impulse generated by each foot to understand its individual contribution to the task.
  - **Rotational Maneuvers:** Capture ground reaction forces across the sagittal, frontal, and transverse planes to gain insights into load distribution during high-intensity or sport-specific tasks like golf swing and baseball batting.
- **Real-Time Feedback:** Use detailed metrics like force-time curves, load symmetry, and joint-specific contributions to tailor rehabilitation exercises and sport-specific training protocols.



# The Technology Behind 3D Force Plates

## The 3D Force Plate Technology (Forces, Moments, and Planes of Motion)

A 3D force plate is built with advanced components that work together to measure forces in three dimensions and calculate moments (rotational forces) around these axes.

### Key Components

**Sensors or Transducers:** Piezoelectric or strain gauge sensors embedded within the plate, to capture the applied force along the x, y, and z axes simultaneously.

**Force and Torque Calculations:** The plate doesn't just measure forces; it can also calculate torque (rotational forces) around the x, y, and z axes. Torque is essential during rotational movements or asymmetrical landings.

### Planes of Motion and Raw Data Output

The data from 3D force plates correspond to movements in the sagittal (front-to-back), frontal (side-to-side), and transverse (rotational) planes.

The system provides raw force data, moments, and center of pressure (CoP) measurements, allowing for detailed biomechanical analysis.



# PRACTICAL APPLICATIONS

## Practical outcomes of 3D Measurements

- 1. Force:** Information about the magnitude, direction, and distribution of forces during dynamic movements. This data helps identify load imbalances, compensatory patterns, and inefficiencies that could predispose individuals to injury or limit their performance
- 2. Speed/explosiveness:** Quantifies the rate of force development (RFD), which is critical for assessing how quickly an individual can generate force or the ratio between exit velocity and contact time (horizontal RSI). This is particularly important in explosive movements such as sprints, jumps, and rapid changes in direction.
- 3. Power:** Quantifies the combination of force and velocity, providing a direct measure of functional capacity in tasks requiring strength and speed. Power metrics are indispensable for performance optimization and tracking progress in training or rehabilitation
- 4. Asymmetry:** Detects differences in force application between limbs, essential for injury prevention or rehabilitation.
- 5. Kinematics of the joints:** Tracks the movement and angles of joints during tasks, providing detailed insights into mobility, stability, and joint loading patterns. This information is critical for analyzing technique and optimizing movement efficiency when analyzed synchronized with the force data.
- 6. Center of Pressure (CoP):** Tracks the point of force application, revealing balance and stability during static or dynamic tasks and can help in the detection of compensatory strategies in conditions like ankle instability or vestibular dysfunction.
- 7. Real-Time Feedback:** These systems can provide instantaneous data, enabling coaches and therapists to make adjustments during sessions.

## Soccer: Importance of Change of Direction Testing



- 1. Enhanced Performance Insights:** COD testing provides critical data on how athletes manage forces during directional changes, which is essential for optimizing training and performance.
- 2. Injury Risk Assessment:** Understanding force interactions at lower limb joints helps identify potential vulnerabilities, particularly concerning ACL injuries and other injuries related to rapid directional changes.
- 3. Biomechanical Analysis:** Combining COD testing with motion capture allows for detailed assessments of movement patterns, enabling targeted interventions for injury prevention.
- 4. Individualized Training Programs:** The data obtained can inform tailored rehabilitation and training protocols that address specific athlete needs, enhancing both performance and safety.

These points are vital for physiotherapists and sports professionals aiming to enhance player performance and reduce injury rates.



## Understanding Agility and Performance

Agility in soccer refers to the ability to quickly change direction and velocity in response to dynamic game situations. Change of direction (COD) ability is essential for agility, involving rapid acceleration, deceleration, and re-acceleration in confined spaces. Traditionally, COD performance has been assessed through field-based tests that measure completion times for preplanned tasks. However, these methods often fail to capture the intricate biomechanical parameters that indicate an athlete's movement efficiency and injury risk. Laboratory-based COD testing offers detailed biomechanical data, such as ground-reaction forces (GRF), contact times, joint angles, and angular velocities. For example, research with college soccer players has shown significant correlations between vertical and mediolateral GRF and performance cutting angles. This data is invaluable for physiotherapists, enabling them to tailor rehabilitation programs and performance training based on individual athlete profiles.



