



**KINVENT**  
MEASURE. MOVE. PROGRESS.  
PHYSIO



# CMJ ▲ PROCEDURES AND TESTING

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# INTRODUCTION

**Vertical jumping has been widely used for the assessment of dynamic performance, with the countermovement jump (CMJ) being the most common force platform assessment used in applied settings.<sup>1</sup>**

The CMJ is a simple, practical, valid, and is the most reliable measure of lower-body power, compared to other jump tests. Also, the CMJ has been shown to correlate with sprint performance, 1RM maximal strength, and explosive-strength tests. This test can be performed either with or without an arm swing. It has been shown that performing the CMJ with the arm-swing could increase key performance-related features by 10%–30%.<sup>2,3</sup> Contact mats, accelerometers, high-speed cameras, and infrared platforms have all been shown to provide a relatively valid and reliable measure of CMJ performance if strict execution guidelines are met. On the other hand, force platforms provide the most accurate and detailed measurements of neuromuscular performance and are generally considered to be the 'gold-standard'.

JUMP HEIGHT PER LOAD

DYNAMIC REPORT — 36.0/MIN  
CoP ANALYSIS — STANCE EVALUATION  
CENTER OF PRESSION AND WEIGHT  
—  
ANALYSIS, MEASUREMENT  
EVOLUTION

# HOW CMJ AND FORCE PLATFORMS ARE IMPORTANT IN THEIR TRAINING / REHAB



“

I've been searching so long for such a tool! K-Deltas are my go-to solution to measure jump height and explosivity to ensure that my players are ready for game days. What I love the most is the fact that you can actually combine the force plates with the goniometer to gain even more insight into the jump patterns of your athletes.

## **Aurélien Broussal-Derval**

CSCS, Author and Founder of ABD Formations

Kinvent K-Deltas have been my favorite tool to assess lower limb strength so far. Incredibly accurate and very solid so you can have athletes step on it with heavy loads (loaded barbells, kettlebells,...)

## **Ryan Lauderdale**

CSCS and Founder of Ryphen Fitness

If you're serious about Rehab and Return to Play, you're serious about how to assess your athletes. I use the K-Deltas specifically for that: get the data I need to take my team to the next level!

## **Alex Shafiro**

PT, DPT, OCS, CSCS and Clinical Manager at HSS

WANT TO LEARN MORE ABOUT THE TECHNOLOGY THEY ARE USING?

[BOOK A DEMO](#)



# DATA COLLECTION

## HOW TO PREPARE THE TEST

It is critical to understand that the test must be performed in a consistent environment and on level ground at all times, otherwise the reliability of subsequent tests may suffer. The examiner must decide whether to include or exclude the arm-swing, as it is important to understand that using the arm can improve performance. If the participant is not allowed to use their arms, they must keep their hands on their hips throughout the test (akimbo position).

The participant should perform a standardized warmup in order to prepare his/her body to achieve its best performance.

### An example of a warmup<sup>4</sup> could be:

- 5 min of jogging at a self-selected intensity greater than 50% perceived maximum effort
- 5 min dynamic warmup consisting of leg swing, lunges, jumping, jacks, etc.
- 10 bodyweight squats (hands on hips), and 10 standing calf raises at a slow pace
- 10 squats pushing up into a calf raise (combined movement)

For optimal data collection, please choose each warmup protocol carefully not to induce fatigue.

### How to perform the test:

For the CMJ it has been recommended to perform at least 3 repetitions with 1 minute of rest, in order to prevent fatigue during testing. Before starting the test, it is better to give the participant a few seconds on the platform to prepare.



#### THE PARTICIPANT:

- Stands relaxed, without any movement in the upright position
- Lowers his/her center of mass (COM) by flexing their hips, knees and ankles
- Jumps immediately as fast as possible by rapid extension of the hips, knees, and ankles
- Finishes the test with a controlled landing on the force plates

It is strongly suggested that more than one trial should take place, because of the effects of inherent intraindividual variation in execution and motivation.



# DATA TREATMENT

## SIGNAL PROCESSING

THE DATA ARE COLLECTED BY FOUR (4) FORCE SENSORS IN EACH K-FORCE DELTA, WITH A SAMPLING RATE OF 1000 HZ. A MOBILE APPLICATION (K-PHYSIO) IS CONNECTED BY BLUETOOTH TO THE FORCE PLATES, IN WHICH DATA ARE FILTERED AND ANALYZED.

Sampling frequency is very important for accurate measurements. KINVENT collects force data at 1000 Hz (1000 data points per second) to provide very detailed signals and in some cases (i.e. measuring landing forces) sampling at even higher frequencies is suggested. Data are digitally filtered with a 2<sup>nd</sup> Order Low Pass Butterworth Filter using a cutoff frequency of 50Hz.

### HOW THE SENSORS DETECT THE MOVEMENT/SIGNAL

**KINVENT platforms consist of 4-strain gauge load cells.** A load cell usually consists of a steel test body to which the 4-strain gauge grid support is glued. Under the influence of a force, the test body expands or shrinks. The force applied to this body causes a deformation leading to stress. A gauge is a support that contains a conductive measuring grid that will either compress or stretch, thereby changing the electric resistance in the filaments of the grid to determine the strain.

