VALD

FORCEDECKS

DUAL FORCE PLATE SYSTEM

User Guide

Understanding force plate analysis, testing protocols, and metrics.

November 2023

Contents

1 Introduction

This document aims to provide health and performance professionals with an understanding of force plate testing and analysis, including the calculations and metrics used by ForceDecks, as well as common applications.

This document assumes the reader has a basic knowledge of how to use ForceDecks, including setting up the hardware and software, managing individual profiles, running tests, and generating reports. To get up to speed on these processes, check out the ForceDecks Starter's Guide [ForceDecks – VALD Knowledge Base]

1.1 Understanding Force Plate Data

A force plate can be thought of as a weighing scale, but instead of recording a single weight, a force plate records force values constantly over time (in ForceDecks' case, up to 1,000 times every second) and plots that data on a graph. The sole purpose of the hardware is to accurately capture exact forces at exact time points, while the software performs analysis by applying algorithms to that data and automatically reporting its results. Though it is possible to manually perform this in Excel, the primary benefits of ForceDecks are:

1. ForceDecks allows people access to information that they may not know how to edit and calculate themselves, thus eliminating the need for specific training and experience to manually calculate values of interest; and
2. ForceDecks exponentially speeds up data processing and greatly supports those who work in high pressure and/or time-sensitive environments, such as in elite sport or clinical practice.

To understand force plate data, it should be acknowledged that force plates directly measure only two things: force and time. In turn, these force and time values are what allow for the calculation of a host of other derivatives and metrics based on known physics principles, however these additional derivatives and metrics are calculated, not directly measured.

Understanding how force and time underpin all force plate data will help users identify improper testing procedures and ensure greater validity and reliability. For example, if bodyweight is captured while the individual is unstable on a force plate, then their bodyweight will likely be recorded inaccurately. Subsequently, given that acceleration calculations are reliant on bodyweight, the downstream calculations of displacement and power will also be incorrect, thus demonstrating how one poor protocol can affect a host of other results. This can have significant ramifications across a dataset, making it less reliable and/or applicable in practice.

1.2 Understanding Force Derivatives

ForceDecks provides a host of information on a range of metrics, all of which are derived from simple underlying measurements. At a fundamental level, all force plates measure two things directly:

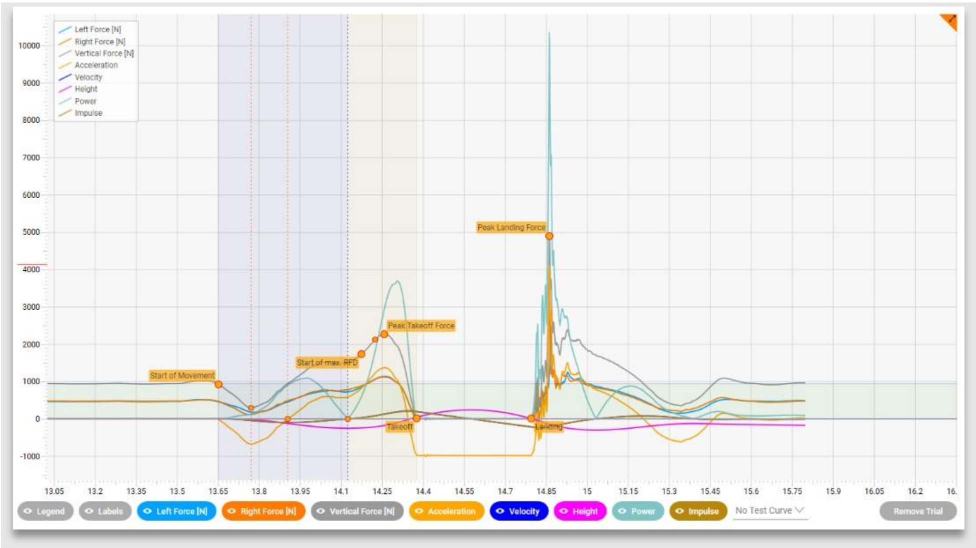
- Force (F); and
- Time (t)

From these two measurements and the known acceleration of gravity (g), ForceDecks uses Forward Dynamics and Newton's Laws to calculate a host of other derivatives such as:

- Body Mass (BM) = $F \div g$
- Impulse (Imp) = $F \times t$
- Acceleration (a) = $(F - BW) \div m$
- Velocity (V) = $v_0 + a.t$
- Power (P) = $F.v$
- Change in Displacement (S) = $v.t$

In ForceDecks *Raw Data* view, these derivatives are color-coded to assist with readability. Any one of them can be toggled on/off by clicking on its name in the legend at the bottom of the graph.

Force Derivative
Left Force (N)
Right Force (N)
Vertical Force (N)
Acceleration (m/s^2)
Velocity (m/s)
Height (m)
Power (W)
Impulse (Ns)



1.3 Understanding Key Moments and Phases

ForceDecks records raw time-series data for each of these derivatives, which in turn are used to identify key moments and phases such as:

Key Moment examples:

Start of Movement (SoM);
Start of max Rate of Force Development (RFD);
Takeoff;
Landing; and

- End of Movement Phase (EoM) examples:

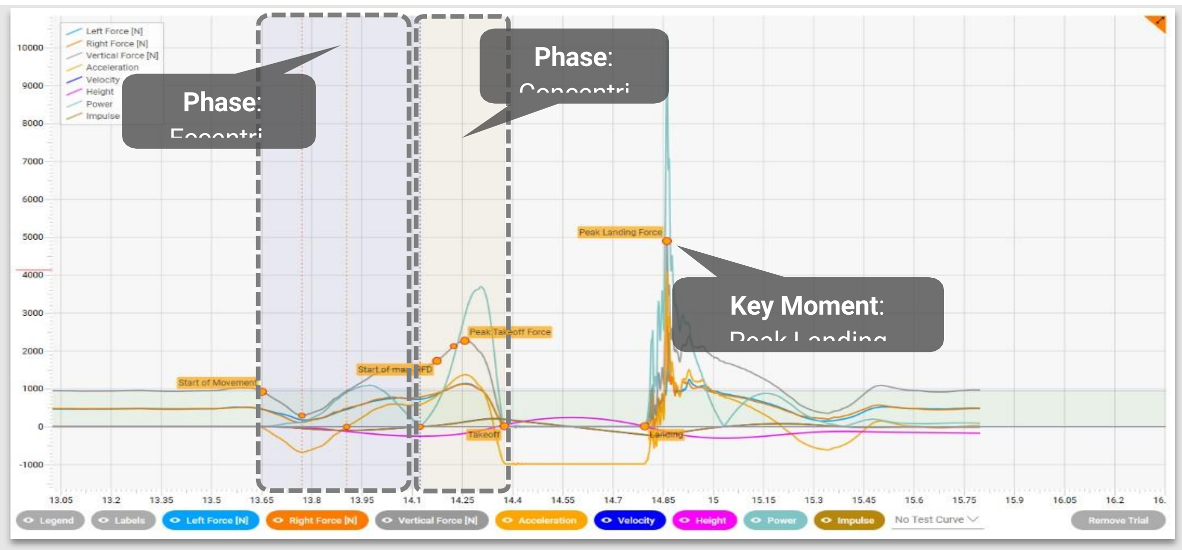
Eccentric phase;
Braking Phase;
Deceleration Phase; and
Concentric Phase.

Start of Movement Analysis:
Start of Movement (SoM) is the moment when ForceDecks detects that the rep being conducted has begun. ForceDecks default method is 20N for every test, however it is customizable for the following test types:

- Countermovement Jump
- Countermovement Jump – Loaded
- Squat Jump
- Squat Jump – Loaded
- Abalakov Jump
- Single Leg Jump

See this article for Customize Start of Movement Analysis.

In ForceDecks *Raw Data* view, key moments are labelled, and phases are shaded to assist with readability. Key moments can be toggled on/off by clicking on '**Labels**' in the legend at the bottom of the graph.



2 Test Types

Test Types	Descriptions	Other Test Types in this Category	Pros	Cons	Page Number
Countermovement Jump (CMJ)	Jump for maximum height with hands on hips.	• Single Leg Jump (SLJ) • Loaded Countermovement Jump (LCMJ) • Abalakov Jump (ABCMJ)	• Quick to test (<1min) • Easy to perform • Low stress • Abundant data • Shows "jump strategy"	• Considered less specific than other test types	9
Countermovement Rebound Jump (CMRJ)	Perform a Countermovement Jump and then a rebound jump for maximum height immediately upon landing.		• Fast to set up and perform • Generate outcome metrics for a slow and fast SSC movement	• Cannot control the drop height for the rebound jump • No true metrics for the Countermovement Jump	16
Squat Jump (SJ)	Jump for maximum height with hands on hips, starting from a paused squat position.	• Loaded Squat Jump (LSJ)	• Specific "overcoming" test (No SSC) • Can use RFDs • Low Stress	• Difficult to remove countermovement • No eccentric phase/data	22
Drop Jump (DJ)	Starting from a box, dropping onto force plates then rebound jump for maximum height.	• Single Leg Drop Jump (SLDJ)	• Starting from a box, dropping onto force plates then rebound jump for maximum height.	• Starting from a box, dropping onto force plates then rebound jump for maximum height.	29
Squat Assessment (SQT)	Loaded or bodyweight squats. Any external load can be entered manually or auto detected.	• Single Leg Squat Assessment (SLSQT)	• Fits gap between isometrics and jumps • Can track force production along with velocity (F:V Profile) • Immediate, rep-by-rep results provide biofeedback	• Slower to set up than other tests • Detection works better for faster squats (without pause or slow tempo)	37
Hop Test (HJ)	Starting with a sub- maximal CMJ, followed by 5-10 consecutive hops using ankles only (no knee flexion).	• Single Leg Hop Test (SLHJ)	• Easier to perform/learn than DJ for some • Test's elastic ability • Faster to set up and test than DJ	• Asymmetries cannot be used with confidence • Difficult for some to stay on force plates	45
Land And Hold (LAH)	Jumping with one or two legs from ground/box onto force plate/s, then holding in landing position until completely stable.	• Single Leg Land and Hold (SLLAH)	• ECC/landing only test • Specific Impact Asymmetries • Effective in numerous RTP scenarios	• Limited data (<10 metrics) • Aggressive impact forces when done for performance	53

Quiet Stand (QSB)	Stand as stationary as possible for a set amount of time.	• Single Leg Stand (SLSB) • Single Leg Range of Stability (SLROSB)	• Immediate objective data • Quantify asymmetry in balance • Track centre of pressure movement over time	• Slower test to perform • Can be difficult to interpret the results without baseline data	58
Isometric Test (ISOT)	Static maximal strength test.	• Single Leg Isometric Test (SLISOT) • Isometric Mid-Thigh Pull (IMTP) • Isometric Squat (ISQ) • Isometric Shoulder I/Y/T Test (SHLDISOI/Y/T)	• Safe, fast, and reliable test of maximal strength • RFD metrics for return to play and fatigue monitoring	• Can require specific equipment slower than jump testing • Requires attention on setup and execution	62 68

ForceDecks can auto-detect 16 different test types (as at software version 2.0.8702 and iOS 1.9.0) ranging across various jump protocols, isometric tests, and dynamic squat assessments. This section aims to explain the raw data, key moments, and movement phases for each of the major ForceDecks test types, so that users can identify key characteristics and understand test results. This section also covers common methods to determine whether a test may be invalid, and if so, how to correct it or prevent future errors.

2.1 Countermovement Jump (CMJ)

The Countermovement Jump (CMJ) is arguably the most popular force plate test due to its wide range of applications and significant number of available metrics.

The CMJ can be easily used in:

- Individual profiling;
- Fatigue and adaptation monitoring; and
- A wide range of return-to-play scenarios.

The CMJ test in ForceDecks reports information on numerous phases and offers excellent asymmetry analysis.

The goal of the CMJ is to jump as high as possible.

Below is a raw data trace of a typical Countermovement Jump test in ForceDecks, (showing only left, right and total vertical force – all other derivatives and key moment labels are toggled off to help with viewing):

2.1.1 Protocol

To perform a **Countermovement Jump** test, follow these steps:

Starting position:

- Normal standing posture.
- Hands on hips (if unweighted) or hands on barbell (if weighted).
- Chest up and looking forward.

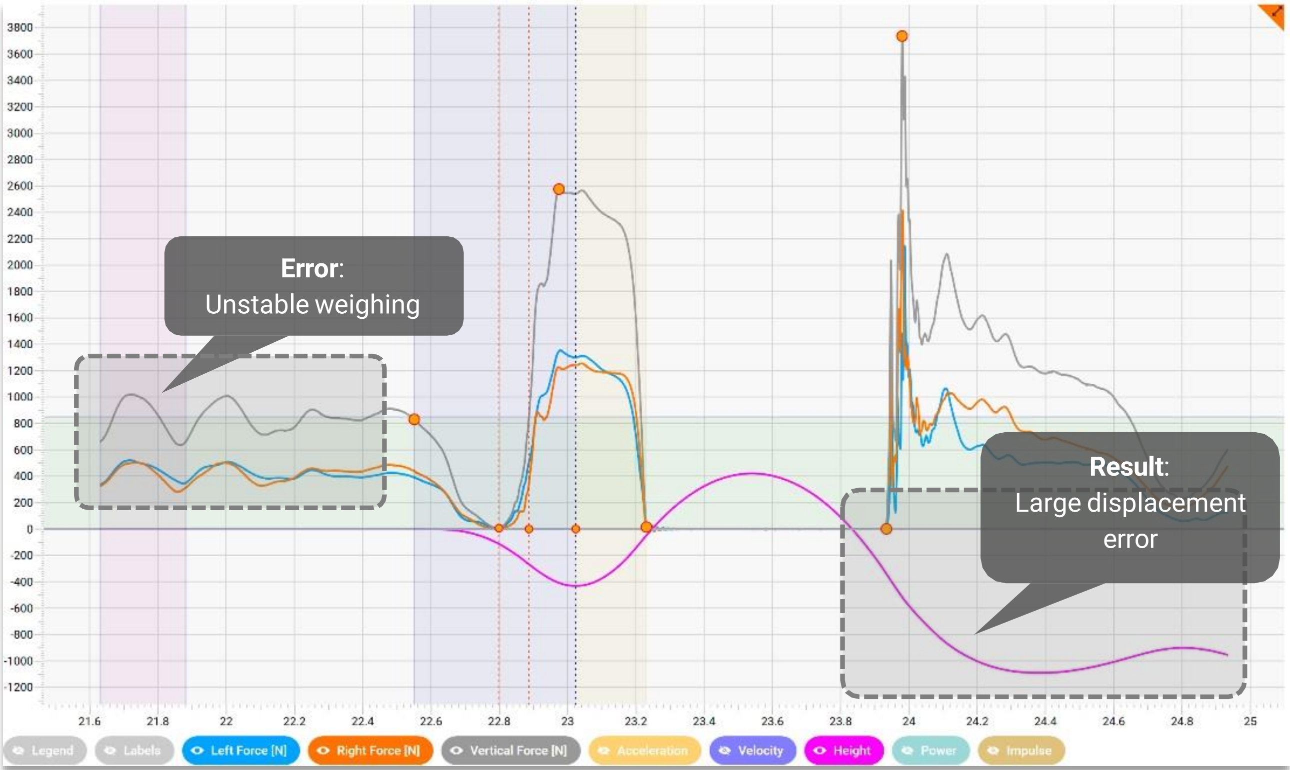
Protocol:

1. **Zero Plates** – Zero the plates. Ensure nothing is touching the plates during this step.
2. **Assume starting position** – Ask the individual to assume the starting position on the plates.
3. **Weigh individual** – Measure the individual's weight.
4. **Stabilize individual** – Instruct the individual to remain completely still, in the starting position for 2-3 seconds before and between each rep in the test.
5. **Perform test** – Instruct the individual to:
    a. Keep the chest up and looking forward;
    b. Bend down; then
    c. Jump up; then
    d. Land softly; then
    e. Assume starting position again.
6. **Repeat** – Repeat step 5 to record the desired number of reps.
7. **Complete the test** – Click to stop the recording and check the results.

Common protocol errors include:

Error	Potential Effect(s)
Not stable during weighing.	Bodyweight recorded inaccurately, which can introduce significant error into metrics such as jump height (flight time or Imp-Mom), power, and relative force values.

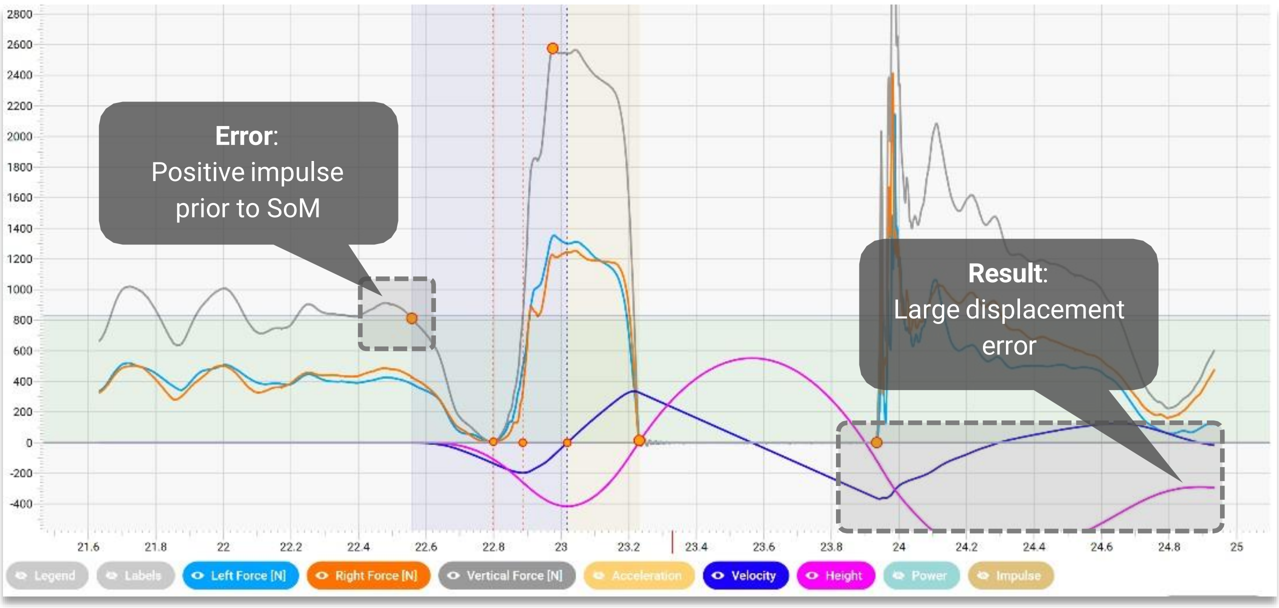
Error example:



*Here is a test with a very unstable weigh period which in turn affects the displacement curve (**pink**) significantly. This can be expected to also have ramifications in SoM and jump height, which would then affect time-sensitive metrics and any metrics relying on jump height (e.g.: RSI Mod).*

Error	Potential Effect(s)
Pre-jump positive impulse (Plantar flexion).	Poor start of integration as there is already a positive velocity at SoM. This will influence a host of metrics from jump height to the entire displacement curve along with metrics associated with displacement.