## Motion Capture Technology

### Enhanced Analysis Capabilities

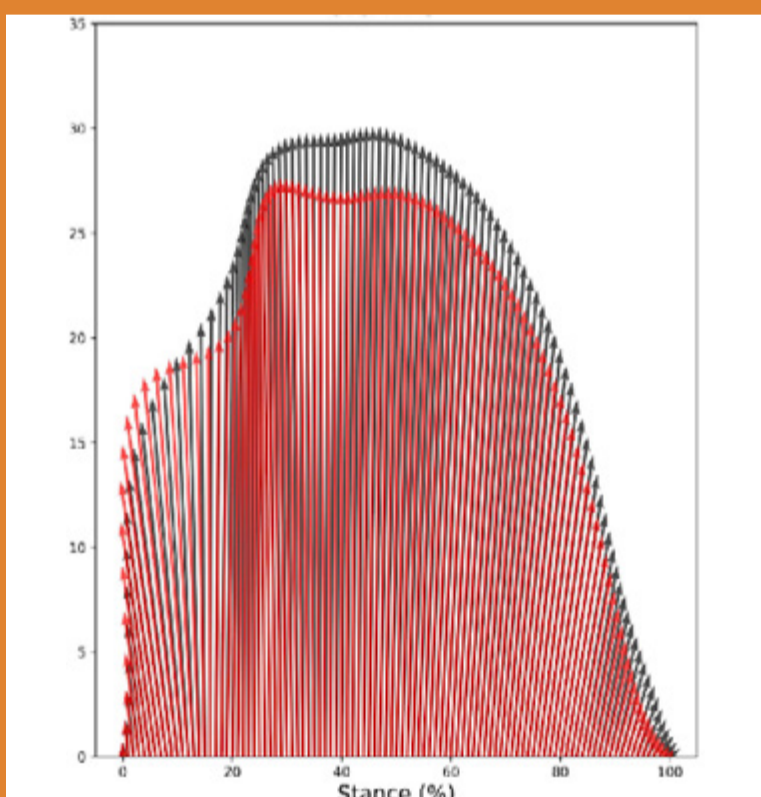
The integration of markerless motion capture systems using mobile phone cameras allows for precise tracking of athletes' movements during change of direction (COD) tasks without the need for reflective markers.

- 1. Markerless Technology:** Utilizes cameras from mobile devices (smartphones, tablets) for efficient and accessible movement analysis.
- 2. Kinematic Analysis:** Captures detailed movement data, allowing for real-time feedback on performance.
- 3. Force Vector Visualization:** Helps clinicians understand how forces affect lower limb joints during COD.
- 4. Injury Risk Identification:** Detects biomechanical weaknesses that could predispose athletes to injuries, enabling targeted interventions, for example differences between sides on entry velocity or reactivity and contact time.



## Force Vector

When analyzing COD movements through motion capture 3D force analysis, it becomes possible to assess how effectively an athlete can manage their center of mass relative to their base of support during rapid directional changes. The relationship between the force vector and its distance from the joint center is crucial in biomechanics, particularly during activities like change of direction (COD) in sports. A greater distance from the joint center increases torque ( $\text{Distance} \times \text{Force}$ ), which can lead to higher stress on the joint during movement. This is particularly relevant during change of direction (COD) tasks, where large forces acting far from the joint can elevate injury risk, especially for structures like the ACL. Understanding this relationship helps identify weaknesses in an athlete's biomechanics, enabling targeted interventions to enhance performance and reduce injury susceptibility.



## Injury Prevention and Performance Enhancement

### Targeting Asymmetries in multiple planes of motion

Biomechanical studies reveal that lower limb asymmetries are common in soccer players, impacting performance and injury risk. For example, differences between the preferred and non-preferred kicking legs are evident during COD tasks. Combining COD testing with motion capture allows physiotherapists to create targeted interventions, improving performance and reducing injury risk.

### Optimizing Training Protocols

COD testing data can refine training by identifying weaknesses, such as prolonged contact times or inefficient cutting angles. Specific drills can then enhance technique, strength, and movement patterns, boosting performance and supporting long-term joint health.