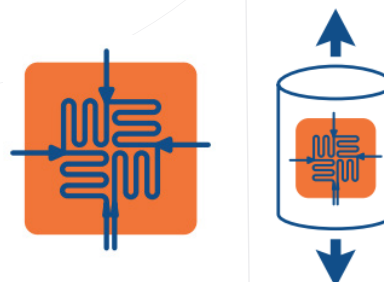


The force transducers contain 4 strain gauges connected to each other, known as a **Wheatstone Bridge**, which has:

- 2 gauges parallel to the force vector
- 2 gauges mounted laterally to the applied force

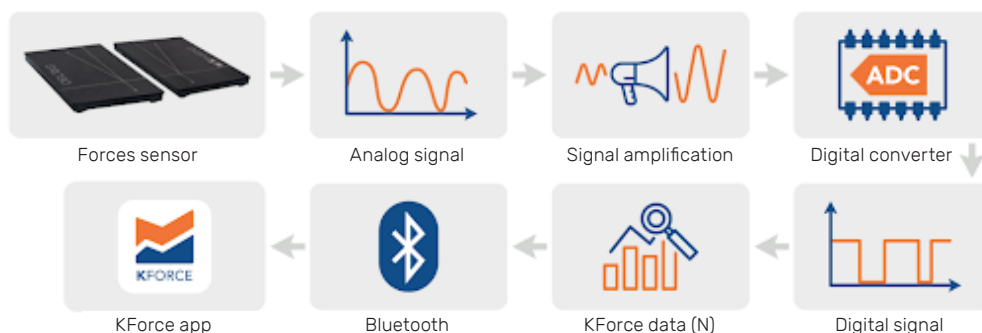
These 4 strain gauges are glued to the test body.

When a force is applied to a load cell, the steel deforms and the electric resistance of the strain gauge changes. The output signal gives information about this deformation and thus the force acting on the gauges is calculated.



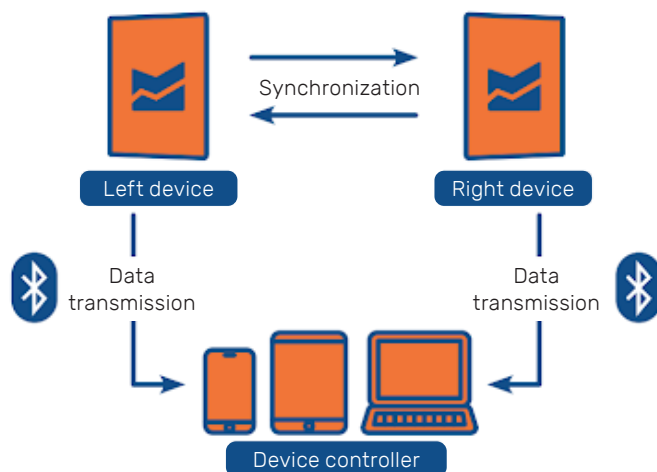
## HOW THE SIGNAL IS DIGITIZED AND SENT TO THE APP

**The devices have 8 force sensors (4 for each pair).** These load cells send out small amplitude analogue signals (a few millivolts). These signals are amplified, then digitized using an analogue-to-digital converter (A/D). The microcontroller in the devices uses our algorithm to determine the force in N, from the signal in volts. As the force plates are connected through a mobile application (K-Force app), the data are transmitted via Bluetooth to the application.



We have built our sensor network using «**SIMULTANEOUS MULTI-PROTOCOL**» technology, which utilizes two communication networks using different transmission protocols at the same time:

- **Data transmission network:** This primary network is used to transfer data between the sensors and the master device. This network uses a standardized transmission protocol like Bluetooth to support more hardware.
- **Synchronization network:** This is the secondary network, containing only the sensors or actuators to be synchronized. The sensors and actuators use this network to exchange synchronization information. The synchronization network uses this protocol to exchange synchronization information between the sensors without interrupting the transmission of data to the mobile device.

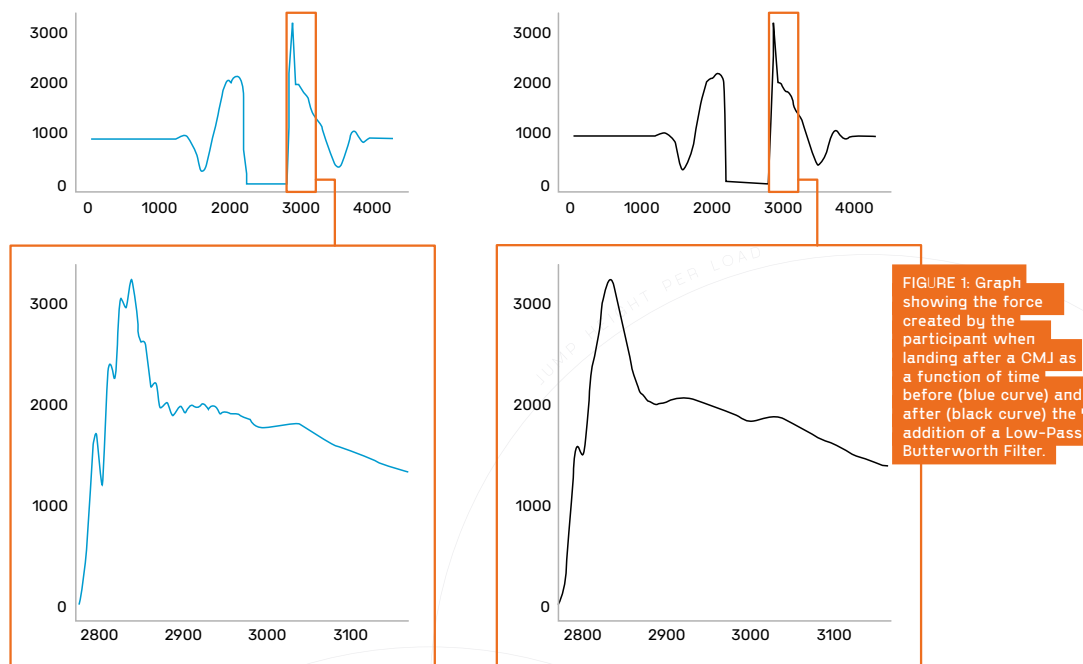


*Illustration of the data transmission network and data synchronization network*



## HOW THE SOFTWARE PROCESSES THE INCOMING SIGNAL

Once the signal has been received, the data will be processed by a proprietary algorithm built into the application. This algorithm will make it possible to filter the data to remove noise from the signal. Additionally, it will make it possible to calculate various parameters for interpreting the signal.