Error example:

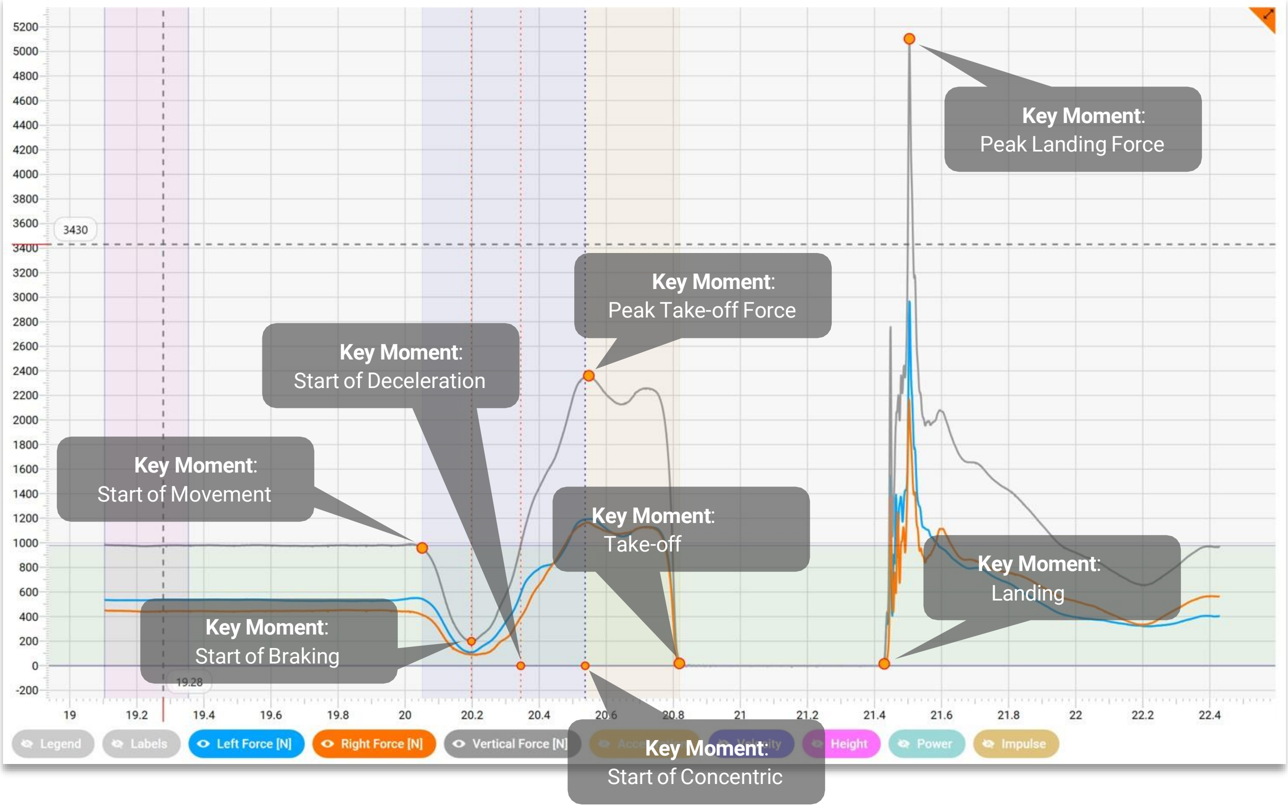


*Positive Impulse immediately prior to the countermovement influences integration calculations, as they are based on the assumption of a zero-velocity start. If a positive velocity exists, displacement (**pink**) and therefore Jump Height will be less than the results show.*

2.1.2 Key Moments and Phases

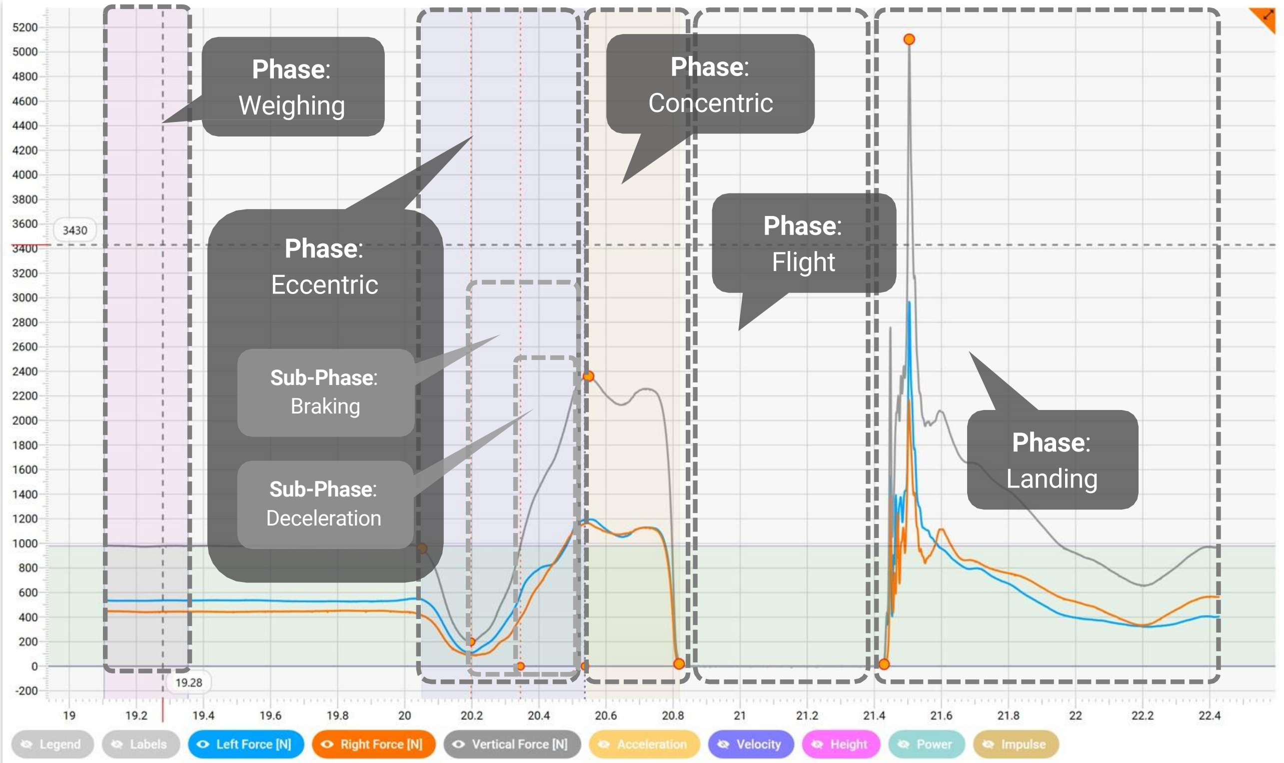
ForceDecks auto-detects the following key moments in a Countermovement Jump:

Key Moments	Description
Start of Movement	Point where a 20N threshold is exceeded. This criteria is customizable in Settings.
Start of Braking Phase	Minimum force until end of eccentric phase.
Start of Deceleration Phase	Peak eccentric velocity until end of eccentric phase.
Start of Concentric Phase	Zero Velocity until take-off.
Start of Max. RFD	Point of steepest concentric force.
End of Max. RFD	Peak take off force.
Peak Take-off Force	Highest force value obtained during the jump (eccentric/concentric phase).
Take-off	Point where force is below 20N.
Landing	Point where force rises above 20N.
Peak Landing Force	Highest force obtained during landing phase.



ForceDecks auto-detects the following phases in a Countermovement Jump:

Phase	Description
Weighing Phase	Steady phase for weight to be recorded.
Eccentric Phase	Phase containing negative velocity.
Braking Phase	Sub-phase within eccentric phase: minimum force until end of eccentric phase.
Deceleration Phase	Sub-phase within eccentric phase: peak eccentric velocity until end of eccentric phase.
Concentric Phase	Zero velocity until take-off.
Flight Phase	From take-off until landing.
Landing Phase	Point where force rises above 20N, then eventually returns to bodyweight.



From these key moments and phases in a Countermovement Jump test, ForceDecks software calculates and reports 112 metrics on performance and asymmetry.

2.1.3 Commonly Used Metrics

Some of the most commonly used metrics from a Countermovement Jump test include:

Metrics	Description	Common Application(s)
Performance Metrics		
Jump Height (Imp-Mom)	Outcome measure which gives context to other metrics.	Fatigue monitoring, adaptation monitoring
Flight Time: Contraction Time and RSI-Modified	Time spent in the air divided by time spent on the ground (eccentric and concentric phases).	Fatigue monitoring, adaptation monitoring
Eccentric Duration	Length of time spent in the eccentric phase.	Fatigue monitoring
Eccentric Mean Power	Average amount of power generated in the eccentric phase.	Individual profiling and adaptation monitoring
Peak Power	Maximal power in the concentric phase.	Profiling and adaptation monitoring
Asymmetry Metrics		
Concentric Impulse Asymmetry	Difference between left and right limb in total concentric work.	Return to play monitoring
Eccentric Deceleration RFD Asymmetry	Difference between limbs in the rate at which the deceleration force is generated.	Return to play monitoring
Peak Landing Force Asymmetry	Peak force difference between limbs on landing.	Return to play monitoring

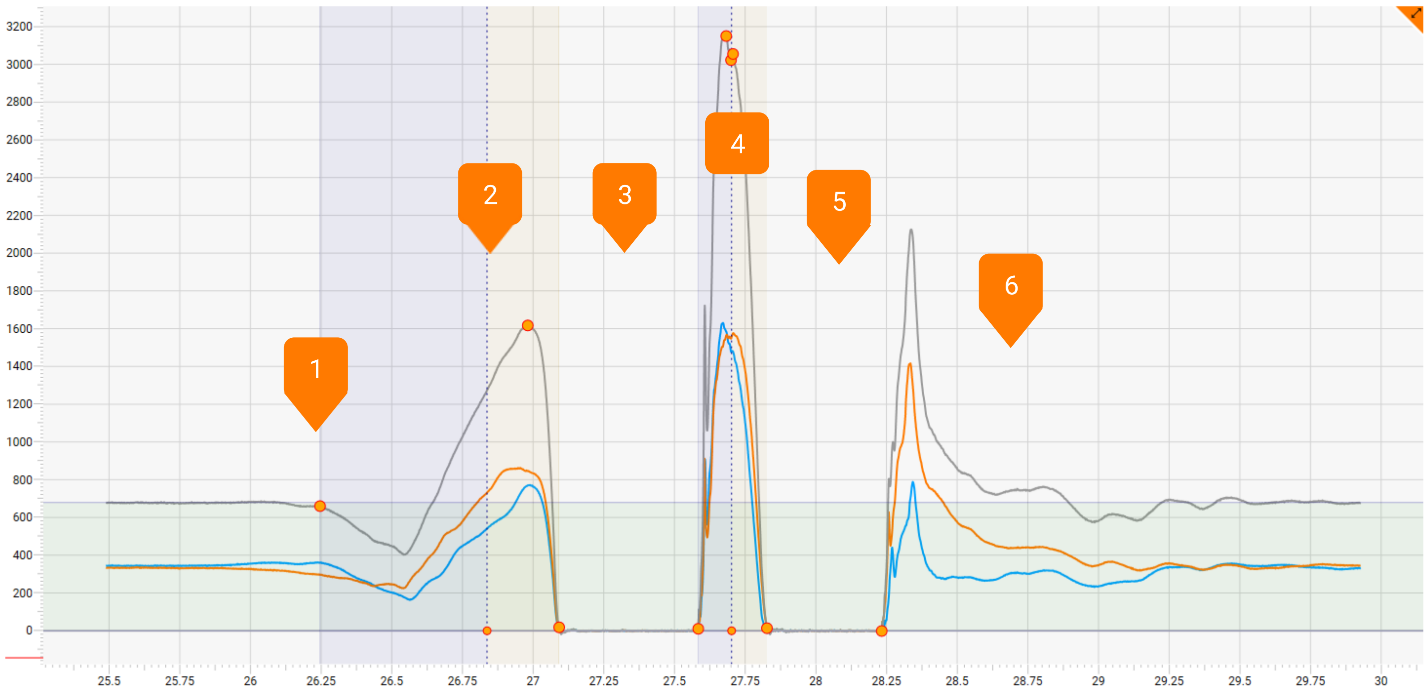
2.2 Countermovement Rebound Jump (CMRJ)

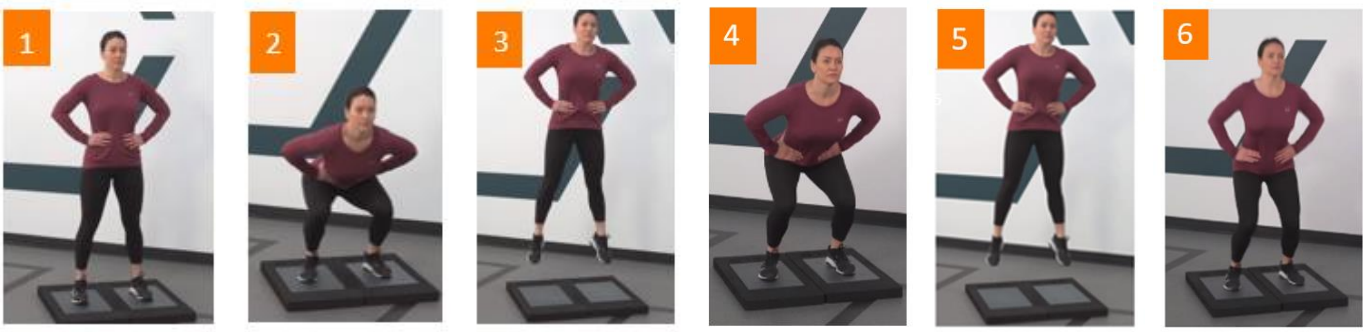
The Countermovement Rebound Jump (CMRJ) is a test that combines the benefits of a Countermovement Jump with a Drop Jump.

The test can be performed with one or two limbs. The individual performs a Countermovement Jump with a slow stretch-shortening cycle, followed immediately upon landing by a rebound jump with a fast stretch-shortening cycle.

The test allows for quick comparison of both jumping strategies.

Below is a raw trace of a Countermovement Rebound Jump in ForceDecks:





2.2.1 Protocol

To perform a **Countermovement Rebound Jump** test, follow these steps:

Starting position:

- Normal standing posture.
- Hands on hips.
- Chest up and looking forward.

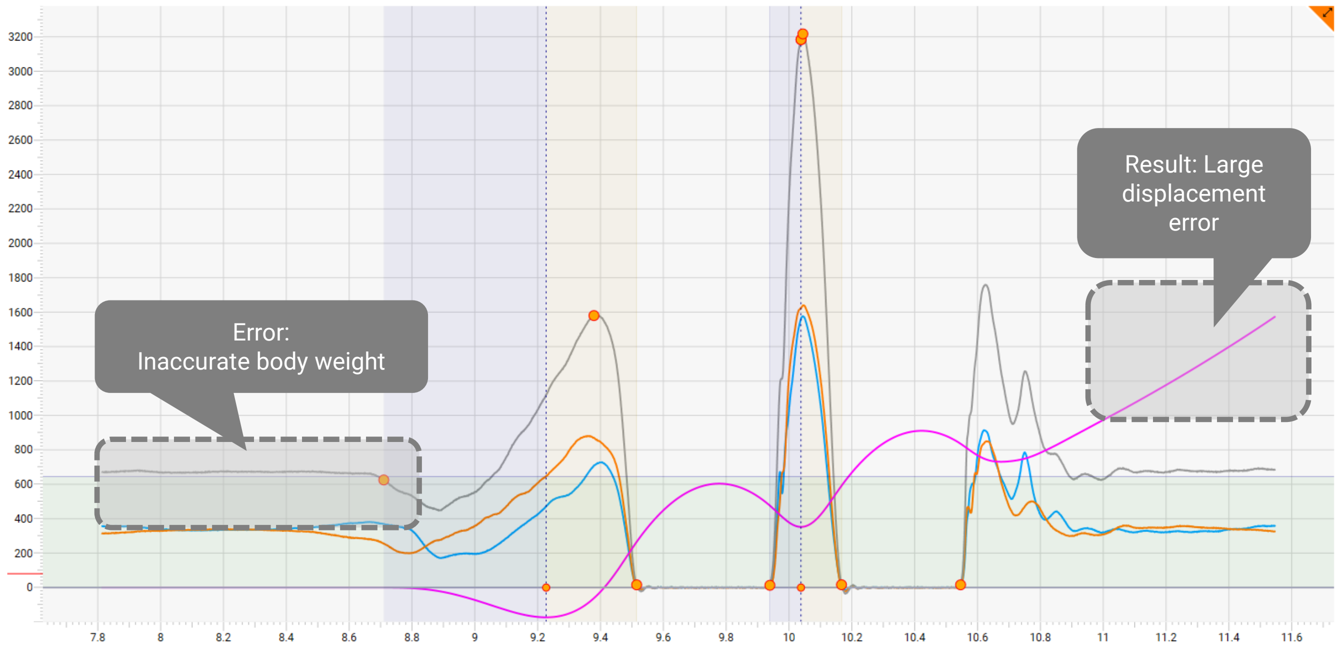
Protocol:

1. **Zero Plates** – Zero the plates. Ensure nothing is touching the plates during this step.
2. **Assume starting position** – Ask the individual to assume the starting position on the plates.
3. **Weigh individual** – Measure the individual's weight.
4. **Stabilize individual** – Instruct the individual to remain completely still, in the starting position for 2-3 seconds before and between each rep in the test.
5. **Perform test** – Instruct the individual to:
    f. Keep the chest up and looking forward;
    g. Bend down; then
    h. Jump up; then
    i. Land on the plates with both feet at the same time; then
    j. Immediately jump as high as possible; then
    k. Land softly; then
    l. Assume starting position again.
6. **Repeat** – Repeat step 5 to record the desired number of reps.
7. **Complete the test** – Click to stop the recording and check the results.

Common protocol errors include:

Error	Potential Effect(s)
Pre-jump movement or inaccurate weighing	Given the length of a Countermovement Rebound Jump, small errors in protocol to start a test have lots of time to amplify during a test. Incorrect weight or movement prior to the test will result in inaccuracies in the velocity and height measurements.