# Key Metrics

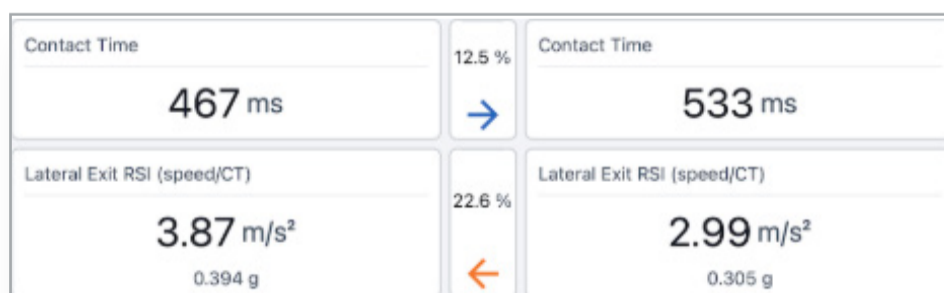
The **change of direction** provides a range of kinetic and temporal metrics, including:

- 1. Entry velocity:** Evaluates the velocity the athlete touches the ground before switching direction.
- 2. Exit velocity:** Evaluates the velocity the athlete leaves the ground after switching direction.
- 3. Lateral Reactivity Index:** The index of exit velocity and contact time which evaluates the reactive ability of the athlete on the lateral plane.
- 4. Entry-Exit Impulse (N·s):** Quantifies the total force applied over time in the lateral direction, reflecting an athlete's ability to sustain forceful movements.
- 5. Peak Force (N x-y-z):** Measures the maximum force generated in each direction, a direct indicator of an athlete's capacity for powerful movements in different planes.



**Figure 1.** Sample results from report

- 6. Relative Force (N x-y-z/kg):** Normalizes lateral force to body weight, offering a more precise comparison across athletes of different sizes.
- 7. Total Movement Time (s):** Captures the time the athlete is in contact with ground until the completion of the movement, correlating with agility and reaction speed.



**Figure 2.** Sample results from report

## Basketball : Lateral jump (skater jump) or Lateral Countermovement Jump (LCMJ)

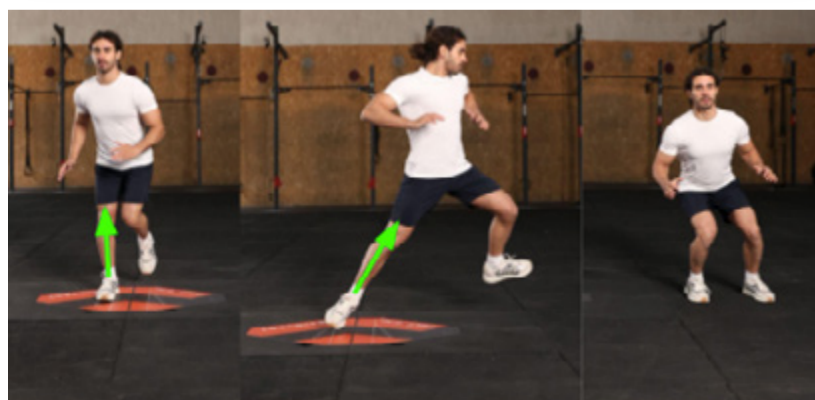
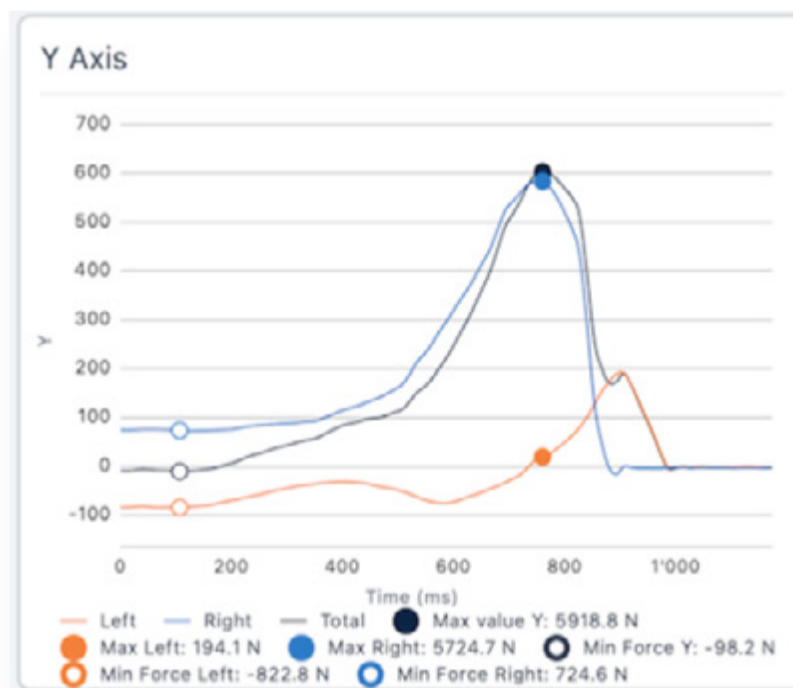