Once the signal is filtered, curves of acceleration–time, velocity–time, and displacement–time are calculated from the ground reaction force record obtained. The velocity–time curve is derived by dividing the resultant force–time curve by the jumper’s body mass to obtain the acceleration–time curve, and then by numerical integration of the acceleration curve using the trapezoid rule. Using the trapezoid rule again, the velocity–time record is numerically integrated to get the displacement–time record.

## BIOMECHANICS

The countermovement jump (CMJ) is a highly-used movement to help coaches determine performance changes and fatigue levels. Force platforms are among the most frequently used in the field of sports biomechanics. The participant performs a downward CMJ (i.e., a flexion of the lower limbs) immediately followed by a full extension of the lower limbs. During this jump, the participant is instructed to jump as high as possible. Because of the increased availability of affordable force platform systems, and because many different terms have been used to describe the different CMJ phases in the literature, clarification of key CMJ phases during the use of force platform-based CMJ assessment is necessary.



# CHARACTERISTIC PHASES OF THE CMJ

## WEIGHING PHASE

The weighing phase is self-explanatory, but its importance may be less obvious, and it is therefore likely to be overlooked by practitioners. When performing a countermovement jump, the weighing phase (or stance phase) is the first thing done during the assessment. The athlete must stand as still as possible for at least 3 seconds during this phase. System weight is calculated during this time before the movement begins.

**THERE ARE SEVERAL REASONS WHY ACCURATE BODYWEIGHT (BW) COMPUTATION IS NECESSARY. SOME OF THEM ARE:**

### 01

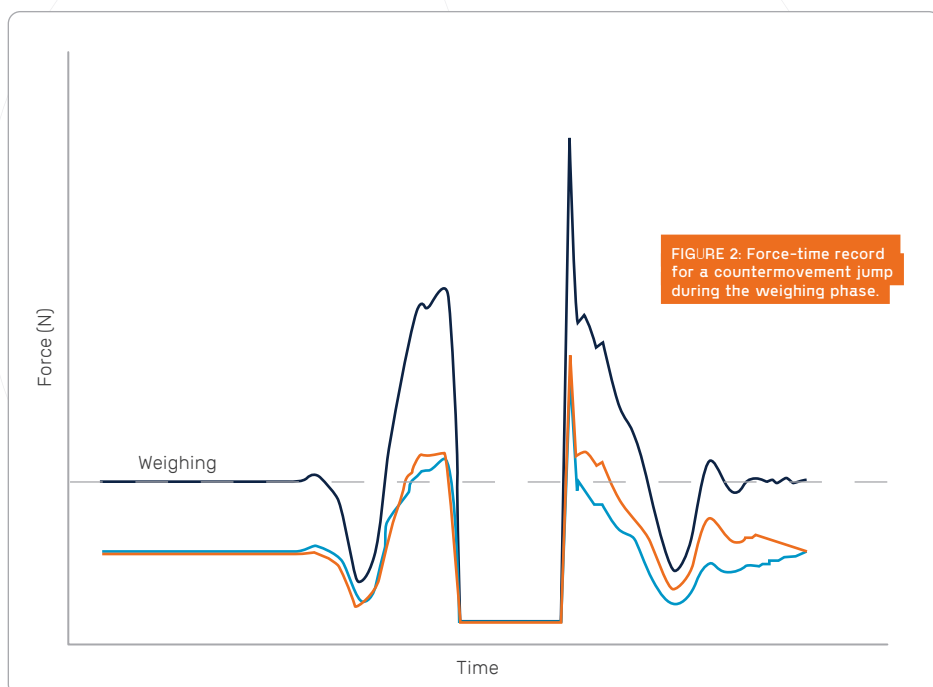
It is used to determine an onset threshold to determine movement initiation

### 02

BW is included in a series of calculations of important variables obtained from the force signal

### 03

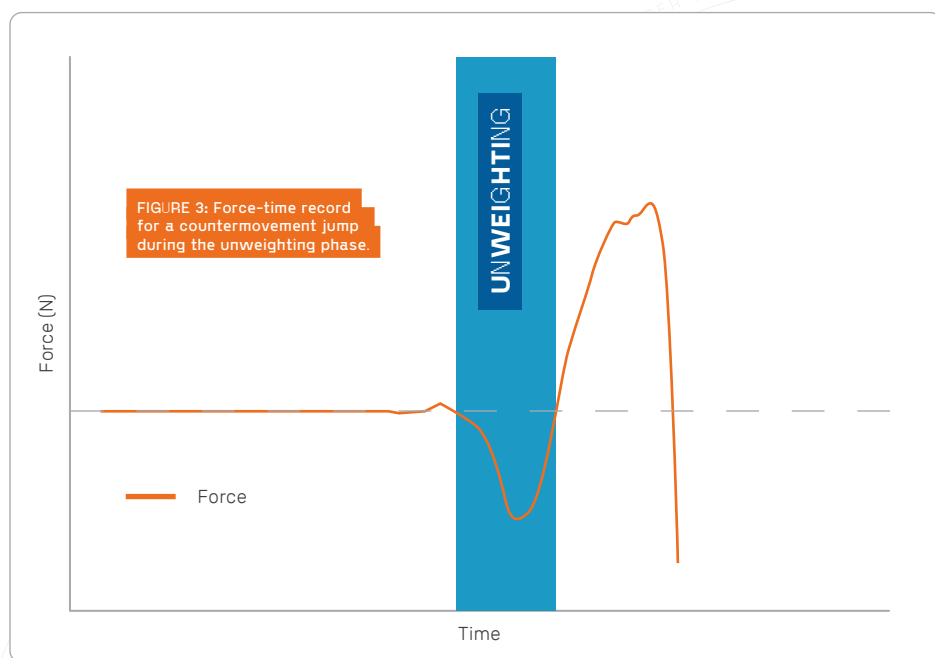
Obtained values are often used in relevance to BW in order to be comparable across different time periods (a person's BW can fluctuate significantly from time to time) or with a database of other individuals.