Error Example:

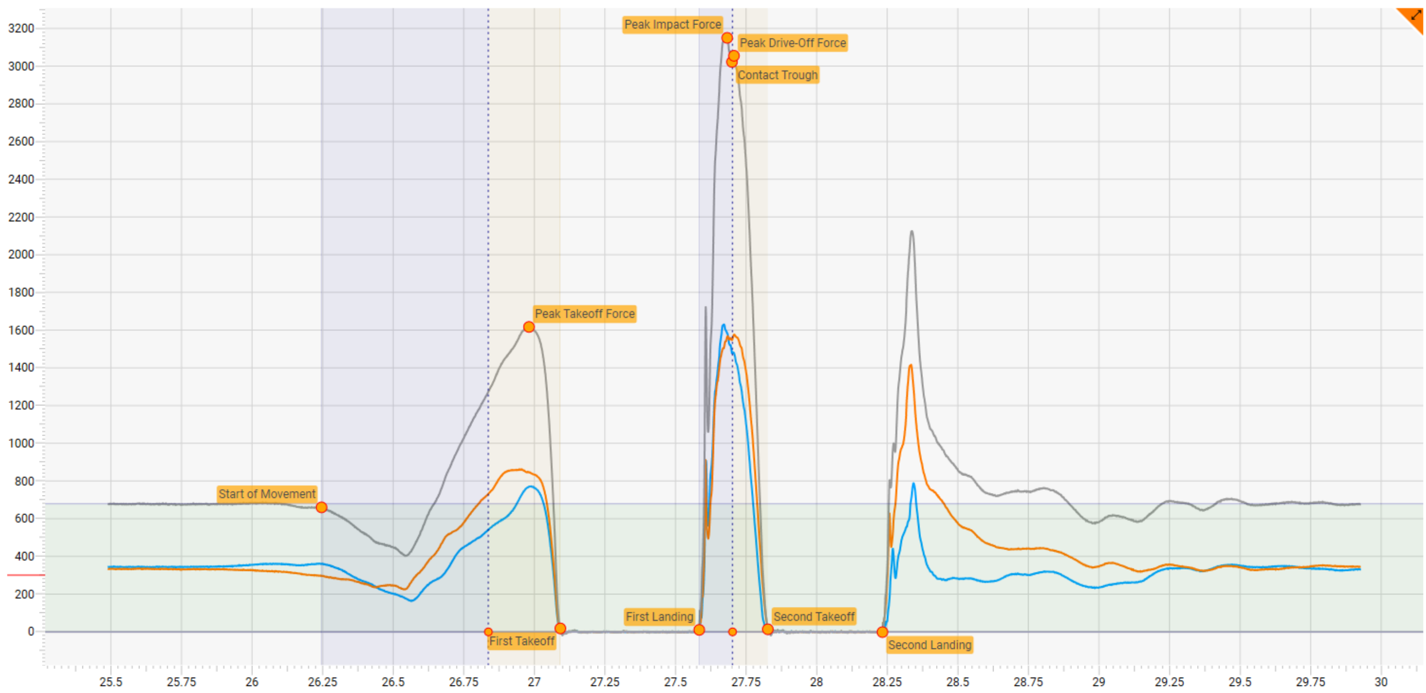


*Here is a test which starts with an inaccurate body weight. This in turn affects the height (i.e., displacement) curve (**pink**). Additionally, this will impact the velocity, power, and impulse curves, and any metrics which are derived from them.*

2.2.2 Key Moments and Phases

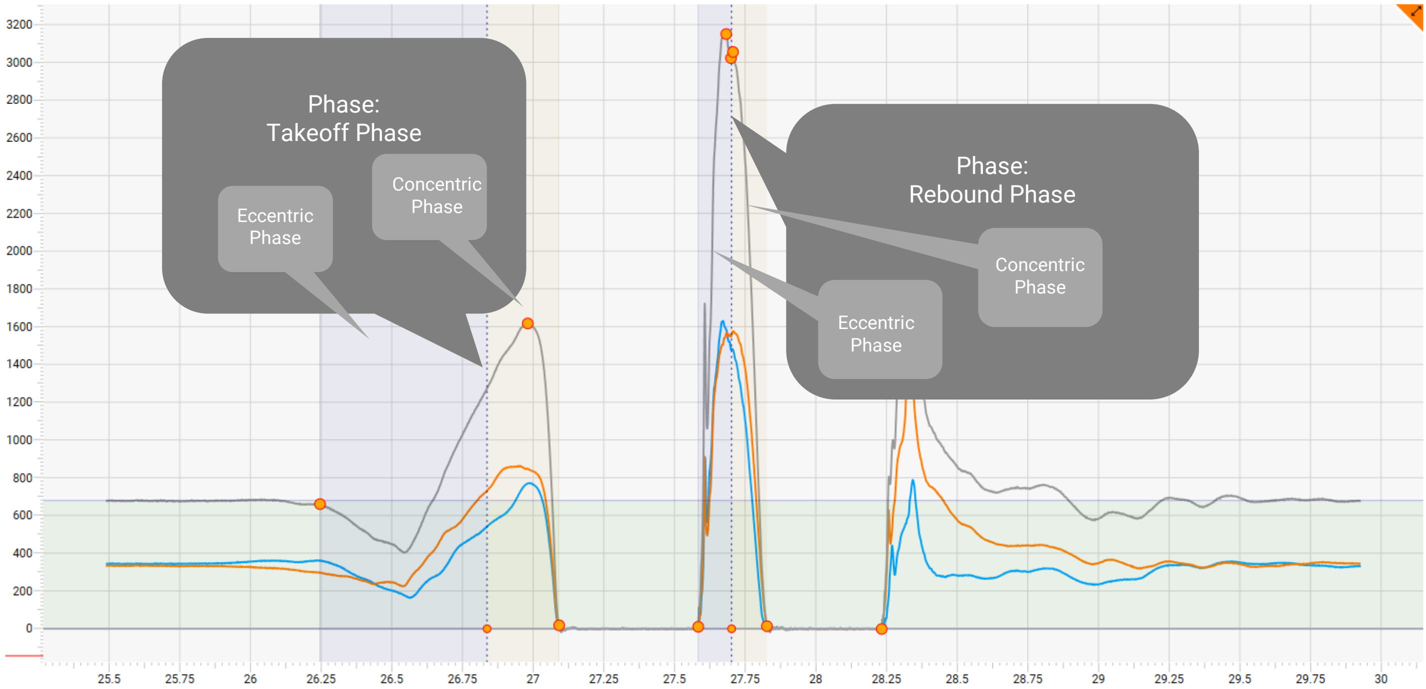
ForceDecks auto-detects the following key moments in a Countermovement Rebound Jump:

Key Moment	Description
Start of Movement	Point where a 20N threshold is exceeded.
Start of Concentric Phase	Zero Velocity before first takeoff.
Peak Takeoff Force	Maximum force prior to first takeoff.
First Takeoff	Point where force is below 20N.
First Landing	Point where force rises above 20N.
Peak Impact Force	Greatest passive force on impact from first landing.
Contact Trough	Lowest force point between peak impact and peak drive-off force.
Start of Concentric Phase	Zero Velocity before second takeoff.
Peak Drive-Off Force	Greatest active force prior to second takeoff.
Second Takeoff	Point where force is below 20N.
Second Landing	Point where force rises above 20N.



ForceDecks auto-detects the following phases in a Countermovement Rebound Jump:

Phase	Description
Takeoff Phase	Phase between start of movement and first takeoff.
Eccentric Phase	Phase between start of movement and start of concentric phase.
Concentric Phase	Phase between start of concentric phase and first takeoff.
Rebound Phase	Phase between first landing and second takeoff.
Eccentric Phase	Phase between first landing and start of concentric phase.
Concentric Phase	Phase between start of concentric phase and second takeoff.



From these key moments and phases in a Countermovement Rebound Jump test, ForceDecks software calculates and reports 82 metrics on performance and asymmetry.

2.2.3 Commonly Used Metrics

Some of the most commonly used metrics from a Countermovement Rebound test include:

Metrics	Description	Common Application(s)
Performance Metrics		
First Jump Height (Imp-Mom)	Outcome measure to anchor/give context to other metrics.	Fatigue monitoring, adaptation monitoring, profiling
Rebound Jump Height (Imp-Mom)	Measure to compare to the first jump with a slower takeoff.	Fatigue monitoring, adaptation monitoring, profiling
Rebound Contact Time	Time to complete the rebound takeoff.	Fatigue monitoring, adaptation, monitoring, profiling
Takeoff Peak Power / BM	Power produced by the individual normalized to their body mass.	Individual profiling
Asymmetry Metrics		
Peak Drop Landing Force	L/R difference of landing force from the first jump.	Return to play monitoring, adaptation monitoring
Peak Landing Force	L/R difference of landing force from the second jump.	Return to play monitoring, adaptation monitoring

2.3 Squat Jump (SJ)

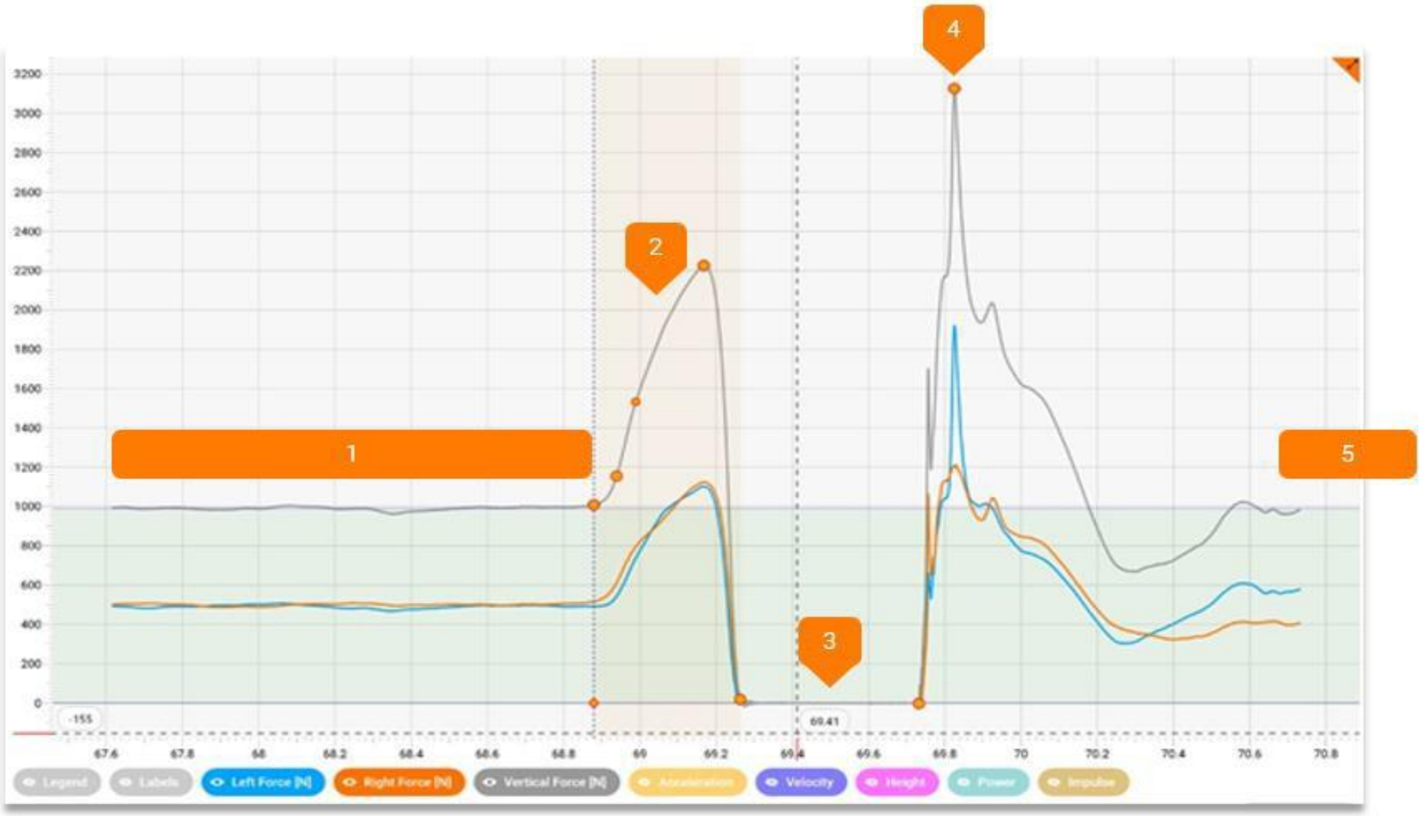
The Squat Jump (SJ) test is used to evaluate triple extension performance by isolating the concentric phase of a jump.

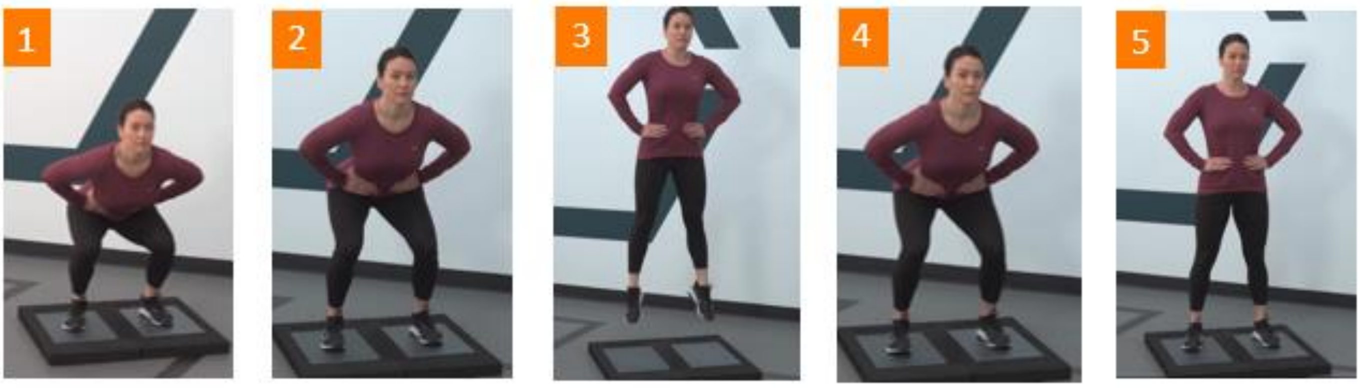
The SJ is a highly effective test to determine an individual's ability to exhibit pure concentric force, without utilizing the stretch shortening cycle.

The protocol is extremely strict and must be performed precisely to ensure correct software detection and accurate results.

The goal of the SJ is to jump as high as possible.

Below is a raw data trace of a typical Squat Jump test in ForceDecks, (showing only left, right and total vertical force – all other derivatives and key moment labels are toggled off to help with viewing):





2.3.1 Protocol

To perform a **Squat Jump** test, follow these steps:

Starting position:

- Partial or quarter-squat position
- Hands on hips

Protocol:

1. **Zero plates –** Zero the plates. Ensure nothing is touching the plates during this step.
2. **Assume starting position –** Ask the individual to assume the starting position on the plates.
3. **Weigh individual –** Measure the individual's weight.
4. **Stabilize individual –** Instruct the individual to remain completely still, in the starting position for 2-3 seconds before and between each rep in the test.

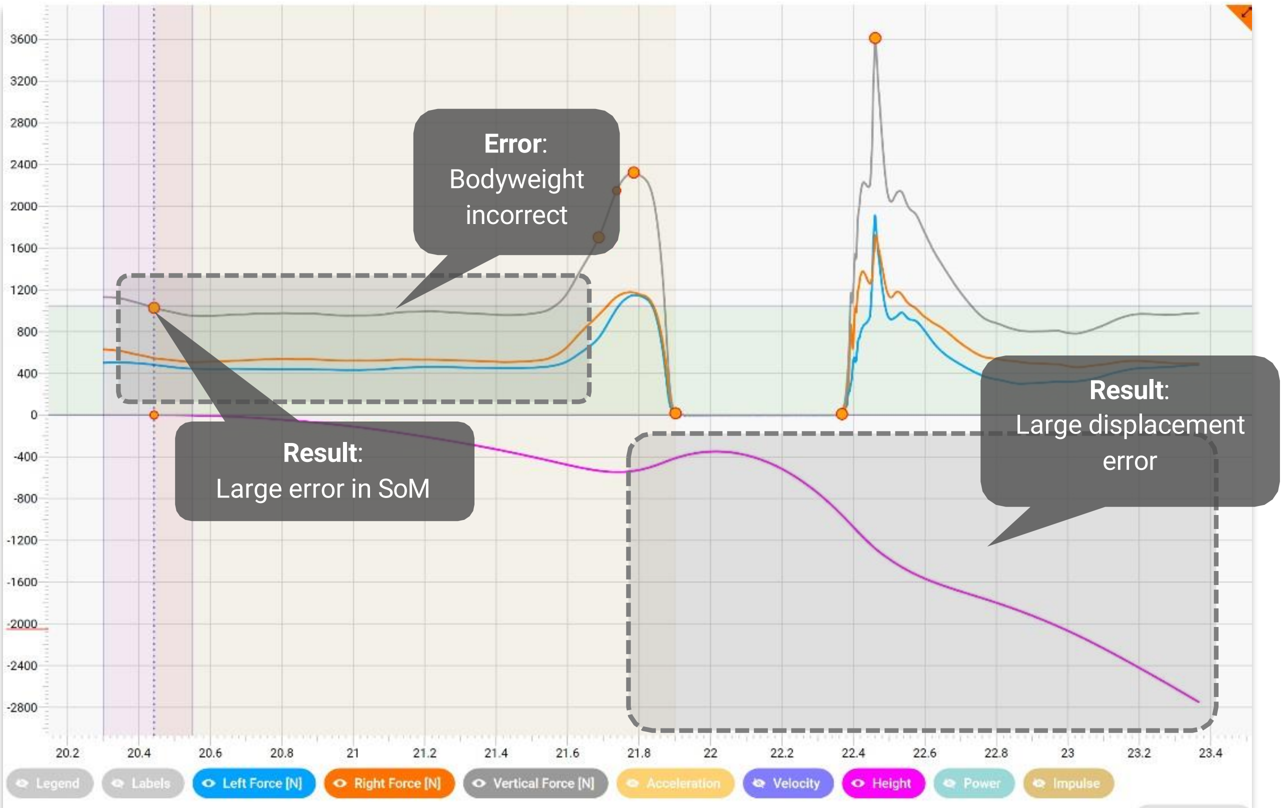
> Important: ensure there is no downward movement from the starting position.

5. **Perform test –** Instruct the individual to:
   a. Keep the chest up and looking forward;
   b. Jump up; then
   c. Land softly; then
   d. Assume starting position again.
6. **Repeat –** Repeat step 5 to record the desired number of reps.
7. **Complete the test –** Click to stop the recording and check the results.

Common protocol errors include:

Error	Potential Effect(s)
Not stable during weighing.	Bodyweight recorded inaccurately, which can introduce significant error into metrics such as jump height (Imp-Mom), power and relative force values.