### Use in Basketball Performance

Basketball requires frequent lateral movements, as players spend up to 31% of game actions shuffling. Effective lateral acceleration and deceleration are pivotal for defensive maneuvers, maintaining positioning, and offensive plays like cutting or driving to the basket. The **lateral jump** is a reliable tool for identifying athletes who excel in these movements, as faster shufflers are characterized by greater relative lateral force outputs during the test. By measuring this capability, the lateral jump helps coaches and physiotherapists tailor training programs to enhance performance in lateral movements, ultimately improving agility and defensive efficiency.



The **Lateral jump or skater jump** is a dynamic, sport-specific assessment tool designed to evaluate lateral force production and shuffling performance, particularly among elite basketball players. This test assesses how well athletes generate lateral force during a single-leg jump from a stationary position, providing valuable insights into their performance in lateral movements critical to basketball, such as defensive shuffling and cutting.



# Assessing Return-to-Play Readiness

The lateral jump is also an effective assessment for return-to-play (RTP) protocols, especially after lower extremity injuries such as ACL reconstruction. This test evaluates key metrics related to strength, symmetry, and force production, which are critical in determining an athlete's ability to safely resume sport-specific activities. For example, asymmetries in lateral force production can indicate potential compensations or incomplete rehabilitation. When paired with other assessments, the lateral jump can ensure that athletes meet the biomechanical and functional benchmarks required for safe RTP.

## Key Metrics

The lateral jump provides a range of kinetic and temporal metrics, including:

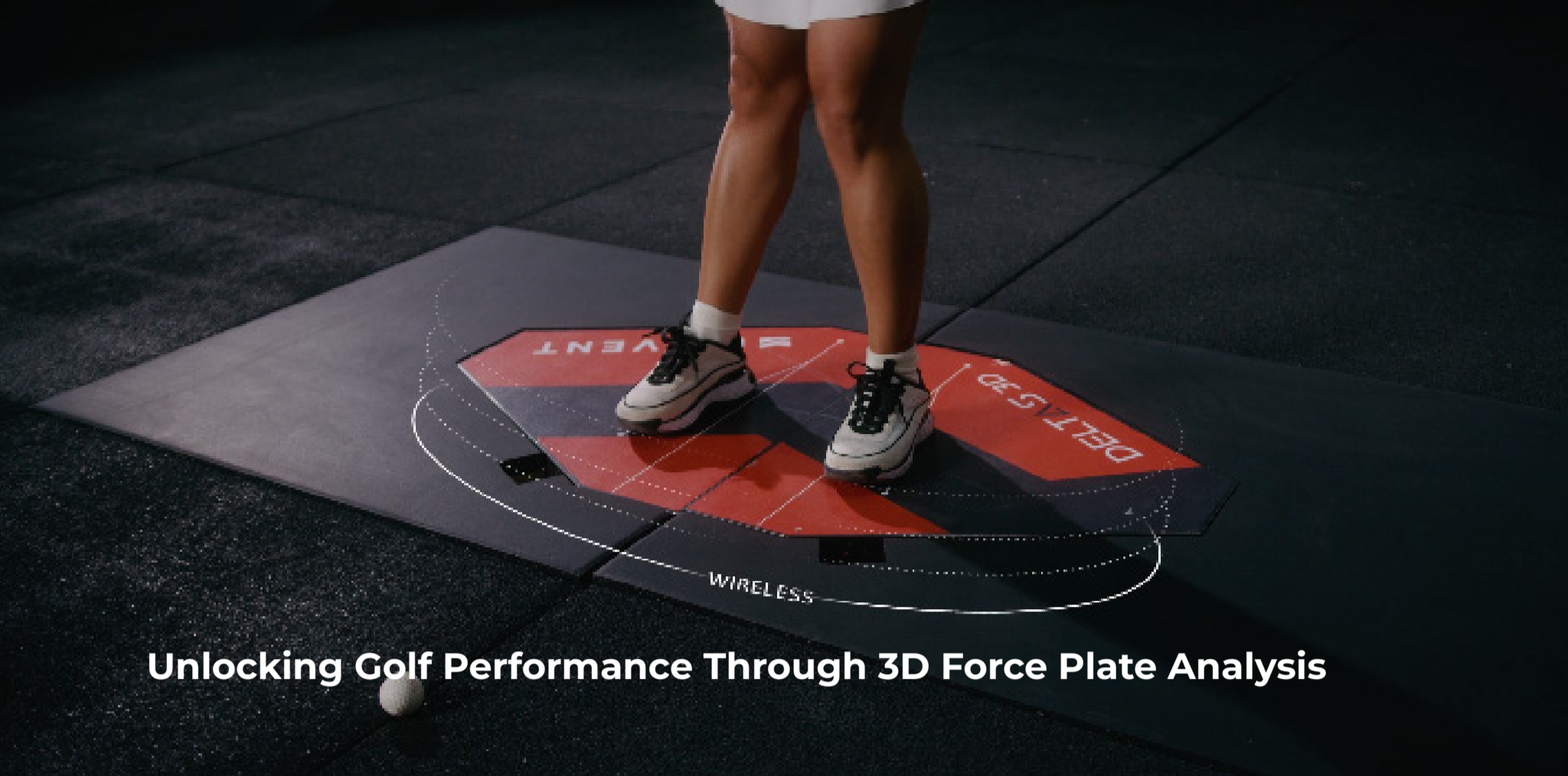
- 1. Lateral Impulse (N·s):** Quantifies the total force applied over time in the lateral direction, reflecting an athlete's ability to sustain forceful movements.
- 2. Relative Lateral Impulse (N·s/kg):** Normalized impulse values for individualized performance profiling.
- 3. Rate of Force Development (RFD-ML axis):** Evaluates how quickly lateral forces are produced, critical for explosive horizontal movements.
- 4. Peak Lateral Force (Nx):** Measures the maximum force generated laterally, a direct indicator of an athlete's capacity for powerful lateral movements.
- 5. Relative Lateral Force (Nx/kg):** Normalizes lateral force to body weight, offering a more precise comparison across athletes of different sizes.
- 6. Total Movement Time (s):** Captures the time to initiate and complete the movement, correlating with agility and reaction speed.



## Practical Applications

The LCMJ is advantageous for its simplicity, minimal setup, and reliability. It requires minimal familiarization, limiting the mechanical load on athletes, making it suitable for frequent testing. Basketball practitioners can use the LCMJ to develop athlete-specific benchmarks and track improvements over time. It also complements other tests, such as the countermovement jump (CMJ), to provide a comprehensive profile of an athlete's vertical and lateral capabilities.

By integrating the LCMJ into training and RTP assessments, coaches and therapists can optimize lateral movement efficiency, prevent injuries, and ensure a safe and effective transition back to competitive play.



## Unlocking Golf Performance Through 3D Force Plate Analysis

3D force plates are revolutionizing the way we analyze and enhance the performance of golfers. These cutting-edge tools provide precise measurements of the forces exerted on the ground during a golfer's swing, capturing their magnitude, direction, and timing with unparalleled accuracy. The data is presented through an advanced graphical interface, allowing detailed insights into the intricate dynamics of the golf swing.

### Key Factors in 3D Force Plate Analysis

#### Center of Pressure and Stance Width

A critical component of 3D force plate analysis is examining the center of pressure (CoP) and stance width. The center of pressure reveals how weight is distributed and shifted under each foot throughout the swing. This information sheds light on the golfer's dynamic balance and overall stability, which are foundational to an effective swing.

- **Forward/Backward Shifts:** If the center of pressure moves excessively toward the toes or heels, it indicates an imbalance that can compromise swing efficiency and consistency.
- **Lateral Shifts:** Significant pressure shifts toward the inside or outside edges of the feet disrupt stability and impede the golfer's ability to generate optimal ground reaction forces (GRFs).