## UNWEIGHTING PHASE

The unweighting phase begins at the onset of movement which is usually identified as the instant at which BW is reduced below a set threshold value of force. The threshold value of force used is when force is reduced by 5 times the standard deviation of BW (calculated on the weighting phase). The unweighting phase continues from the start of the movement through to the instant at which the force returns to the body weight and the individual is essentially in an accelerating-fall.

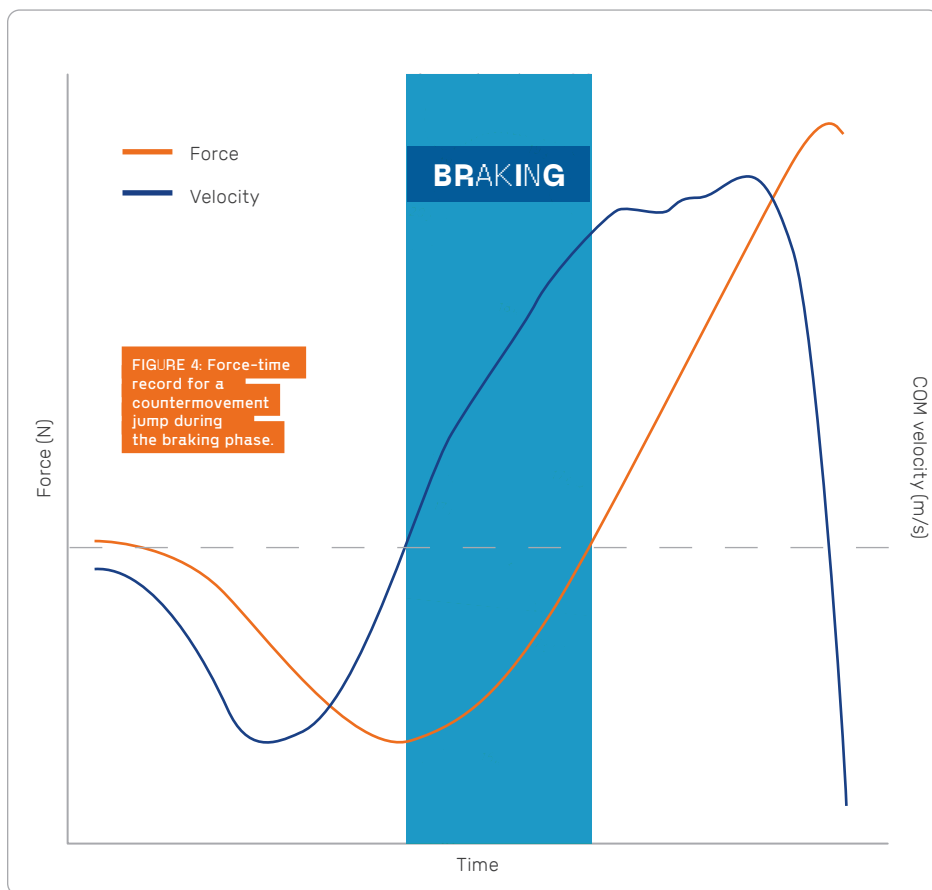
**The instant when force returns to BW coincides with the instant at which peak negative COM velocity is achieved.** Plotting the velocity-time curve alongside the force-time curve is visually useful for checking the duration of the specific phase. Ineffective execution in this phase is usually related to less efficient braking – decelerative capabilities.



## BRAKING PHASE

The braking phase commences from the instant of peak negative COM velocity, through to when COM velocity increases above zero. This coincides with the bottom of the CMJ (the peak negative COM displacement/deepest part of the downward movement). **The braking phase has also been called the stretching phase.**

The leg extensor muscle-tendon unit is thought to be actively stretching to decelerate body mass. This phase can provide information for the practitioner so they can understand how capable the athlete or patient is when decelerating his/her body. If inefficiencies are detected in the braking phase in relation to similar populations, then combined with clinical reasoning this could tell the practitioner to target those types of muscle contractions and qualities.