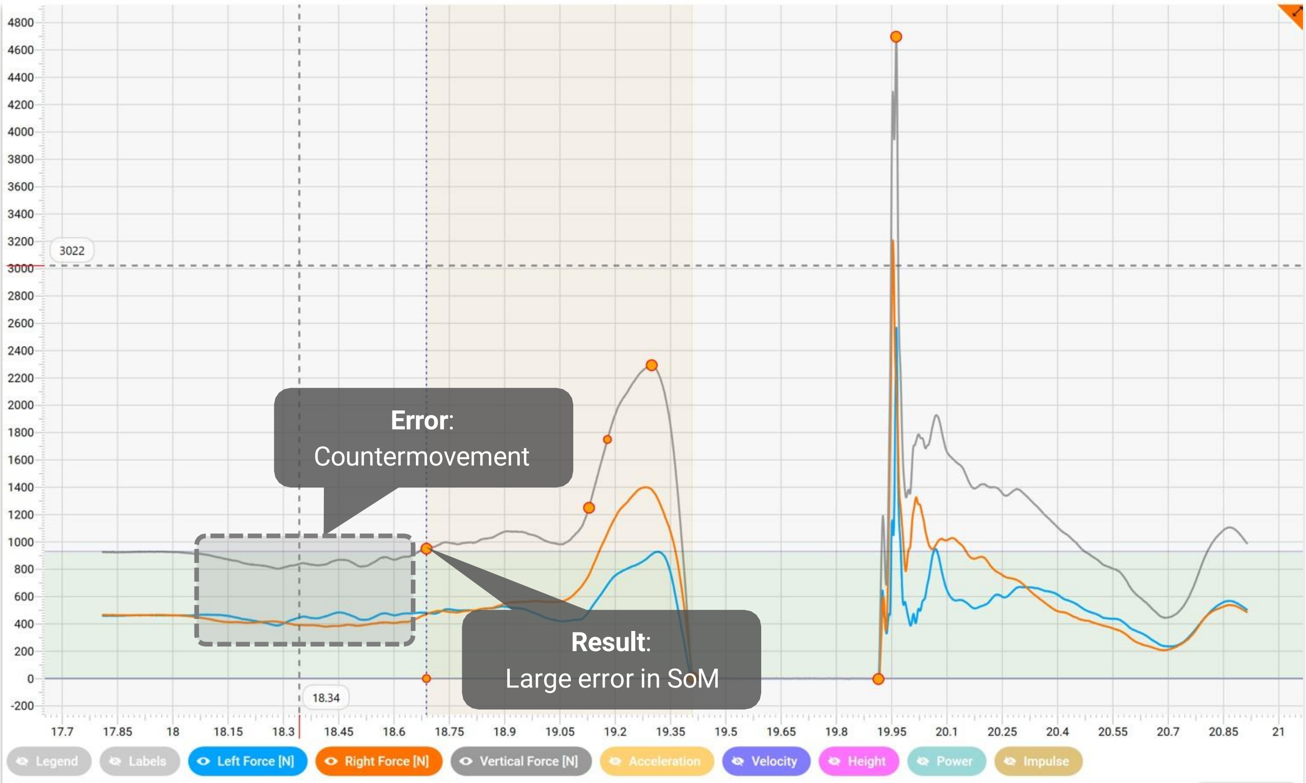
Error example:



Here is an example of an unstable weighing period which resulted in a recorded bodyweight, heavier than the individual's actual bodyweight. This has caused the SoM to be incorrectly detected when the individual stabilizes at normal bodyweight. As can be seen, not only is SoM detected extremely early (i.e., at roughly 20.4s, rather than when it should - at roughly 21.5s), but displacement is incorrect due to incorrect bodyweight integration.

Error	Potential Effect(s)
Countermovement prior to concentric phase.	Can elicit a poor test detection and will negate the goal of a squat jump test as a stretch shortening cycle has been introduced.

Error example:

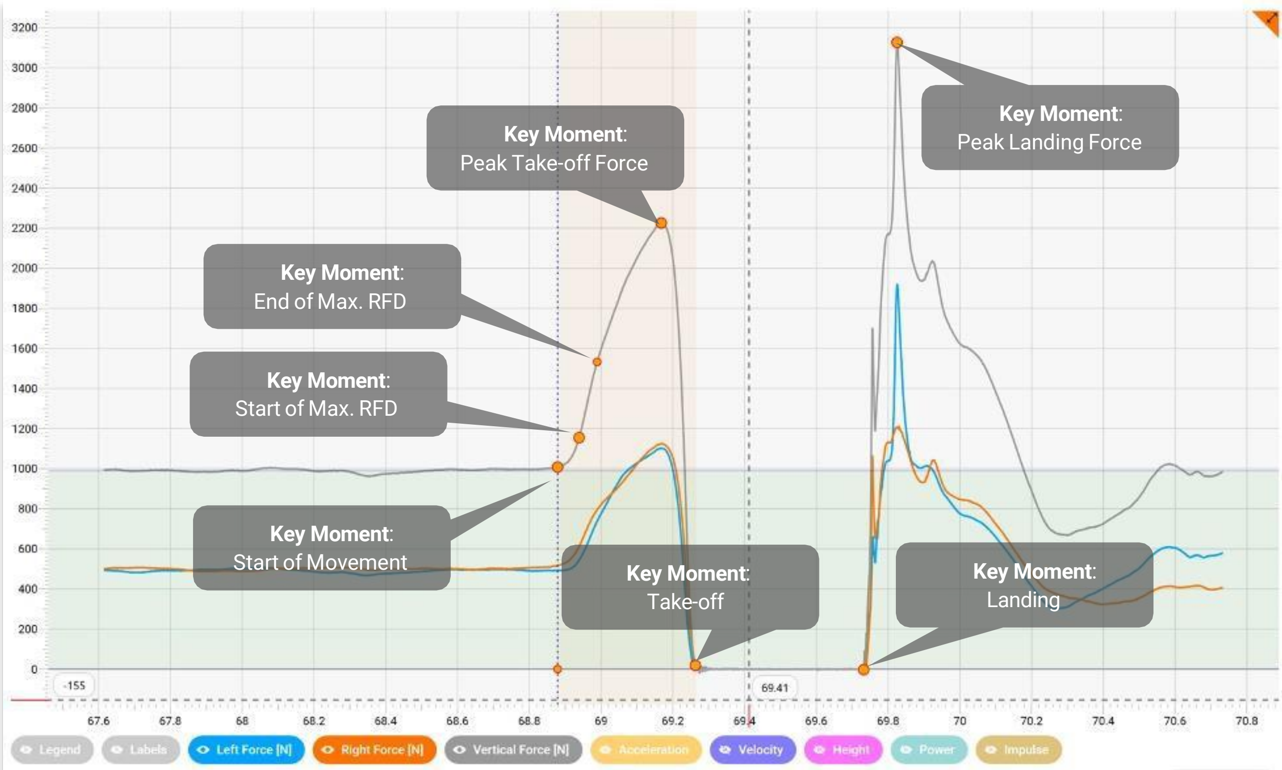


Here we can see not only a countermovement prior to the squat jump, but a poor detection of SoM. SoM should be after the second trough, well inside the concentric phase. Therefore, results for contraction time, all RFD and force, at given time points will all be unreliable.

2.3.2 Key Moments and Phases

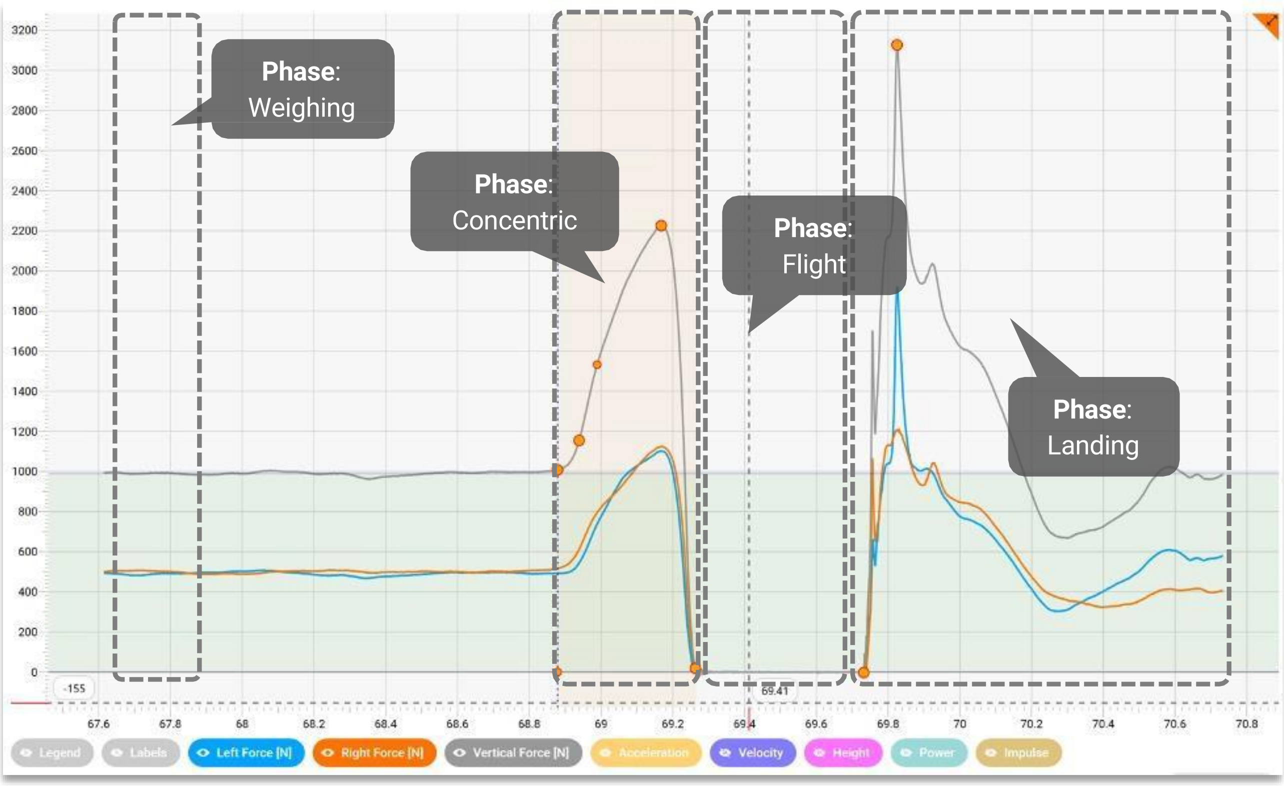
ForceDecks auto-detects the following key moments in a Squat Jump:

Key Moments	Description
Start of Movement	Point where a 20N threshold is exceeded. This criteria is customizable in Settings.
Start of Max. RFD	Point of steepest concentric force.
End of Max. RFD	End point of the largest RFD.
Peak Take-off Force	Highest force value obtained during the jump.
Take-off	Point where force is below 20N.
Landing	Point where force rises above 20N.
Peak Landing Force	Highest force obtained during landing phase.



ForceDecks auto-detects the following phases in a Squat Jump:

Phase	Description
Weighing Phase	Steady phase for weight to be recorded.
Concentric Phase	Zero velocity until take-off.
Flight Phase	From take-off until landing.
Landing Phase	Point where force rises above 20N and settles back to bodyweight.



From these key moments and phases in a Squat Jump test, ForceDecks software calculates and reports 71 metrics on performance and asymmetry

2.3.3 Commonly Used Metrics

Some of the most commonly used metrics from a Squat Jump test include:

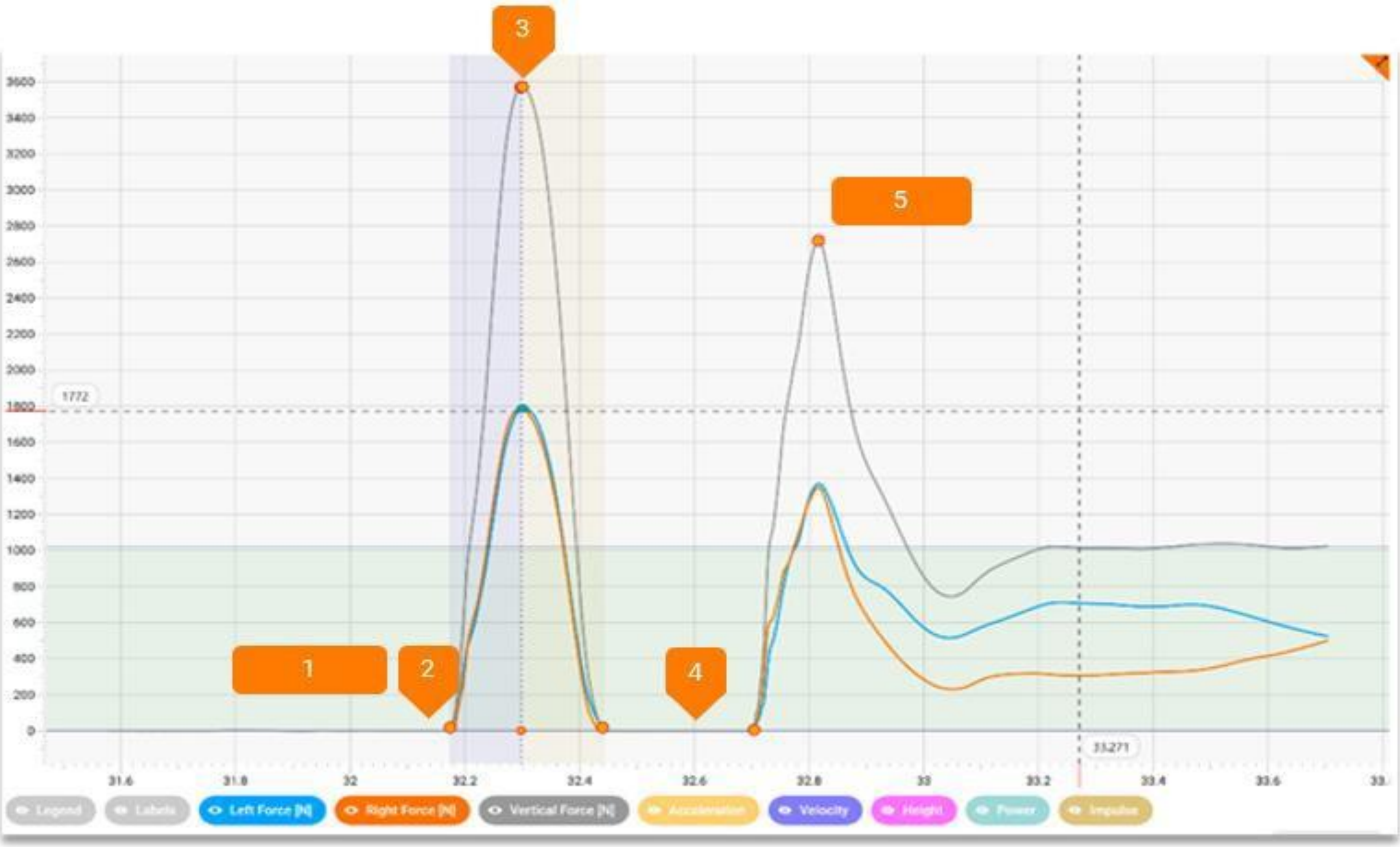
Metrics	Description	Common Application(s)
Performance Metrics		
Jump Height (Imp-Mom)	Outcome measure to give context to other metrics.	Fatigue monitoring, adaptation monitoring
Positive Takeoff Impulse	Total concentric work performed above bodyweight.	Fatigue monitoring, adaptation monitoring
Concentric RFD	Rate of force development (RFD) in the concentric phase.	Fatigue monitoring, profiling
Peak Power / BM	Maximal power in the concentric phase relative to bodyweight.	Individual profiling and adaptation monitoring
Peak Net Takeoff Force / BM	Peak net force (above bodyweight) relative to bodyweight.	Profiling and adaptation monitoring
Asymmetry Metrics		
Positive Takeoff Impulse Asymmetry	L/R difference of concentric work performed above bodyweight.	Return to play monitoring
Concentric RFD Asymmetry	Rate of L/R force development in the concentric phase.	Return to play monitoring
Force at Peak Power Asymmetry	L/R difference in force output at the moment of peak force application.	Return to play monitoring

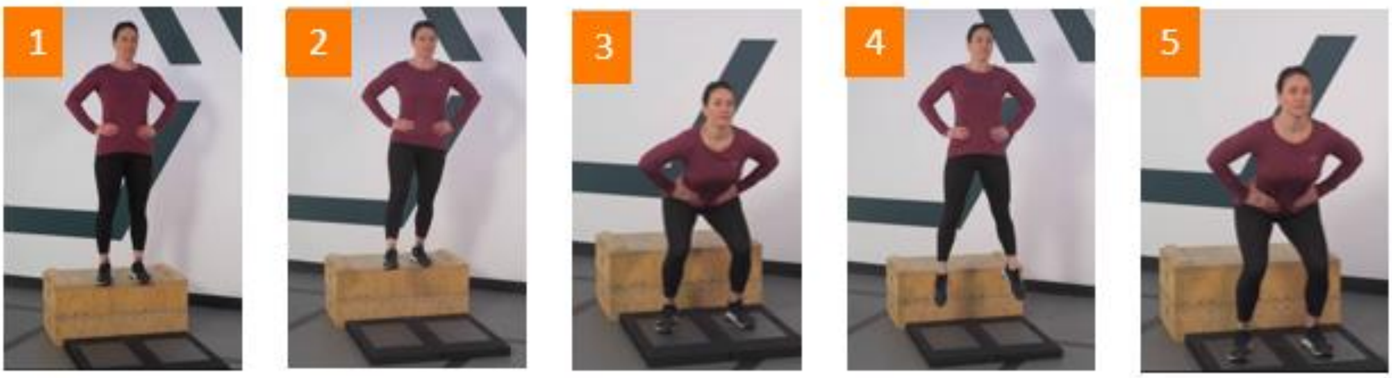
2.4 Drop Jump (DJ)

The Drop Jump (DJ) test evaluates reactive ability and an individual's stretch-shorten cycle capacity. The test has many similarities with repeat jumping and cutting maneuvers in athletics.

The goal of the DJ is to jump as high as possible but after minimal ground contact time.

Below is a raw data trace of a typical Drop Jump test in ForceDecks, (showing only left, right and total vertical force – all other derivatives and key moment labels are toggled off to help with viewing):





2.4.1 Protocol

To perform a **Drop Jump** test, follow these steps:

Starting position:

- Standing on box or elevated platform immediately behind force plates
- Normal standing posture
- Hands on hips
- Chest up and looking forward

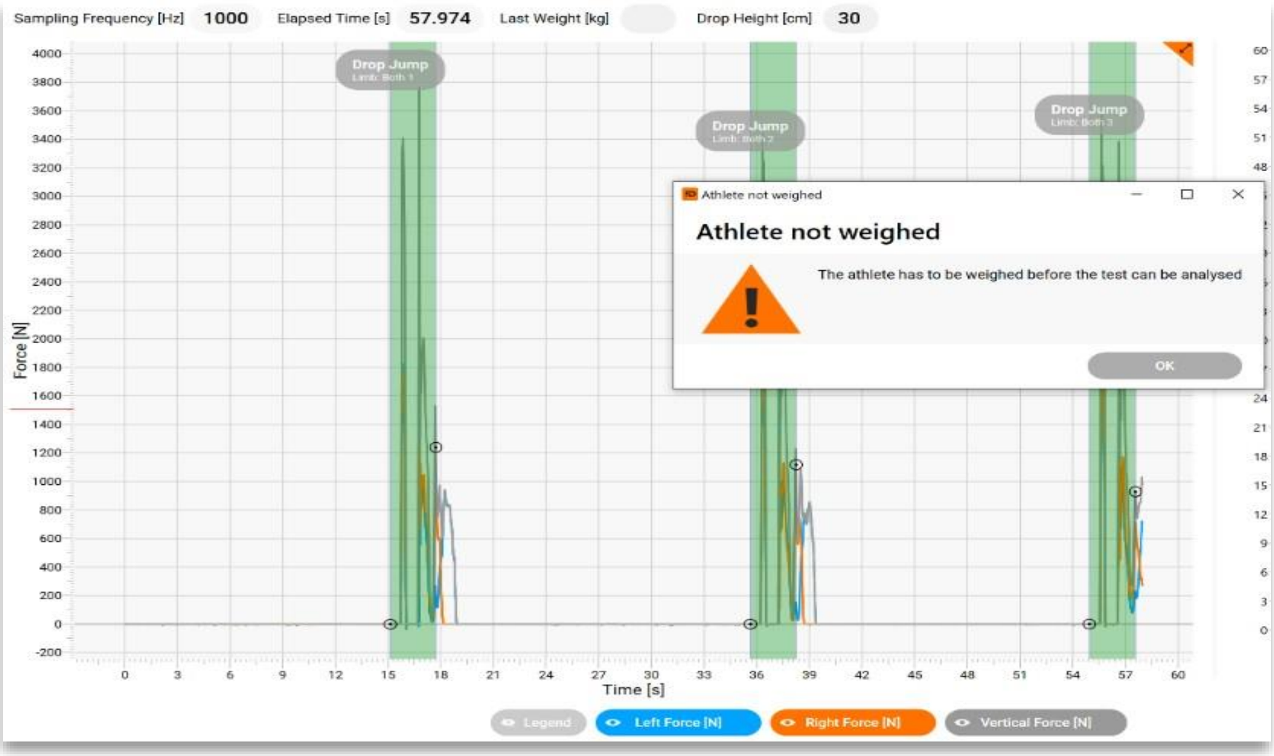
Protocol:

1. **Zero plates –** Zero the plates. Ensure nothing is touching the plates during this step.
2. **Weigh individual –** Measure the individual's weight.
3. **Assume starting position –** Ask individual to assume the starting position on the plates.
4. **Perform test –** Instruct the individual to:
    a. Keep chest up and looking forward;
    b. Step out from the box(maintain hip height until drop of both feet); then
    c. Land on the plates with both feet at the same time; then
    d. Immediately jump as high as possible; then
    e. Land softly, remaining completely still on the plates for 2-3 seconds; then
    f. Assume the starting position again.
5. **Repeat –** Repeat steps 3 and 4 to record the desired number of reps.
6. **Complete the test –** Click to stop the recording and check the results.