#### Pressure Transition Between Feet

Tracking how the center of pressure transitions between the left and right foot provides valuable insights into the golfer's weight transfer during each phase of the swing. This helps identify the contribution of each leg to the motion and highlights any asymmetries or inefficiencies. By optimizing these transitions, we can help golfers refine their swing mechanics to align with their unique body mechanics.

## Integrating 3D Ground Reaction Forces and Motion Capture

The true power of 3D force plate technology lies in its ability to integrate ground reaction force data with 3D motion capture. Together, these technologies provide a comprehensive understanding of how the golfer interacts with the ground and how their movement patterns influence this interaction.

- **Ground Reaction Forces (GRFs):** The timing and magnitude of GRFs reveal whether the golfer is effectively utilizing the ground to produce energy or losing power due to inefficiencies.
- **Motion Capture Insights:** By aligning GRFs with motion capture data, we can visualize how the golfer's stance width, weight distribution, and swing sequence impact their performance.

### Optimizing Performance Through Data

This integrated analysis enables physiotherapists and coaches to identify areas where adjustments are necessary. For example, if ground reaction forces do not align with motion capture findings, it may indicate technical flaws, stability issues, or biomechanical limitations. Corrective strategies can then be developed, such as:

- Adjusting stance width to enhance stability.
- Refining weight transfer patterns to maximize energy generation.
- Tailoring drills and exercises to target specific biomechanical deficiencies.



## Practical Applications for Physiotherapists

For physiotherapists working with golf athletes, 3D force plate analysis offers a unique opportunity to:

**Diagnose Movement Inefficiencies:** Identify subtle imbalances or asymmetries that may be contributing to suboptimal performance or increasing injury risk.

**Design Targeted Interventions:** Use data-driven insights to create individualized rehabilitation and performance programs.

**Monitor Progress:** Track changes in center of pressure, ground reaction forces, and movement patterns over time to ensure continued improvement.

By leveraging the power of 3D force plate technology, physiotherapists can play a pivotal role in enhancing the performance, efficiency, and longevity of golf athletes. This approach not only helps athletes reach their peak potential but also ensures they maintain optimal physical health throughout their careers.

## Enhancing Rugby Performance with Drop and Side Jump Tests Using 3D Force Plates and Motion Capture



3D force plates and motion capture provide invaluable tools for assessing and improving rugby performance. These technologies measure ground reaction forces and motion patterns, offering critical insights into strength, power, and joint health. For rugby players, drop and side jump tests are essential for evaluating explosive power, lateral agility, and minimizing injury risks.



## Key Insights from Drop and Side Jump Tests

### Drop & Side Jump Test

This test evaluates explosive power and reactive strength. Key metrics include:

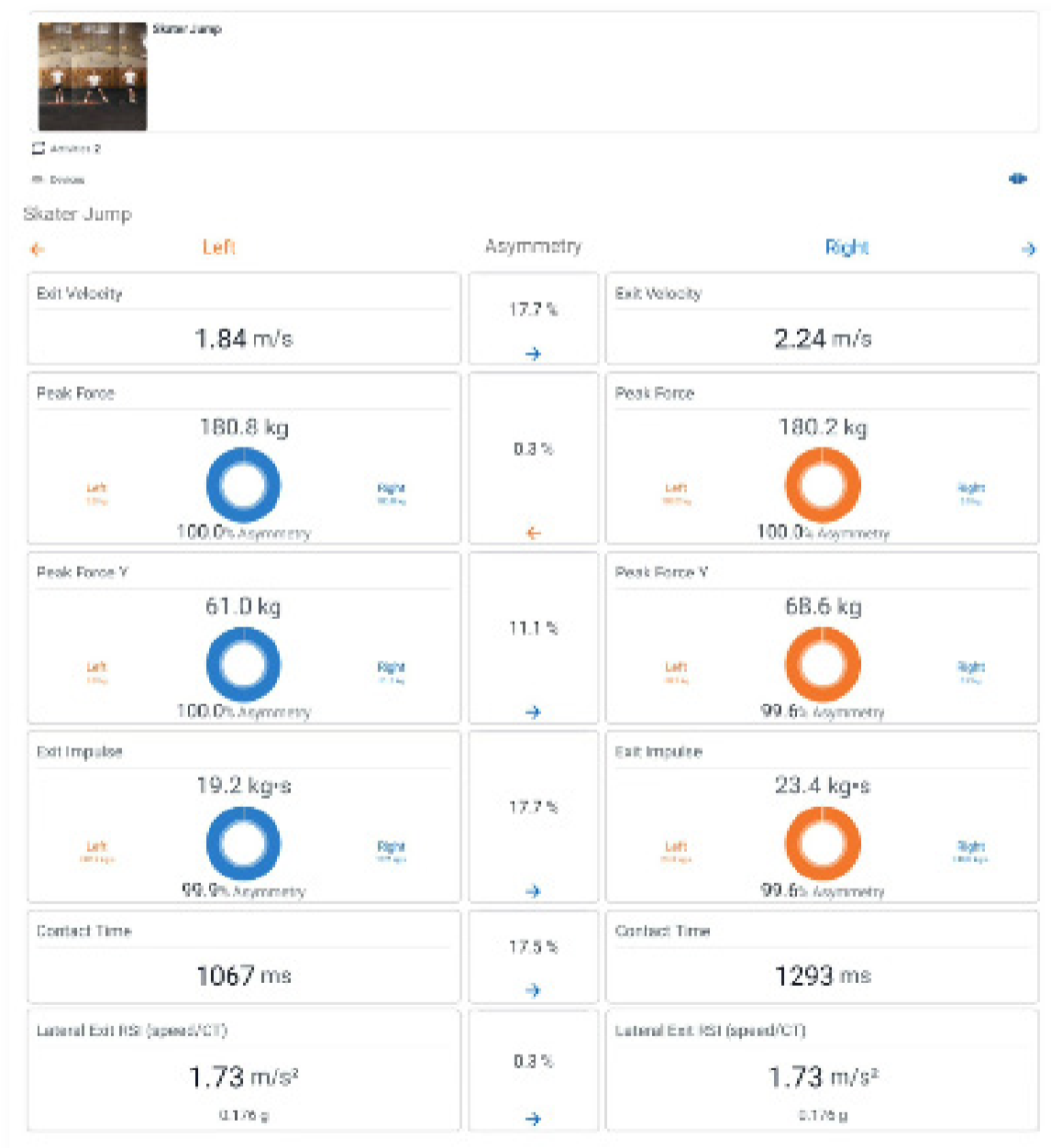
- **Ground Contact Time (GCT):** Indicates the speed of force generation.
- **Landing Forces:** Highlights control and shock absorption to reduce injury risk.
- **Force Vector Alignment:** Motion capture identifies the path of force relative to the knee joint center. Misalignment increases torque on the knee, raising injury risks.
- **Lateral Ground Reaction Forces:** Measures efficiency in generating lateral forces.
- **Asymmetry Analysis:** Highlights imbalances between legs.
- **Knee Stability:** Evaluates alignment and control during lateral movements.

# Practical Applications for Physiotherapists

- **Identifying Performance Gaps:** Detecting areas of inefficiency or excessive knee torque during lateral jumps.
- **Tailored Rehabilitation:** Guide recovery for injuries like ACL tears using objective data.
- **Enhancing Agility and Power:** Develop targeted training plans to improve explosive and lateral movements while protecting joint health.

## Key Metrics to Monitor

- **Peak Vertical and Lateral Forces:** Assess explosive power and agility.
- **Symmetry Index:** Ensure balanced force application between legs.
- **Landing Stability:** Improves control to reduce injury risk.
- **Force Vector Alignment:** Minimizes torque on the knee joint.
- **Relative Lateral Force (N/kg):** Normalizes lateral force to body weight, offering a more precise comparison across athletes of different sizes.
- **Lateral Impulse (N·s):** Quantifies the total force applied over time in the lateral direction, reflecting an athlete's ability to sustain forceful movements.



# The Critical Role of Bilateral Forward Jump Testing in American Football Player Assessments: A 3D Force Plate Perspective



American football demands explosive power, agility, and dynamic balance—qualities essential for player performance and injury prevention. Effective assessments are vital to understanding an athlete's readiness, identifying asymmetries, and minimizing injury risks. Among these, the bilateral forward jump stands out as a primary test for evaluating lower-limb power, neuromuscular control, and coordination. When combined with 3D force plate systems, this test becomes a powerful tool for physiotherapists and sports performance specialists.