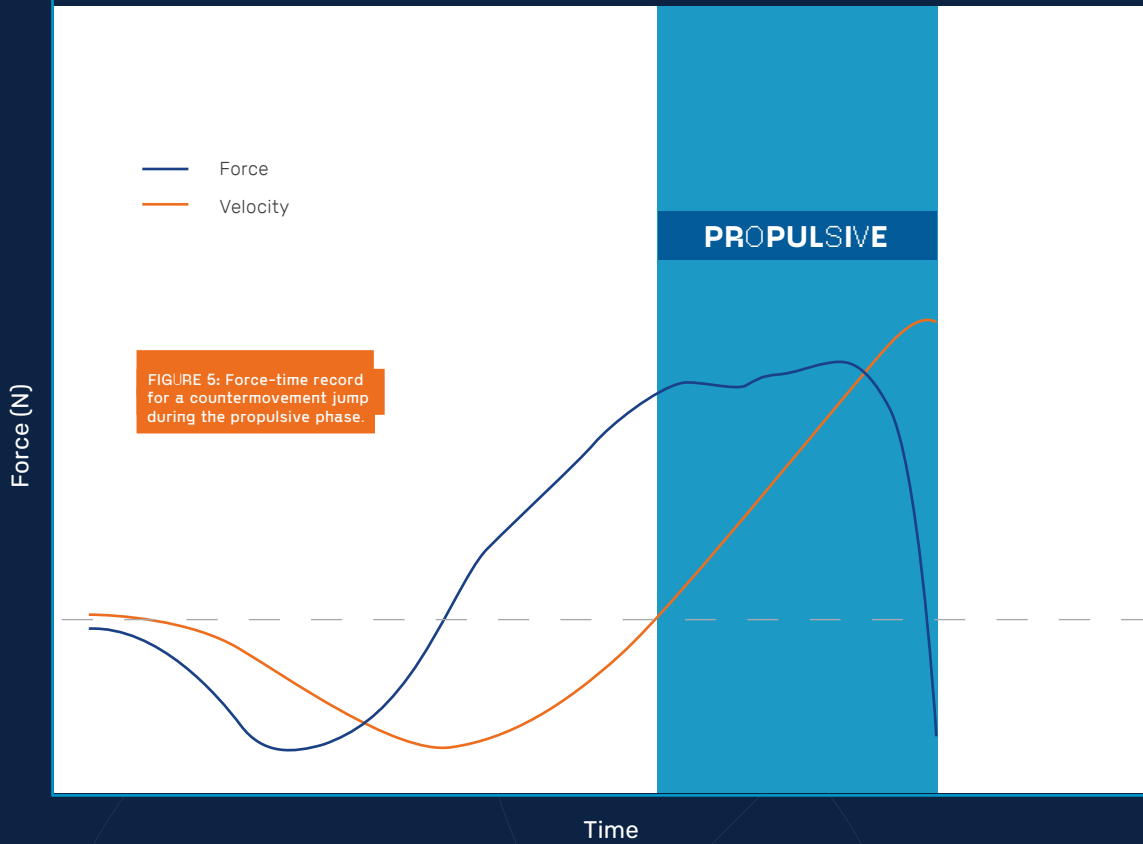


## PROPULSIVE PHASE

The propulsive phase, sometimes called the push-off phase, technically begins when a positive COM velocity is achieved and the first positive value of velocity with a threshold of 0.01 m/s has been used to identify the onset of the propulsive phase.

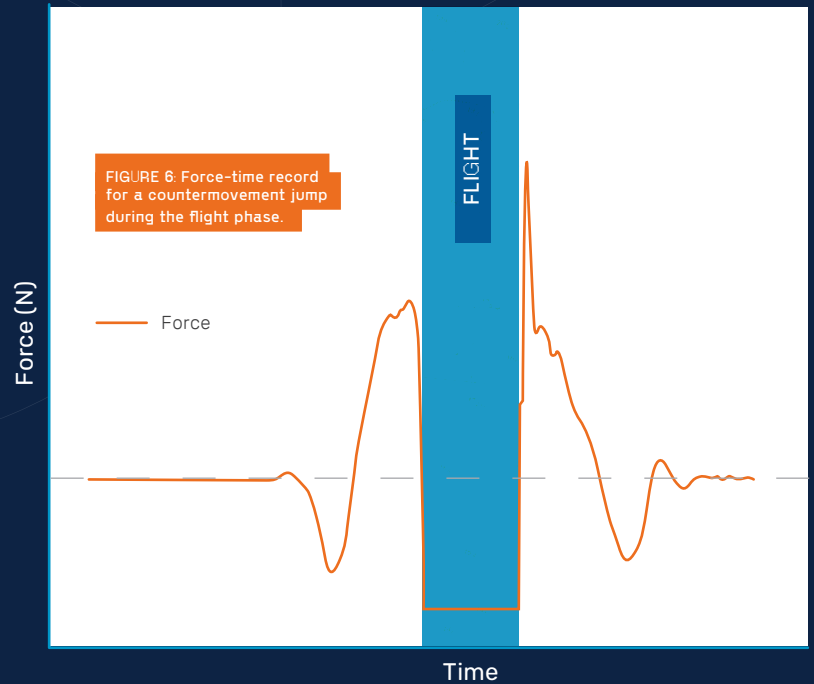
**The propulsive phase is characterized by a forceful extension of the hips, knees and ankles to propel the COM vertically.**

The force platform sampling frequency and the rate at which the athlete transitions from the braking to propulsion phase will likely determine whether an amortization phase can be identified (delay between zero and 0.01 m/s COM velocity which translates to a brief isometric period when velocity is zero). The force at the onset of the propulsion phase is determined by the force at the end of the braking phase (most likely minus any force lost in the amortization phase). The propulsion phase continues through to the instant of take-off. Plotting the displacement-time curve in this phase is useful, as it shows how vertical COM displacement becomes positive. Individuals who exhibit a smoother (spend less time in amortization) transition from braking to propulsive phase are more efficient at transferring momentum. This is an essential attribute for maximizing the athlete's jump performance and potential for improvement.



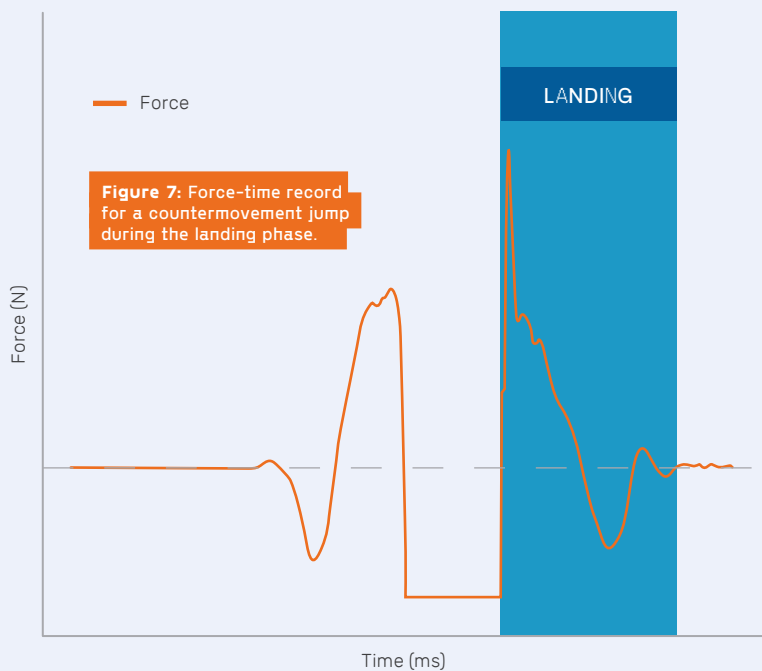
## FLIGHT PHASE

The flight phase commences at the instant of take-off when the force falls below a set threshold. A threshold of force equal to 5 times the standard deviation of flight force (when the force platform is unloaded), taken over a 300-ms portion of the flight phase, has been successfully used to identify take-off. The flight phase ends when the athlete contacts the force platform again and the force rises above 5 times the standard deviation of flight force.