Common protocol errors Include:

Error	Potential Effect(s)
Not taking individual's weight prior to jump	With no bodyweight taken, detection will not be successful.

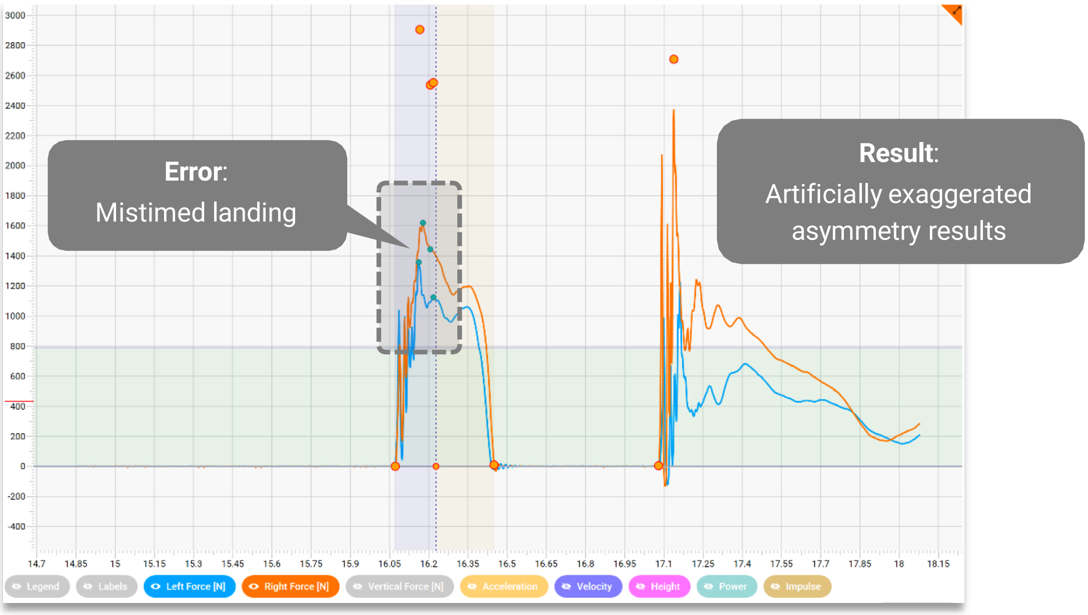
Error example:



Here is an example of a test where 3 drop jumps were performed, but an individual's bodyweight was not taken prior to testing, resulting in an error.

Error	Potential Effect(s)
Walking off the box instead of hopping.	Can influence asymmetries upon impact which can lead to poor data quality especially post injury. This will also influence "effective drop height" as the individual can lower down before dropping and effectively change the drop height. Can also influence contact time lengths if the step down is significant enough.

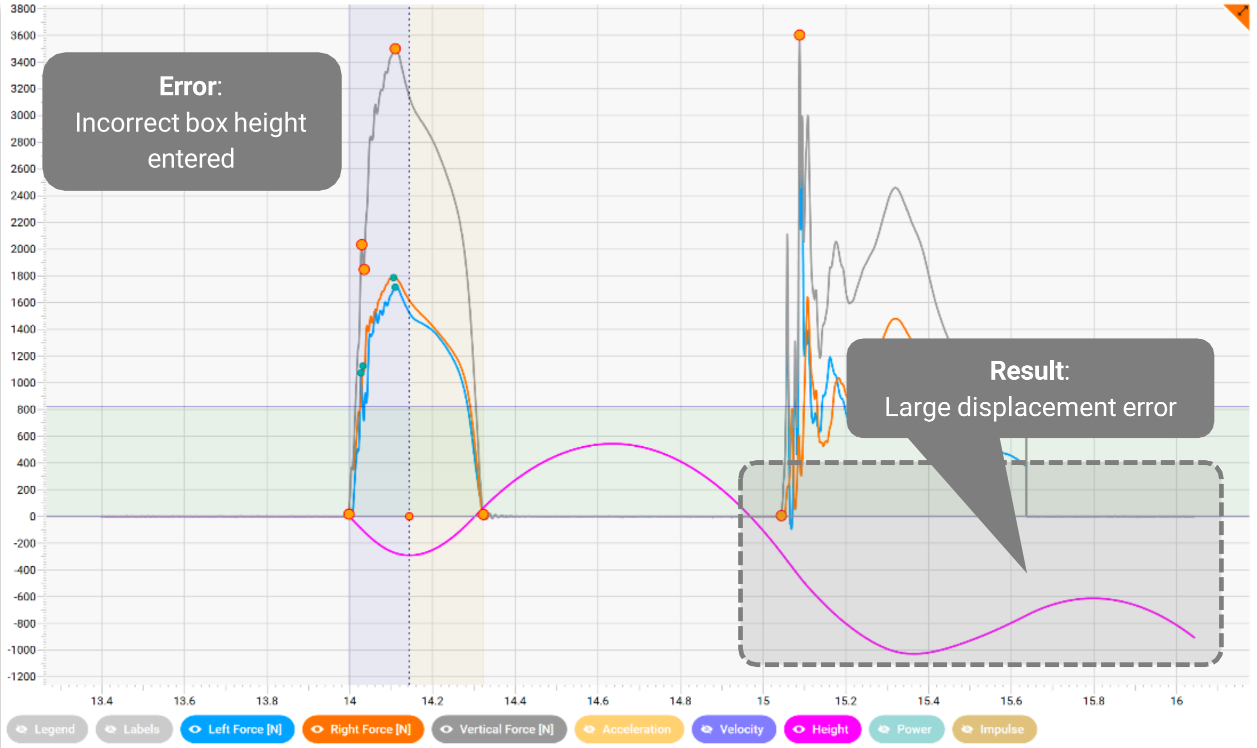
Error example:



Here is an individual that stepped off the with the left leg leading (right foot planted on box). The initial impact can be seen very early on the left leg while the right leg picks up force just slightly later. One objective of the test is for the individual to contact the force plates with both limbs at the same time after stepping off the box.

Error	Potential Effect(s)
Incorrect box height (manual entry).	Jump height from flight time should be very similar to Imp-Mom method. If an error has occurred from manually entering a box height, there will be a difference between jump height via flight time and Imp-Mon calculation.

Error example:



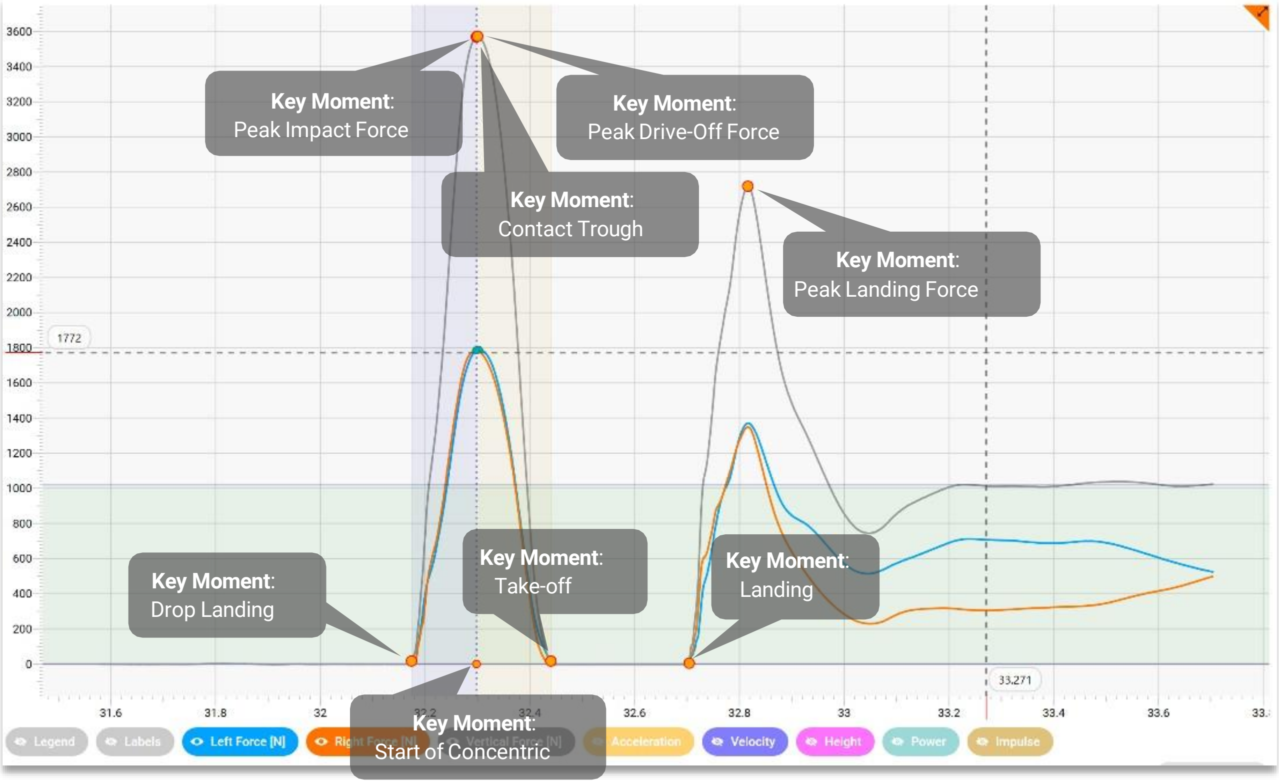
In this example the drop height was entered in at 50cm (the actual height of the box) however the effective drop height was only an average of 38.3cm (as seen below). This was likely due to either the test subject lowering down before stepping off the box or the platform height was not accounted for. Either way the drop height was reduced, and this leads to a large discrepancy in jump height between Flight Time and Impulse-Momentum. This should not be the case on a proper drop jump.

Name	Max	Mean	Fatigue	Trial 1	Trial 2	Trial 3	Trial 4	SD	CoV	SEM
Performance - Takeoff Phase										
Drop Height [cm]	50.0	50.0	0%	50.0	50.0	50.0	50.0	0	0.0%	0
Effective Drop [cm]	44.2	38.3	14.2%	36.0	35.5	37.5	44.2	3.5	9.1%	1.7
Jump Height (Flight Time) [cm]	63.7	57.8	1.6%	63.7	51.0	56.4	60.2	4.7	8.2%	2.4
Jump Height (Imp-Mom) [cm]	54.2	45.4	15.1%	48.0	36.5	43.0	54.2	6.5	14.3%	3.2

2.4.2 Key Moments and Phases

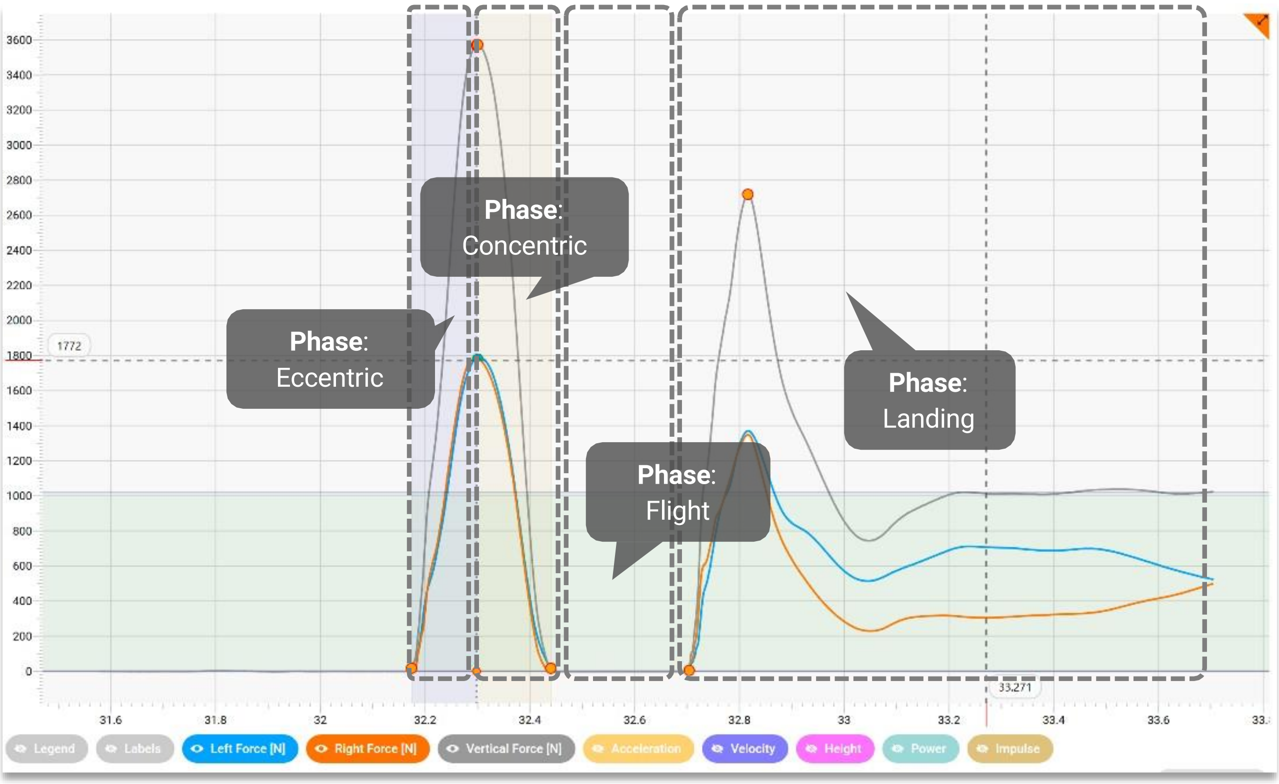
ForceDecks auto-detects the following key moments in a Drop Jump:

Key Moments	Description
Drop Landing	Point where a 20N threshold is exceeded.
Peak Impact Force	Greatest passive force on impact from box drop.
Contact Trough	Lowest force point between peak impact and peak drive-off force.
Start of Concentric	Rising from the lowest position after landing.
Peak Drive-Off Force	Peak active force (contraction based).
Take-off	Point of toe off/beginning of flight time.
Landing	Point of touch down (Force over 20N).
Peak Landing Force	Greatest force generated on landing.



ForceDecks auto-detects the following phases in a Drop Jump:

Phase	Description
Eccentric Phase	From drop landing until zero velocity.
Concentric Phase	Zero velocity until take-off.
Flight Phase	From take-off until landing.
Landing Phase	Point where force rises above 20N and settles back to bodyweight.



From these key moments and phases in a Drop Jump test, ForceDecks software calculates and reports 59 metrics on performance and asymmetry.

2.4.3 Commonly Used Metrics

Some of the most commonly used metrics from a Drop Jump test include:

Metrics	Description	Common Application(s)
Performance Metrics		
Jump Height (Imp-Mom)	Outcome measure to anchor/give context to other metrics.	Fatigue monitoring, adaptation monitoring
RSI	Flight time divided by contact time.	Fatigue monitoring, adaptation monitoring, profiling
Active Stiffness	Peak active force (in concentric phase) divided by the change in displacement of CoM from contact to the minimum value (the lowest point during contact phase).	Fatigue monitoring, adaptation, monitoring, profiling
Peak Power	Maximum power value attained during the trial.	Individual profiling and adaptation monitoring
Contact Time	Time spent on the ground between drop landing and takeoff.	Adaptation monitoring, fatigue monitoring
Asymmetry Metrics		
Concentric Impulse Asymmetry	L/R difference of concentric work performed.	Return to play monitoring
Eccentric Impulse Asymmetry	L/R difference of eccentric work performed.	Return to play monitoring
Drop Landing RFD Asymmetry	L/R difference in rate of force produced/accepted on initial drop landing.	Return to play monitoring

2.5 Squat Assessment (SQT)

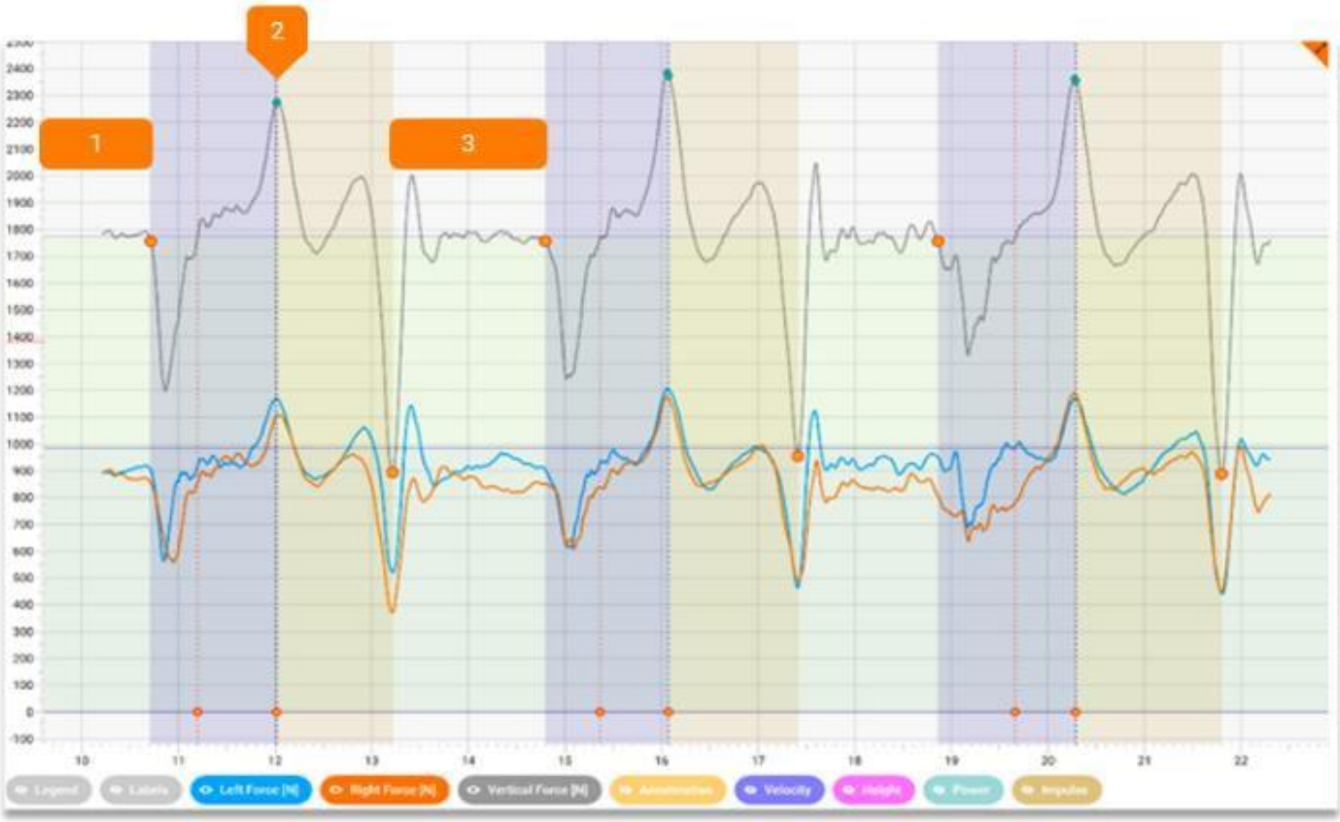
The Squat Assessment (SQT) enables detailed analysis of both body weight and externally loaded squats.