## Why Bilateral Forward Jump Testing Matters in Football Assessments

The bilateral forward jump, or broad jump, evaluates horizontal power, lower-limb coordination, and stability. This test is particularly relevant for American football due to:

- 1. Explosive Power:** Horizontal propulsion directly translates to sprinting speed, acceleration, and agility—key performance indicators in football.
- 2. Symmetry and Injury Prevention:** Identifying asymmetries in force production can help prevent common football injuries like ACL tears, hamstring strains, and ankle sprains.
- 3. Return-to-Play Assessments:** This test benchmarks recovery progress, ensuring athletes regain strength and stability post-injury.
- 4. Neuromuscular Coordination:** Efficient movement coordination is vital for football-specific actions like cutting, blocking, and tackling.

### Advantages of Using 3D Force Plates in Jump Testing

While the bilateral forward jump is insightful on its own, integrating 3D force plates enhances its diagnostic power. Key benefits include:

- 1. Detailed Force Analysis:** 3D force plates measure ground reaction forces (GRFs) in three dimensions, offering a clear picture of propulsion and stability mechanics.
- 2. Asymmetry Detection:** Subtle imbalances in force production and landing mechanics can be identified, which might not be visible to the naked eye.
- 3. Landing Stability Metrics:** Metrics like time to stabilization reveal insights into post-jump control, critical for injury prevention.
- 4. Fatigue Monitoring:** By tracking changes in jump performance, physiotherapists can monitor fatigue and adjust training loads accordingly.
- 5. Real-Time Feedback:** Immediate, objective feedback engages athletes and facilitates targeted coaching to improve performance and correct inefficiencies.

## Metrics Captured by 3D Force Plate Analysis

3D force plates provide a wide array of quantitative metrics that deepen the understanding of athletic performance and neuromuscular health. Key metrics include:

- 1. Peak Force X-Y-Z:** The maximum forces generated during takeoff, which reflects an athlete's explosive power capacity in all directions.
- 2. Rate of Force Development (RFD):** The speed at which force is produced, an essential indicator of an athlete's ability to generate power quickly.
- 3. Impulse ML axis:** The total force applied over time, which contributes to jump height and horizontal propulsion.
- 4. Asymmetry Indices:** Ratios comparing the force output of the left and right limbs during takeoff, critical for identifying potential injury risks.

## Practical Applications

Consider a linebacker recovering from ACL surgery. A 3D force plate analysis of their bilateral forward jump shows a 15% force deficit on the injured side and prolonged stabilization time, indicating incomplete recovery. This data allows physiotherapists to tailor rehab programs to address these specific deficits.

Similarly, preseason tests revealing lateral force asymmetries in offensive linemen could lead to targeted interventions, reducing injury rates over the season.

The bilateral forward jump provides critical insights into an athlete's biomechanical and neuromuscular function, as well as readiness for competition. Coupled with 3D force plate technology, it offers diagnostic depth for optimizing training, and guiding rehabilitation. In a sport like American football, where performance and injury margins are razor-thin, this combination is an invaluable part of athlete assessment strategies.



# Installation

When installing 3D force plates, several essential considerations must be addressed to ensure accurate and reliable measurements. Here's a concise guide:



## Key Considerations:

### 1. Level Ground:

- The surface where the force plates are installed must be perfectly level.
- Why: Uneven ground can create biased force measurements or inaccurate readings of ground reaction forces, as the load cells within the plate might not be uniformly loaded.

### 2. Secure Placement:

- The force plates must be securely fixed to prevent any movement during use.
- Why: Movement or shifting of the plates can introduce errors in the force data, compromise the accuracy of directional force components (e.g., shear forces), and affect repeatability.

### 3. Isolated Installation:

- Ensure that the force plates do not touch each other, walls, or any surrounding structures.
- Why: Contact with external surfaces can introduce external vibrations or forces, leading to cross-talk and contamination of the force data.

### 4. Calibration Check:

- After installation, check and calibrate the plates according to the manufacturer's instructions.
- Why: Calibration ensures the accuracy of force measurements, accounting for any slight imperfections in the setup.

When installing 3D force plates, several essential considerations must be addressed to ensure accurate and reliable measurements. Here's a concise guide:



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