## LANDING PHASE

The landing phase is the final CMJ phase, whereby the participant applies a net impulse to decelerate the COM from the velocity at which it contacts the force platform. The landing phase ends when the force stabilizes between  $\pm 5\%$  of body weight for one second. This instant is referred to as the time to stabilize.



## KEY PERFORMANCE INDICATORS

The CMJ assessment can answer questions like...



There are several different insights we can obtain from not only the height of an athlete's jump, but also how they performed the jump. Assessing an athlete or patient with the CMJ can provide answers to questions like:



Those are just a few questions a practitioner could ask to gain insights in the strategies employed by athletes or patients to obtain jump height during the CMJ test. Jump height is the metric that most practitioners focus on when they are attempting to measure their performance in a CMJ. When using a force plate, jump height is an important metric to pay attention to, but it is not the only one you should be considering. Before an individual even takes off from the ground, a series of events takes place that determine jump height. Some of the variables that could summarize jumping performance and are also used for measuring progress and monitoring adaptation are listed in the table on the next page.



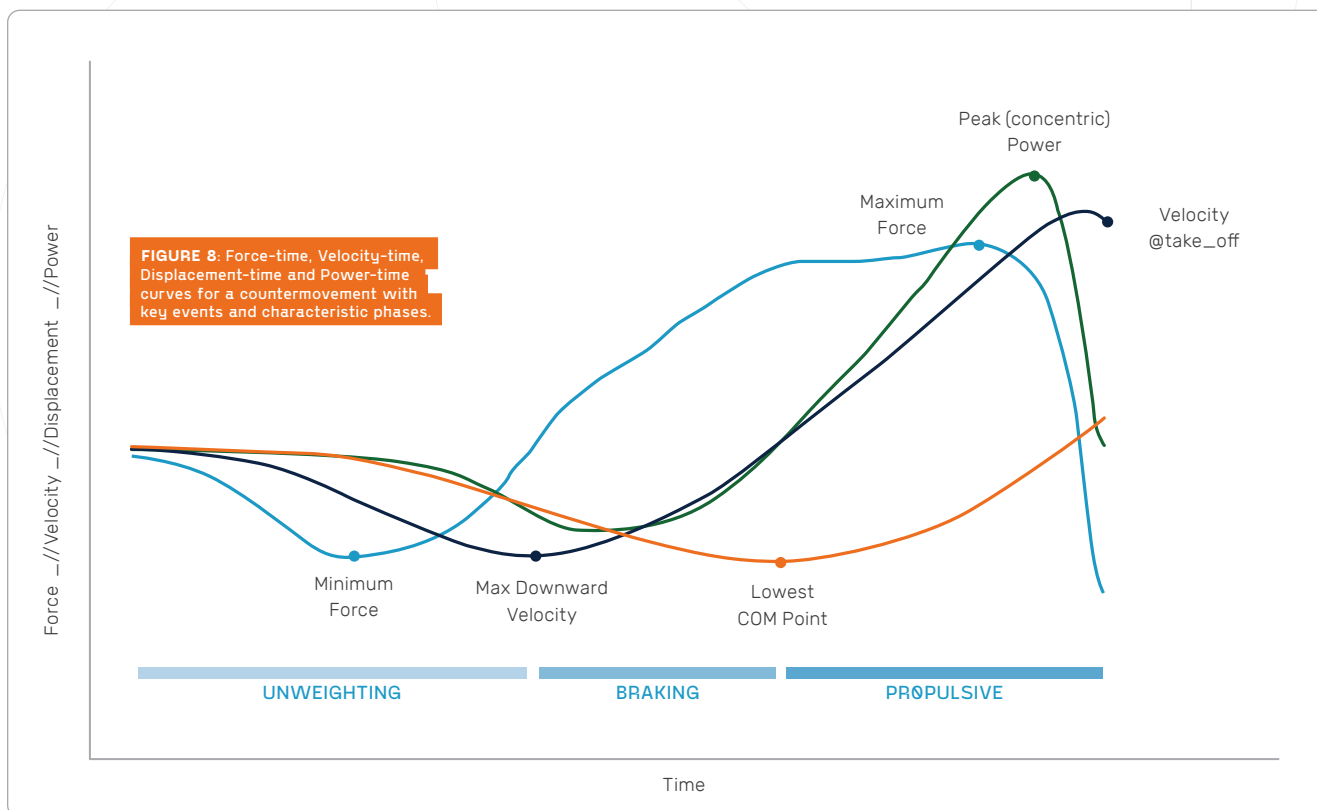
## MOST RELEVANT FEATURES FOR CMJ ASSESSMENT

KPI	DESCRIPTION
<b>JUMP HEIGHT</b>	<p>Jump height is defined as the maximal vertical displacement reached by the participant's COM in relation to initial position, and it can be accurately calculated using the impulse momentum theorem. It can also be calculated from flight time, although less accurately.</p> <p><b>Jump height from velocity at take off (impulse momentum):</b></p> $\text{Jump height} = \text{Velocity@takeoff}^2 / (2 * g)$ <p><b>Jump height from flight time:</b></p> $\text{Jump height} = 1/8 * (g * \text{Flight\_time}^2)$
<b>PEAK FORCE</b>	<p>Peak force is defined as the maximal value of force produced by the individual during ground contact.</p>
<b>PEAK POWER</b>	<p>Peak power is defined as the maximum value of power generated by the participant during ground contact.</p>
<b>RATE OF FORCE DEVELOPMENT (MAXIMUM OR AVERAGE)</b>	<p>Rate of Force Development (RFD), is the first time-derivative of the applied Force, or <math>RFD = dF / dt</math>. Typically, in CMJ it's evaluated during the braking phase of the jump and will show how fast the force is increasing. In practice, it is a measure of the rate at which an athlete increases the applied Force, and has the potential to be a measure of explosiveness, containing both neuromuscular and coordination characteristics in a multi-joint motion, as CMJ does. It does not depend on mass, muscle size, or the dimensions of the athlete, and it has no necessary relationship with power output, which is Force multiplied by Velocity.</p>
<b>TOTAL IMPULSE</b>	<p>Total impulse is defined as the area under the curve of force, and can be calculated from the movement initiation until take off.</p>
<b>CONCENTRIC (UPWARD) IMPULSE</b>	<p>Concentric (Upward) impulse is defined as the area under the curve of force during the concentric (push-off) phase of the jump.</p>
<b>ECCENTRIC (DOWNWARD) DECELERATION IMPULSE</b>	<p>Eccentric (Downward) impulse is defined as the area under the curve of force during the braking phase of the jump.</p>
<b>ECCENTRIC (DOWNWARD) DURATION</b>	<p>Eccentric duration represents the duration of COM trajectory from jump onset until it reaches the deepest point.</p>



KPI	DESCRIPTION
<b>ECCENTRIC (DOWNWARD) PEAK BRAKING FORCE</b>	The maximum value of Force during the braking phase.
<b>ECCENTRIC (DOWNWARD) PEAK POWER</b>	The maximum value of Power during the braking phase.
<b>CONCENTRIC (UPWARD) DURATION</b>	Concentric duration represents the duration of COM trajectory from the deepest point of the counter-movement until take off.