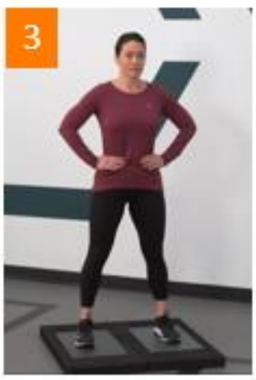
It can be used to:

- Assess performance attributes through Force:Velocity profiling;
- Track asymmetry improvements during rehabilitation; as well as
- Provide biofeedback for performers to improve movement mechanics in real time.

The goals of the SQT will vary based on objectives.

Below is a raw trace of a Squat Assessment with three reps in ForceDecks, (showing only left, right and total vertical force – all other derivatives and key moment labels are toggled off to help with viewing):





2.5.1 Protocol

To perform a **Squat Assessment** test, follow these steps:

Starting position:

- Normal standing posture
- Hands on hips (if unweighted) or hands on barbell (if weighted)
- Chest up and looking forward

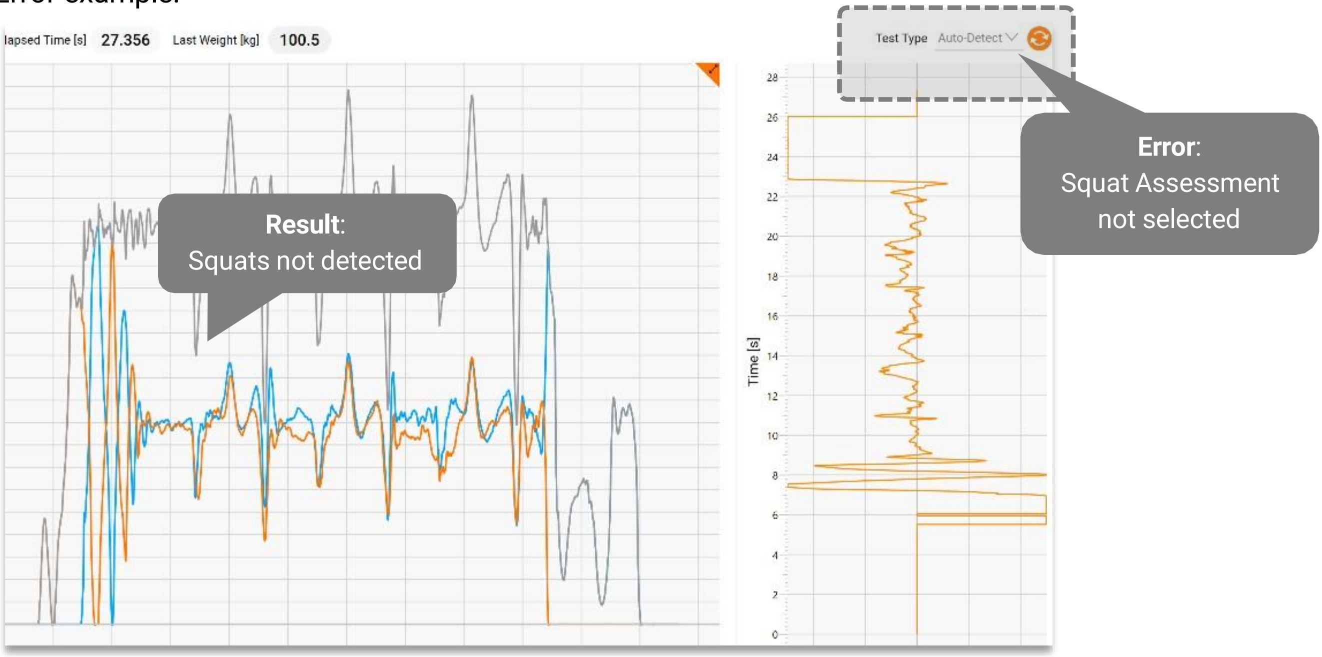
Protocol:

1. **[OPTIONAL] Enter external load –** The weight of the external load can be manually entered.
2. **Zero plates –** Zero the plates. Ensure nothing is touching the plates during this step.
3. **Weigh individual –** Measure the individual's weight without the barbell.
4. **Assume starting position –** Ask individual to assume starting position on the plates.
5. **Stabilize individual –** Instruct the individual to remain completely still, in the standing position for 2-3 seconds before and between each rep in the test.
6. **Perform test –** Instruct the individual to:
    a. Keep the chest up and looking forward;
    b. Bend down into a squat, keeping the knees in line with the toes; then
    c. Push through the heels; then
    d. Assume the starting position again.
7. **Repeat –** Repeat step 6 to record the desired number of reps.
8. **Complete the test –** Click to stop the recording and check the results.

Common Errors Include:

Error	Potential Effect(s)
Not selecting Squat Assessment	The squat needs prior selection to be detected. If this is not selected, you will not get a detection of each repetition.

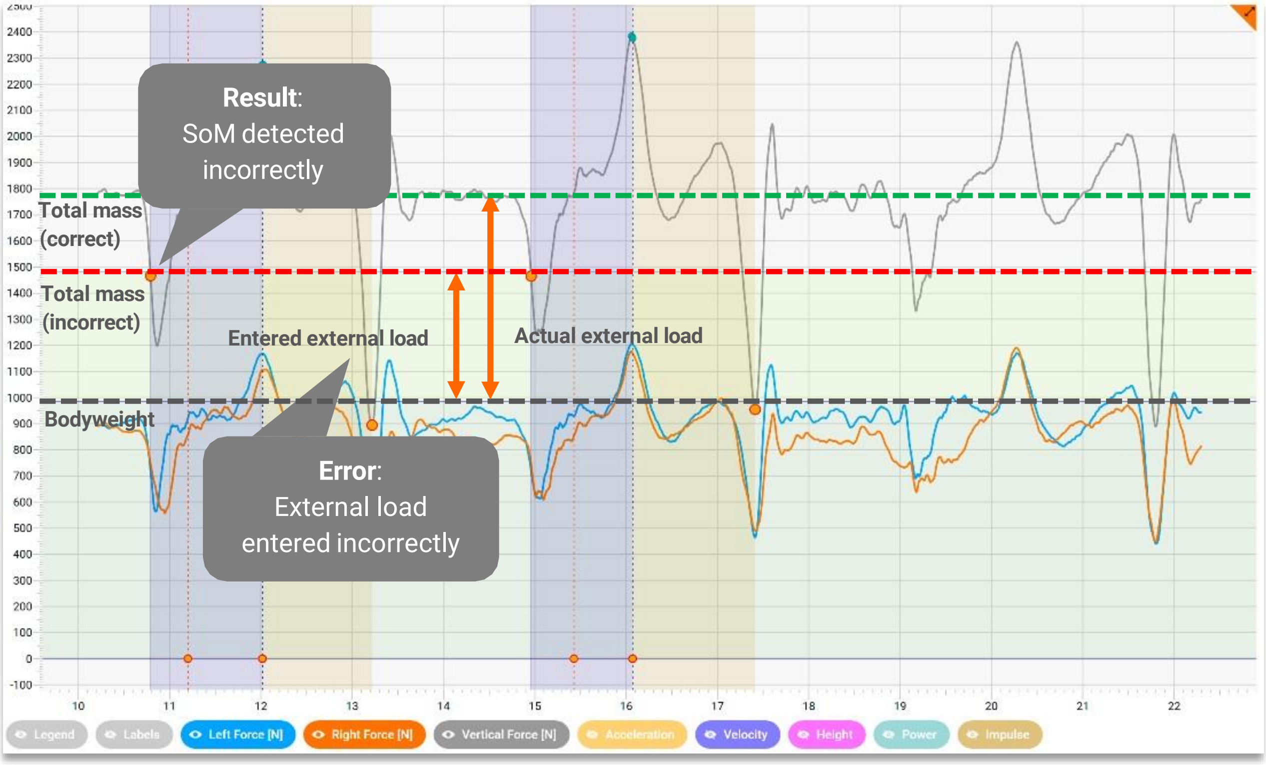
Error example:



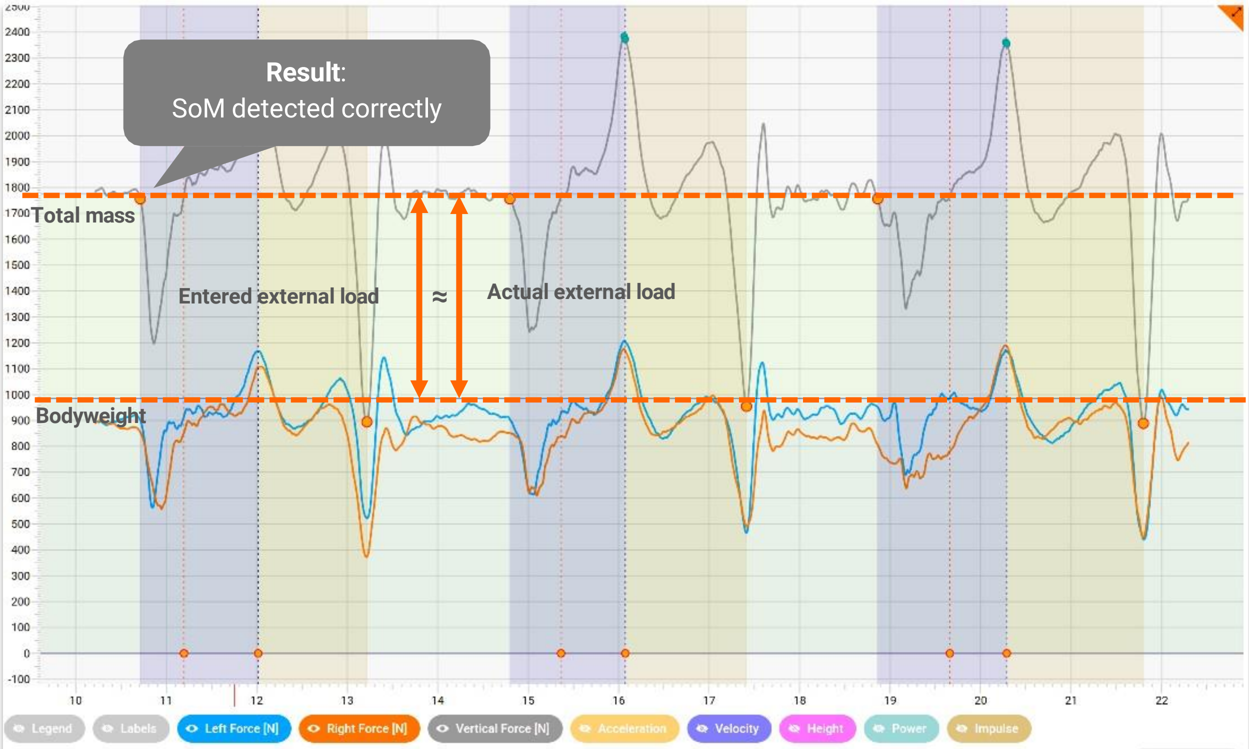
Test Type pre-set left on "Auto-Detect" leaves the squat undetected. This can easily be fixed by selecting Squat Assessment during test setup.

Error	Potential Effect(s)
Manually entering the incorrect weight for the external load	If the external resistance (weight plates etc.) are incorrectly identified as a certain weight, you will get poor data. This will result in the equations having incorrect data and result in incorrect force metrics.

Error example:

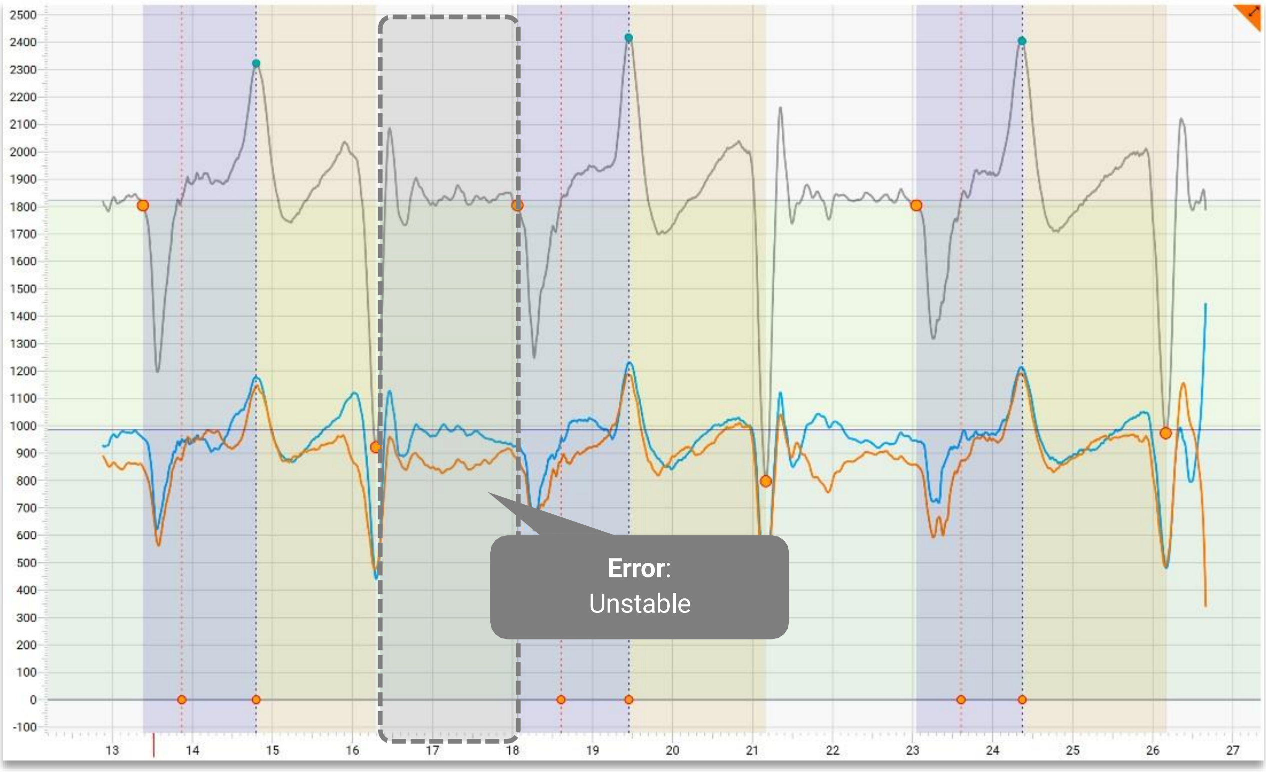


This example has a dramatically incorrect weight attributed to the external load. The true load was 80kg and 50kg was manually entered. The poor detection can be seen in the graph as the SoM happens halfway down the unloading curve and the entire last repetition is missed.
The below example is the correct external load detection.



Error	Potential Effect(s)
Not staying stable between reps	This can become increasingly challenging with extreme loads as the bar will flex and rebound. Without clear separation of reps, start of movement detection and end of rep detection can be challenged by the large oscillating forces

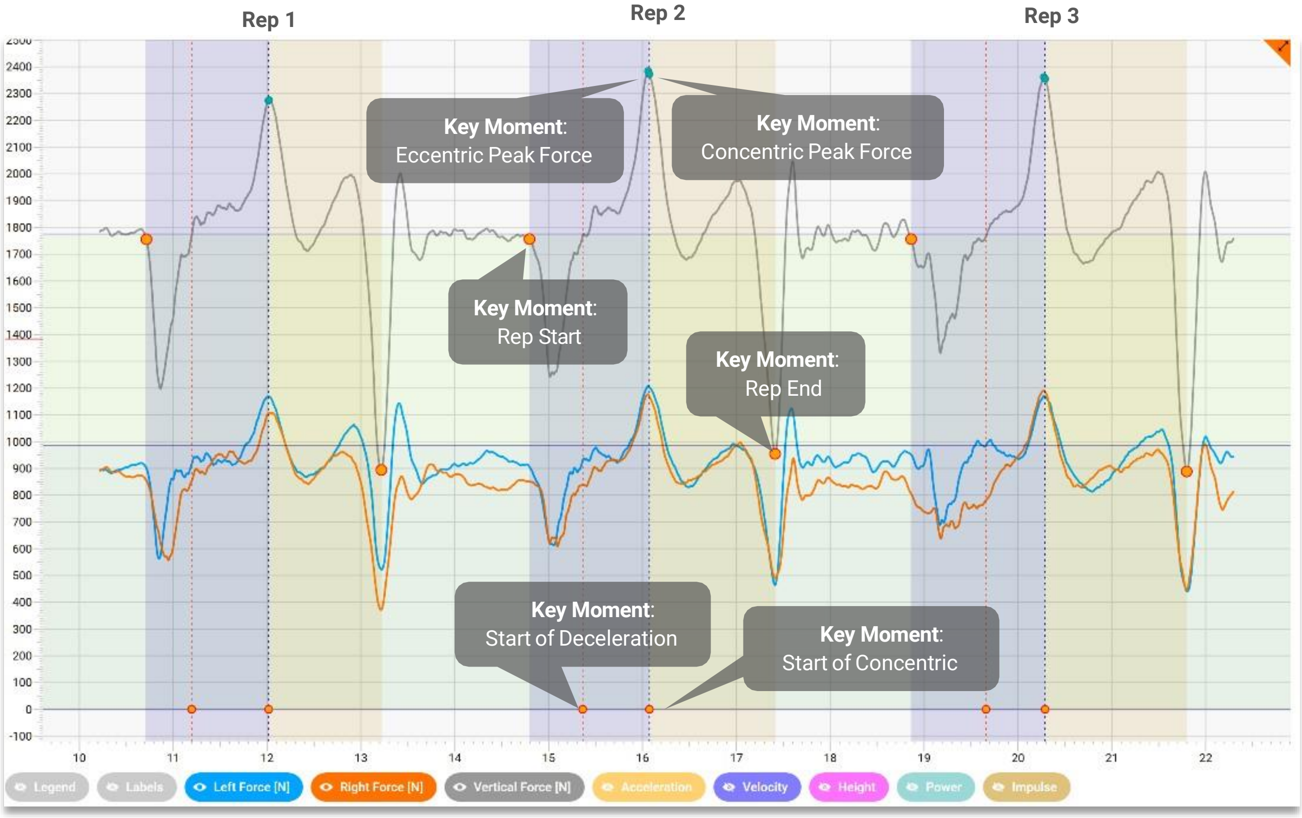
Error example:



2.5.2 Key Moments and Phases

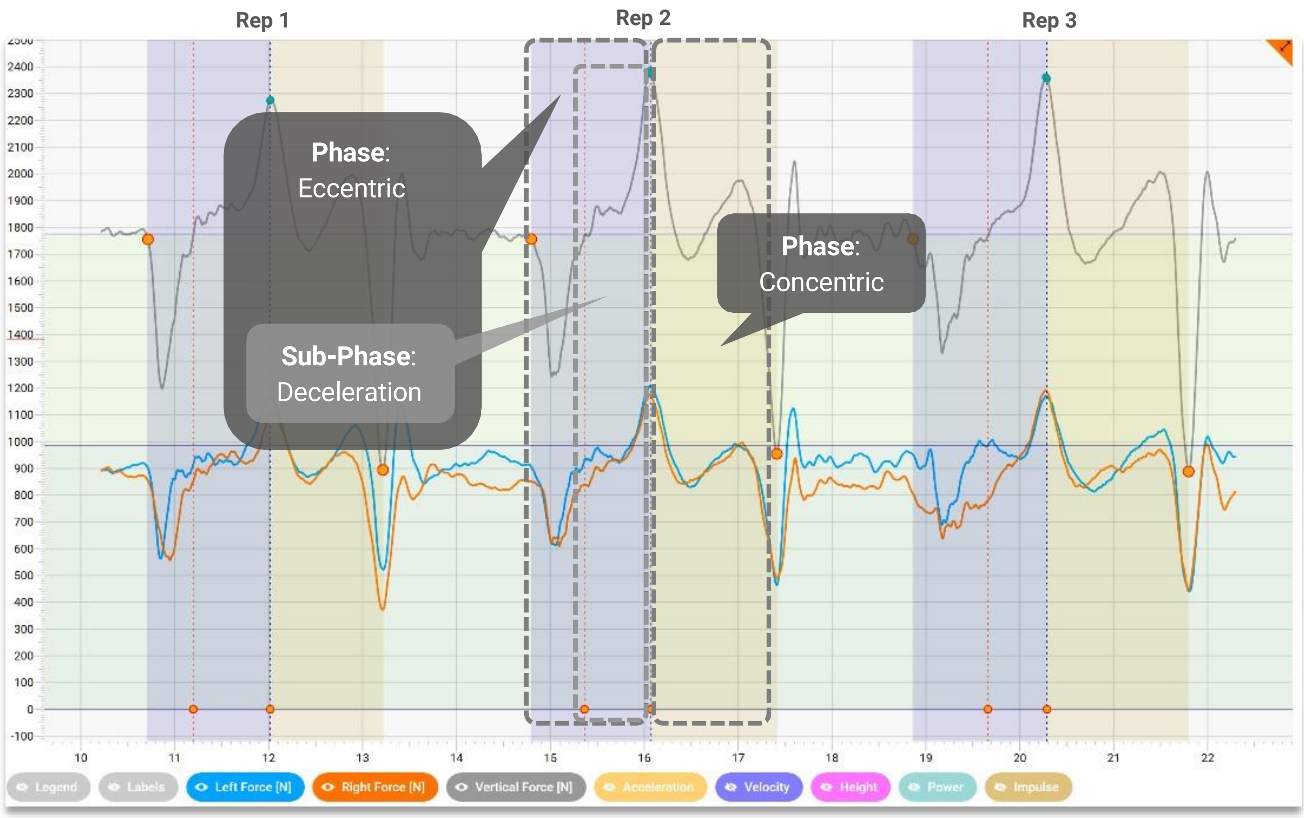
ForceDecks auto-detects the following key moment in a Squat Assessment:

Key Moments	Description
Start of Rep	Point where rep commences.
Start of Deceleration Phase	Point of peak negative velocity.
Eccentric Peak Force	Greatest force found in eccentric phase.
Start of Concentric Phase	Point at zero velocity.
Concentric Peak Force	Peak force found in concentric phase.
End of Rep	Point where force returns to system weight/force.



ForceDecks auto-detects the following phases in a Squat Assessment:

Phase	Description
Eccentric Phase	Point where rep commences to start of concentric phase.
Deceleration Phase	Sub-phase within eccentric phase: point of peak negative velocity to start of concentric phase.
Concentric Phase	Point at zero velocity to end of rep.



From these key moment and phases in a Squat Assessment, ForceDecks software calculates and reports 25 metrics on performance and asymmetry.

2.5.3 Commonly Used Metrics

Some of the most commonly used metrics from a Squat Assessment include:

Metrics	Description	Common Application(s)
Performance Metrics		
Concentric Mean Velocity	Average velocity found through the concentric phase.	Fatigue monitoring, adaptation monitoring
Eccentric Peak Velocity	Greatest negative velocity found during eccentric phase.	Fatigue monitoring, adaptation monitoring
Maximum Negative Displacement	Lowest point the CoM achieved in the squat.	Adaptation monitoring, return to play
Peak Force	Highest force output throughout the entire repetition.	Individual profiling and adaptation monitoring
Eccentric Peak Power	Highest power output achieved in eccentric phase.	Adaptation monitoring, profiling
Asymmetry Metrics		
Concentric Mean Force Asymmetry	L/R difference of concentric force performed.	Return to play monitoring
Eccentric Mean Force Asymmetry	L/R difference of eccentric force performed.	Return to play monitoring
Peak Force Asymmetry	L/R difference in the peak force attained.	Return to play monitoring

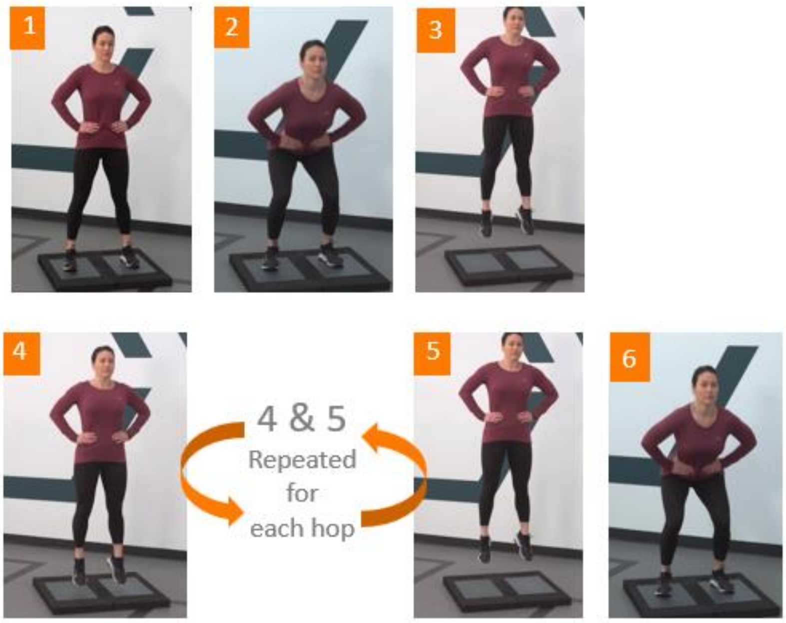
2.6 Hop Test (HT)

The Hop Test (HT) is an excellent option to assess elastic/reactive qualities without the use of a box as during the Drop Jump.

The HT is a bilateral test performed with (relatively) straight legs, using the ankle/calf as the primary means of upward propulsion without squatting downward. The test is commonly done by performing 10 rapid hops and analyzing the best 5.

The goal of the HT is to perform a set number of hops for maximum height and minimal ground contact time, using only the toes/forefoot.

Below is a raw trace of a Hop Test with ten hops in ForceDecks, (showing only left, right and total vertical force – all other derivatives and key moment labels are toggled off to help with viewing):



2.6.1 Protocol

To perform a **Hop Test**, follow these steps:

Starting position:

- Normal standing posture
- Hands on hips
- Chest up and looking forward

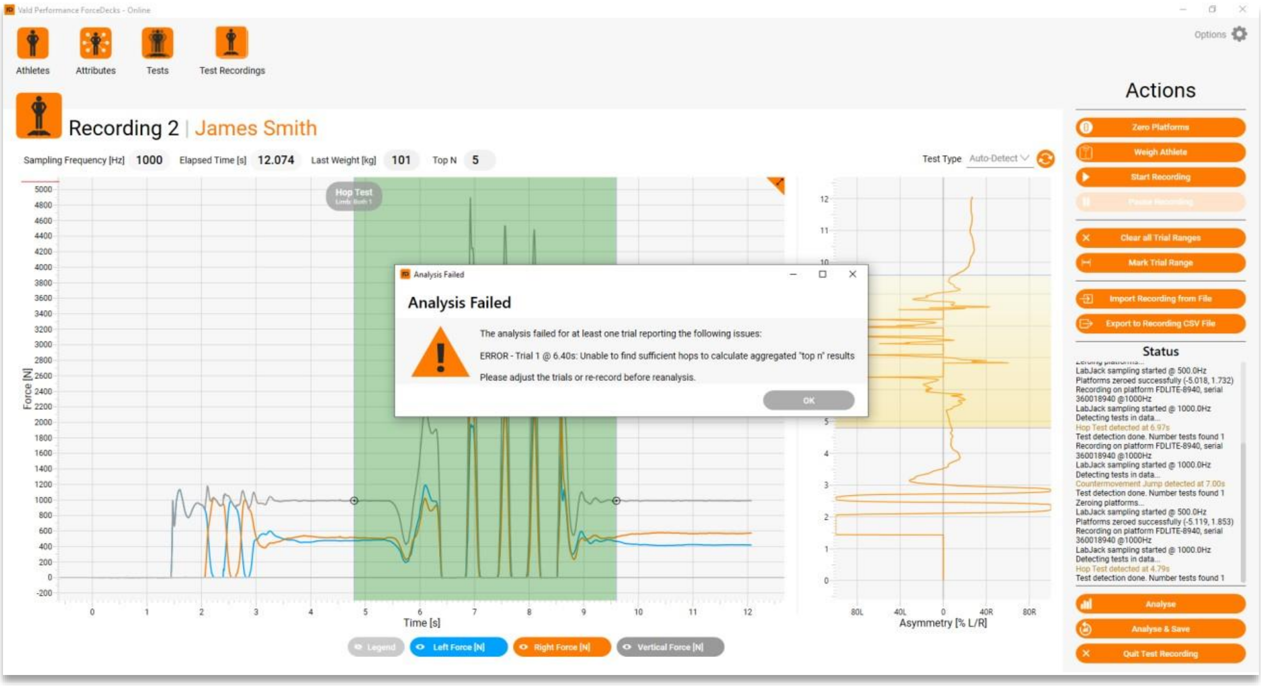
Protocol:

1. **Zero plates –** Zero the plates. Ensure nothing is touching the plates during this step.
2. **Assume starting position** – Ask individual to assume the starting position on the plates.
3. **Weigh individual –** Measure the individual's weight.
4. **Stabilize individual –** Instruct the individual to remain completely still, in the starting position for 2-3 seconds before and between each rep in the test.
5. **Perform test –** Instruct the individual to:
    a. Keep chest up and looking forward;
    b. Bend down; then
    c. Jump up; then
    d. Land stiff-legged on only the toes; then
    e. Quickly jump off the toes, for the desired number of hops, in rapid succession. (Safely keeping the knees as straight as possible.)
    f. Land softly; then
    g. Assume starting position again.
6. **Repeat –** Repeat step 5 to record the desired number of reps.
7. **Complete the test –** Click to stop the recording and check the results.

Common protocol errors include:

Error	Potential Effect(s)
Not performing at least 5 hops	Auto-analysis of hop test will fail.

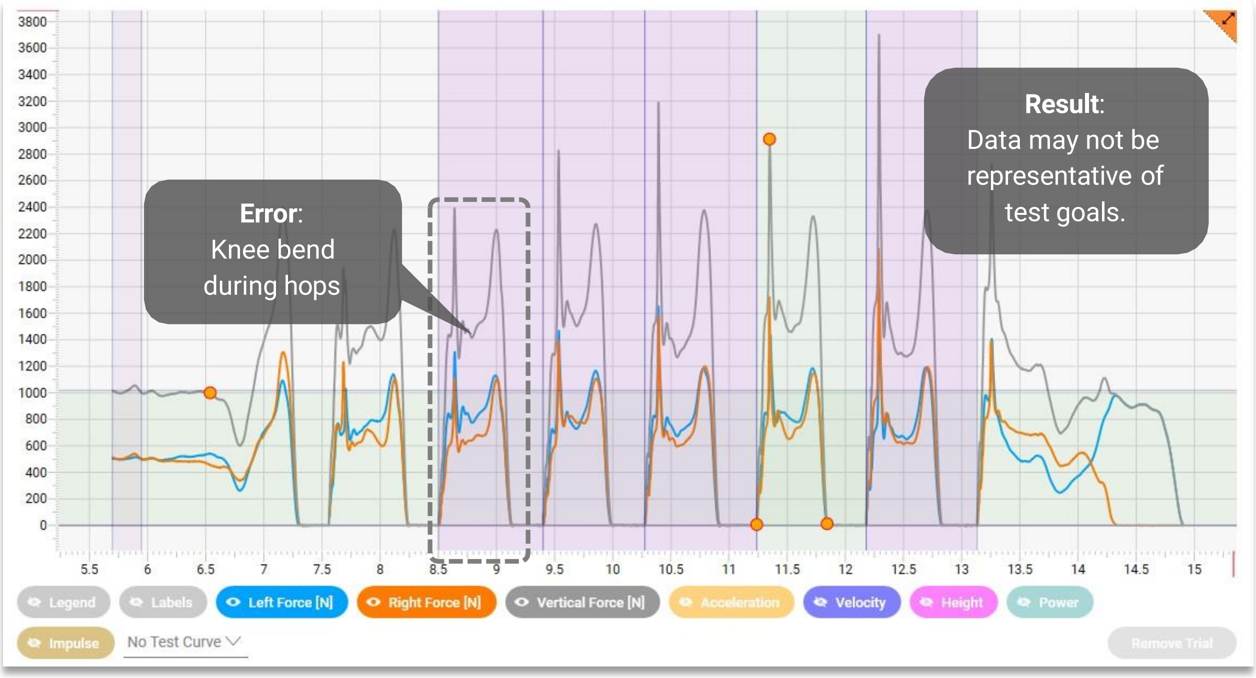
Error example:



Here the Individual has not performed the required minimum of 5 hops to get a detection.

Error	Potential Effect(s)
Allowing the Individual to bend the knees when jumping	This simply changes the test from an ankle dominant, elastic test to a slower SSC lower body test. This will not result in incorrect detection but may produce poor data.

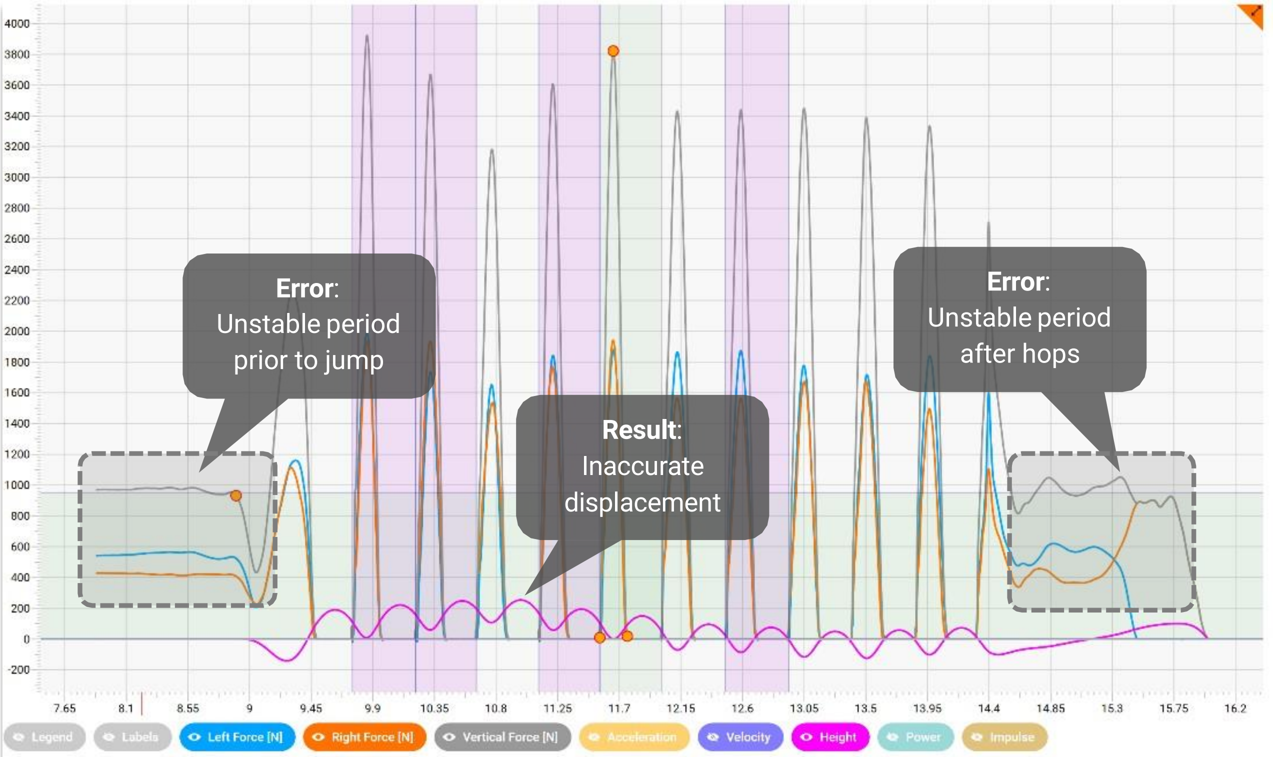
Error example:



Here is an example of a Hop Test that has been performed with a knee bend upon each landing. Note the long contact times and the deep trough between impacts and takeoffs. In this example, some or all analyzed results may not be valid.

Error	Potential Effect(s)
Not starting with a stable period or ending with a stable period	This can lead to displacement drift as the Individual mass is needed to orient displacement.