<b>CONCENTRIC (UPWARD) PEAK FORCE</b>	The maximum value of Force during the concentric (push-off) phase.
<b>CONCENTRIC (UPWARD) PEAK POWER</b>	The maximum value of Power during the concentric (push-off) phase.

The highest instantaneous product of force and velocity in the concentric phase is referred to as concentric peak power ( $P_{\text{PEAK}}$ ), and it is commonly used as a metric in profiling due to its stability over successive measurements and associations with performance in a variety of tasks. The most important use for both concentric  $P_{\text{PEAK}}$  and  $P_{\text{MEAN}}$  is in the process of profiling and evaluating long-term adaptations.



## CMJ ASSESSMENT IN REHABILITATION AND RETURN TO PLAY

While force platforms have traditionally been used to shed light on athletic performance, such assessments can also provide valuable information to medical staff and allied health professionals. Force platform CMJ assessment, combined with other performance data and clinical reasoning, data on bilateral or unilateral asymmetry derived from dynamic and isometric tests, can help guide decision-making regarding load and phase progression throughout rehabilitation and return to play (R-RTP). Residual neuromuscular and biomechanical deficits identified in CMJ jump tests may persist for months or years after R-RTP following ACL reconstruction, and a reduction in these deficits is not strongly associated with time since surgery. **Force platform data can add reliable quantification of an individual's neuromuscular response to injury and rehabilitation,** reducing reliance on subjective improvement criteria and therefore optimizing R-RTP decision-making and outcomes.

R-RTP is characterized by a unique set of contextual factors. First, great care must be taken – with the assistance of medical staff – to determine when certain tests can be safely integrated and when particular variables become significant. For instance, bilateral CMJs may be integrated during lower body R-RTP far earlier than single leg jumps (SL), despite the fact that both are extremely useful, and healthy baseline data is essential wherever possible. Asymmetries, jump strategies, and mechanical variables are likely to be the primary areas of focus for R-RTP monitoring in any occasion. In the process of rehabilitation, it typically takes quite a bit more time for RFD in the braking – deceleration phase and its asymmetries, as well as time-constrained impulses and landing asymmetries, to return to healthy norms. Output variables like jump height and total impulse may quickly get back to their healthy baselines.

### SYMMETRY IN CMJ KPIS

With the increasing adoption of dual force plate systems and the need to understand athletic performance, injury prevention, and rehabilitation; both unilateral and single-leg jumping performance assessments have become increasingly prevalent in both international sports organizations and clinical settings.<sup>5,6,7</sup> This trend can be explained by the fact that these types of analyses provide crucial information about the symmetry of the lower limbs' function to the practitioner. Literature findings indicate that SL jump performance features such as mean power, peak velocity, peak power, and concentric impulse exhibit acceptable reliability for unilateral CMJs, whereas asymmetry variables consistently demonstrate unacceptable reliability and levels of agreement during unilateral CMJs, whereas acceptable reliability and high levels of agreement were achieved for bilateral CMJs.<sup>6</sup> Everything above suggests that SL performance can be obtained with greater reliability during the unilateral CMJ, whereas the bilateral CMJ provides more consistent measures of inter-limb asymmetry; therefore, force plate monitoring of lower limb symmetry is valid and reliable. Peak force, peak braking force, concentric impulse and maximum rate of force development are some of the most frequently used variables for assessing asymmetry.

## Different equations used in literature for asymmetry calculation

KPI	DESCRIPTION	REFERENCE
<b>AI</b>	$(DL - NDL) / (DL + NDL / 2) * 100$	Robinson et al. (1987), Bini et al. (2014)
<b>BAI</b>	$(DL - NDL) / (DL + NDL) * 100$	Kobayashi et al. (2013)
<b>BSA</b>	$(\text{Stronger} - \text{Weaker}) / \text{Stronger} * 100$	Nunn et al (1988), Impelizzeri et al. (2007)
<b>LSI - 1</b>	$(NDL / DL) * 100$	Ceroni et al. (2012)
<b>LSI - 2</b>	$(\text{Right} - \text{Left}) / (0.5 * (\text{Right} + \text{Left})) * 100$	Bell et al. (2014)
<b>SI</b>	$(\text{High} - \text{Low}) / \text{Total} * 100$	Shorter et al. (2008), Sato & Heise (2012)
<b>SA</b>	$(45^\circ - \arctan[L / R]) / 90^\circ * 100$	Zifchock et al. (2008)

**AI**=asymmetry index; **BAI**=bilateral asymmetry index; **BSA**=bilateral strength asymmetry, **DL**=dominant limb; **LSI**=limb symmetry index; **NDL**=nondominant limb; **SA**=symmetry angle; **SI**=symmetry index

## INTERPRETATION OF THE MAGNITUDE OF ASYMMETRY

Previous research has consistently recognized limb asymmetry larger than 10 - 15% to be clinically meaningful, and this criterion has been often used to assist return-to-play decisions following injury.<sup>8,9,10</sup> The lack of evidence establishing the reliability and smallest worthwhile change in inter-limb asymmetry, on the other hand, may render the typical 10 - 15% rule questionable, as it would not allow the isolation of the "signal" from the "noise".<sup>11</sup> It is crucial to understand that, even with the suggested formulas in the previous section for quantifying asymmetries, practitioners still only have a percentage value, known as the magnitude of asymmetry. Thus, when left with the magnitude of asymmetry, it poses the question of how much further we can interpret the data.

Examining and interpreting the differences in light of the typical margin for error associated with the test is a frequently ignored aspect of asymmetry data interpretation. We must accept that every test we conduct contains some amount of inherent error, and this error can originate from a variety of different

sources. Therefore, we must be able to identify what constitutes a "true" asymmetry.

**Exell et al.<sup>12</sup> in their paper stressed the importance of taking intralimb variability into account in addition to the interlimb difference value.** In

essence, it was concluded that an asymmetry could only be regarded as true if it exceeded the test's variability. Technically speaking, this is quantified as the coefficient of variation (CV), which can be calculated from the standard deviation in relation to the average value and then converted into a percentage by multiplying by 100.

However, practitioners are encouraged to determine these for their own groups of athletes or patients due to variations in movement skill and training age. Korhonen et al.<sup>13</sup> in their paper present an example of how to perform the above suggested procedure. Despite any disagreement on a proposed threshold, it is accepted that the lower the CV value, the more reliable the test or metric.<sup>13</sup>

## SUMMARY

Since every individual produces force with a rather unique profile, the assessment of that profile through the force-time curve, over time provides valuable information about training and clinical practice.

**The goal for creating this eBook is to provide answers to any questions that may arise regarding the theory behind, and practical applications of, the countermovement jump in everyday practice.**

In order to help practitioners understand why the standardization of an assessment like the CMJ can be useful in the context of both sports training and clinical practice, we kept in mind that this eBook has to provide information that is as concise and precise as possible. This effort's sole purpose is to help practitioners gain a better understanding of why the use of force plates, in combination with the CMJ, is something that must be performed consistently to track progress and adaptations.

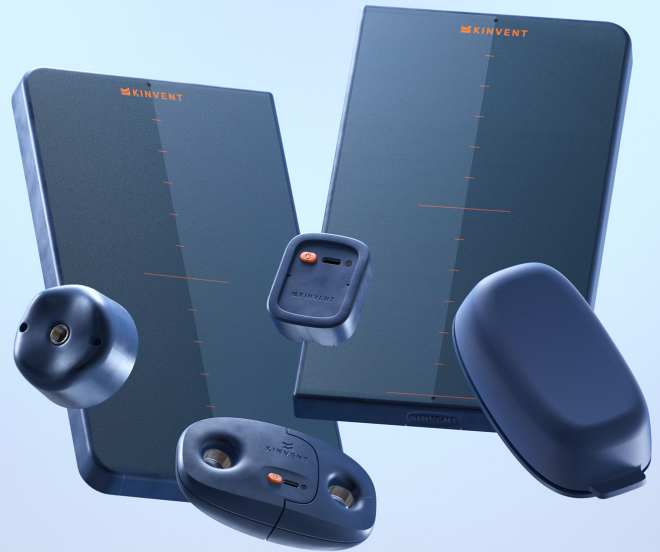


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**PROGRESS  
THROUGH PRECISION.**



**53**  
COUNTRIES

**160**  
METRICS

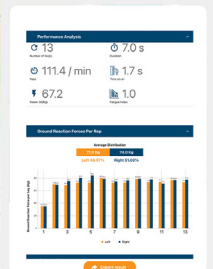
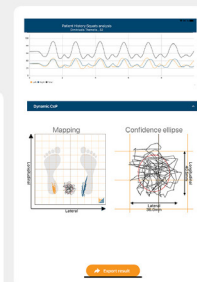
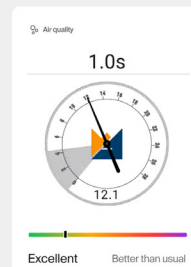
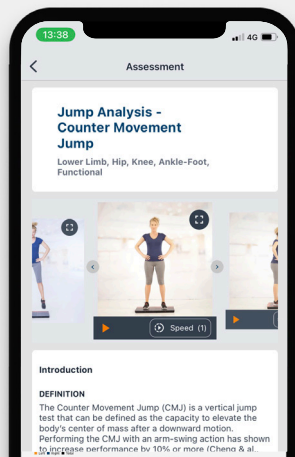
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