Error example:

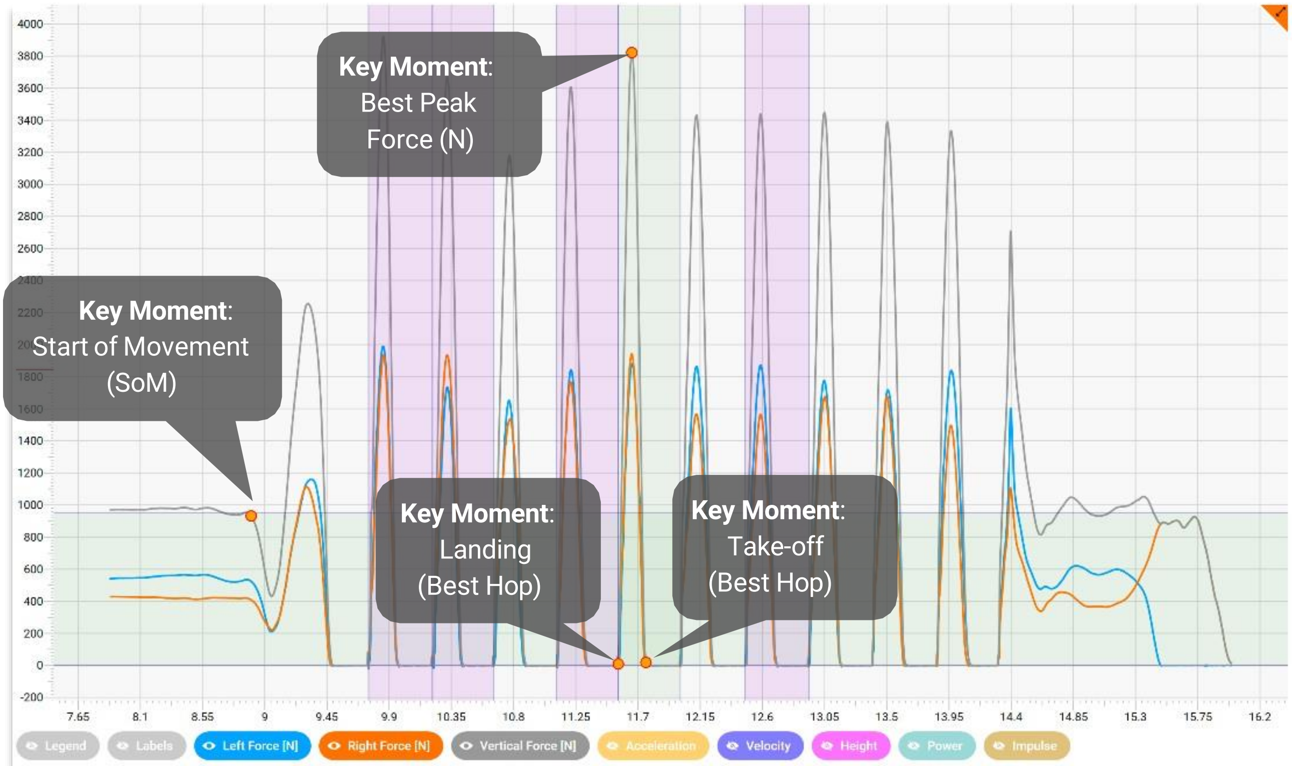


*Shown here is a drifting displacement curve (**pink**) because the individual was never truly stable before jumping or on landing of the last hop.*

2.6.2 Key Moments and Phases

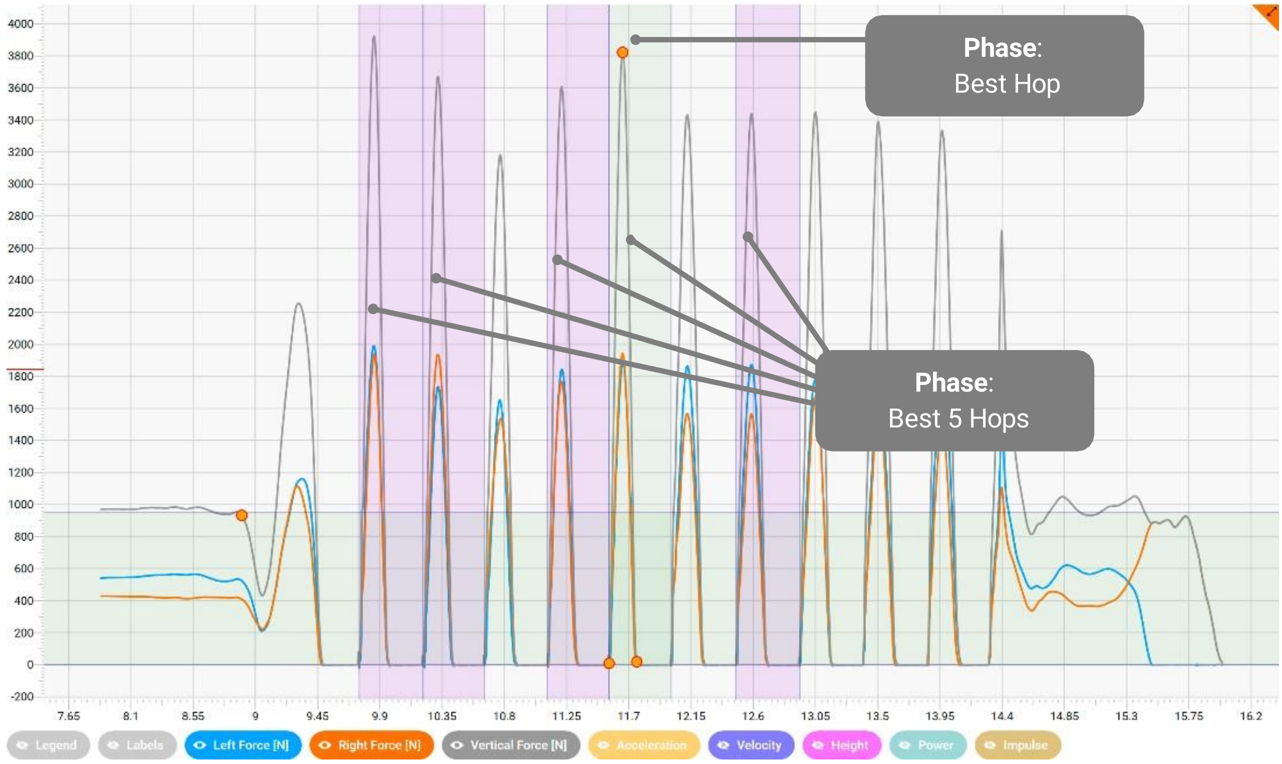
ForceDecks auto-detects the following key moment in a Hop Test:

Key Moment	Description
Start of Movement	Point where hop test commences.
Best Landing	Landing for the best hop.
Best Peak Force	Force value for the best hop.
Best Take-off	Flight time for the best hop.



ForceDecks auto-detects the following phases in a Hop Test:

Phase	Description
Best Hop	The single hop with the highest RSI out of the entire hop test.
Best 5 Hops	The top 5 hops with the highest RSI out of the entire hop test. (Highlighted in purple and green)



From these key moment and phases in a Hop Test, ForceDecks software calculates and reports 54 metrics on performance and asymmetry.

2.6.3 Commonly Used Metrics

Some of the most commonly used metrics from a Hop Test include:

Metrics	Description	Common Application(s)
Performance Metrics		
Best Reactive Strength Index (RSI)	Absolute best RSI (FT:CT) out of a series of hops.	Fatigue monitoring, adaptation monitoring
Contact Time	Time spent on the ground between each hop.	Fatigue monitoring, adaptation monitoring
Mean Active Stiffness	Peak force divided by displacement.	Adaptation monitoring, return to play
Peak Force	Highest force output throughout the entire hop test.	Individual profiling and adaptation monitoring
Mean RSI (over given N Hops)	Average RSI over N hops. This fits the 10/5 RSI where the average of the 5 best hops out of 10 are averaged.	Adaptation monitoring, profiling
Asymmetry Metrics		
Mean Impulse Asymmetry	L/R difference of work performed.	Return to play monitoring
Mean Peak Force Asymmetry	L/R difference of the average of all peak force measures (per rep) performed.	Return to play monitoring
Peak Force Asymmetry	L/R difference in the peak force attained per Hop.	Return to play monitoring

2.7 Land and Hold (LAH)

The Land and Hold (LAH) is a test that evaluates stability as well as how an Individual manages landing impact forces.

This test can be performed with one or two limbs and either off the ground or from an elevated start (e.g.: box). The intensity of the test can also be modified by adding external loads, thus allowing for a large variety of testing options in performance and rehabilitation.

The goal for the LAH test is to land and stabilize as quickly as possible.

Below is a raw trace of a Single Limb Land and Hold Test in ForceDecks:

2.7.1 Protocol

To perform a **Land and Hold** test, follow these steps:

Starting position:

- Standing on box or elevated platform immediately behind force plates
- Normal standing posture
- Hands on hips
- Chest up and looking forward

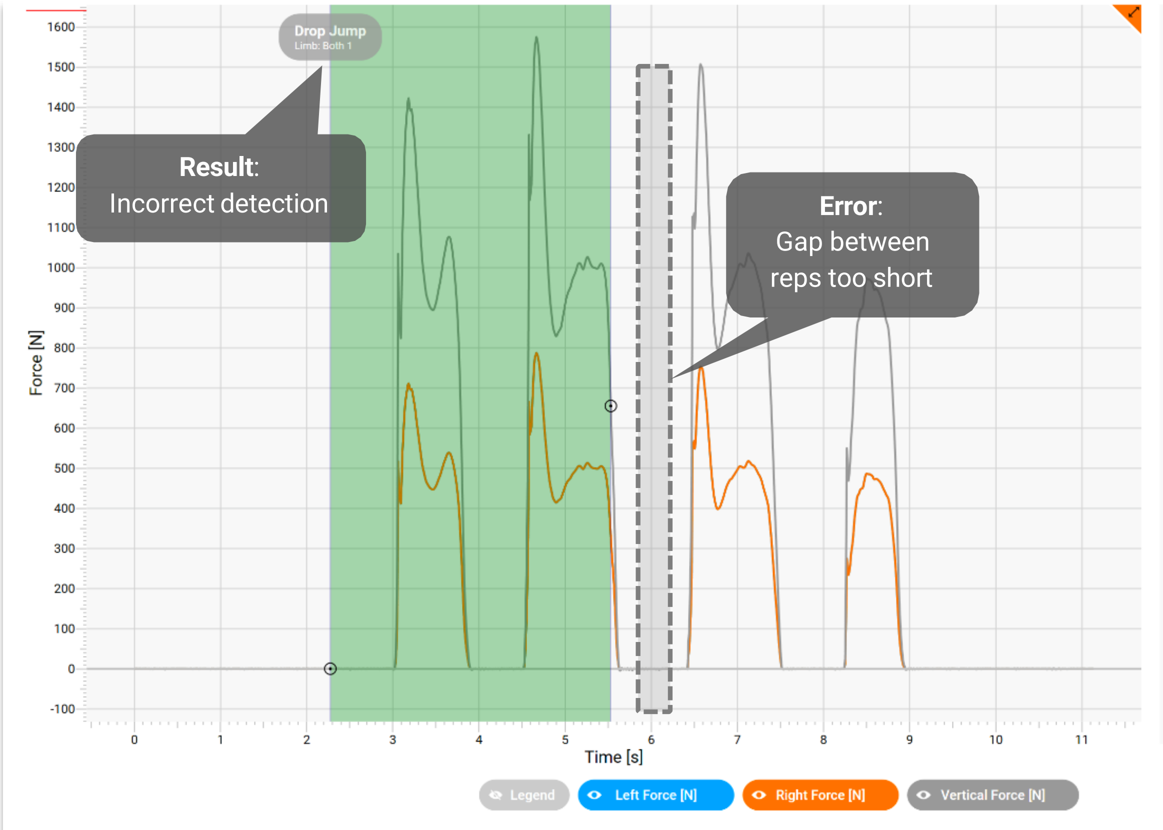
Protocol:

1. **Zero plates –** Zero the plates. Ensure nothing is touching the plates during this step.
2. **Weigh individual –** Measure the individual's weight.
3. **Assume starting position –** Ask individual to assume the starting position on the plates.
4. **Perform test** - Instruct the individual to:
    a. Keep the chest up and looking forward;
    b. Step off the box; then
    c. Land on the plates with both feet at the same time; then
    d. Land softly, remaining completely still for 2-3 seconds; then
    e. Assume starting position again.
5. **Repeat –** Repeat steps 3 and 4 to record the desired number of reps.
6. **Complete the test –** Click to stop the recording and check the results.

Common protocol errors include:

Error	Potential Effect(s)
Not remaining off the force plates for 3 seconds between trials	Detection will be unsuccessful, or trials will be incorrectly detected as Drop Jumps.

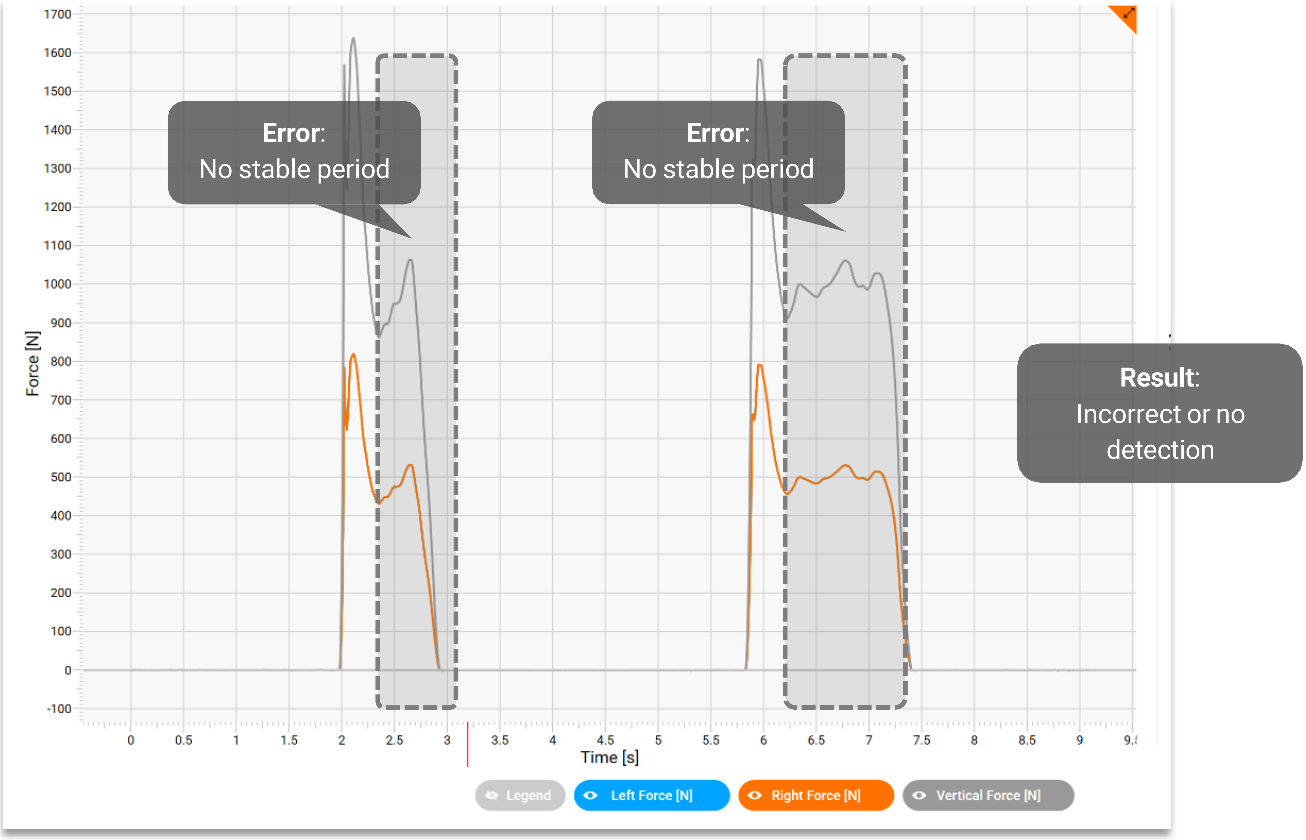
Error example:



Here is a test with four LAH reps performed, but the individual did not remain stable on landing and did not step off the force plates for 3 seconds which has resulted in both undetected and incorrectly labelled tests.

Error	Potential Effect(s)
Not remaining stable upon landing	If the individual is too quick to step off the force plates, puts the other foot down, or hops to gain balance after landing, detection will fail.

Error example:

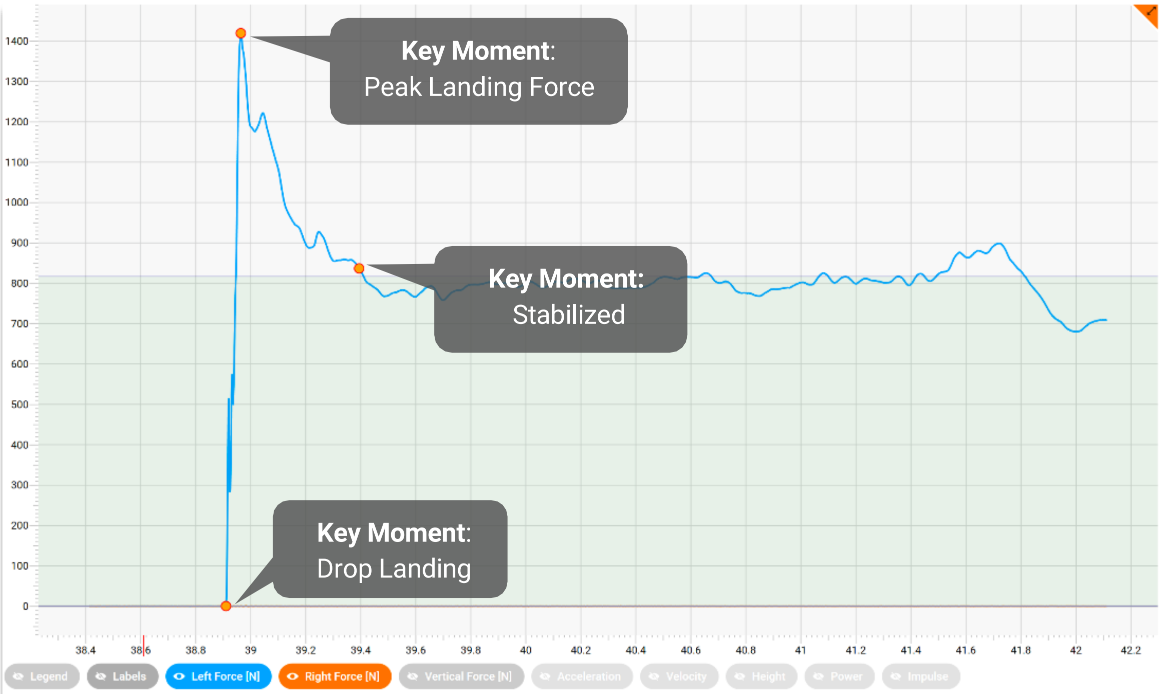


In the test above, the individual simply never came to a point of stability, and therefore no detection was made.

2.7.2 Key Moments and Phases

ForceDecks auto-detects the following key moments in Land and Hold tests.

Key Moment	Description
Drop Landing	Point where landing commences.
Peak Landing Force	Highest landing force obtained.
Stabilized	Point where force is within a 15N standard deviation for 0.5 seconds.



> ***Note**: there are no discrete phases detected in a Land and Hold test.*

From these key moments in a Land and Hold test, ForceDecks software calculates and reports 3 metrics on performance and asymmetry.

2.7.3 Commonly Used Metrics

Some of the most commonly used metrics from a Land and Hold test include:

Metrics	Description	Common Application(s)
Performance Metrics		
Peak Landing Force	Highest Force produced on landing	Adaptation monitoring, return to play, profiling
Time to Stabilization	Time between landing and stability	Adaptation monitoring, return to play, profiling

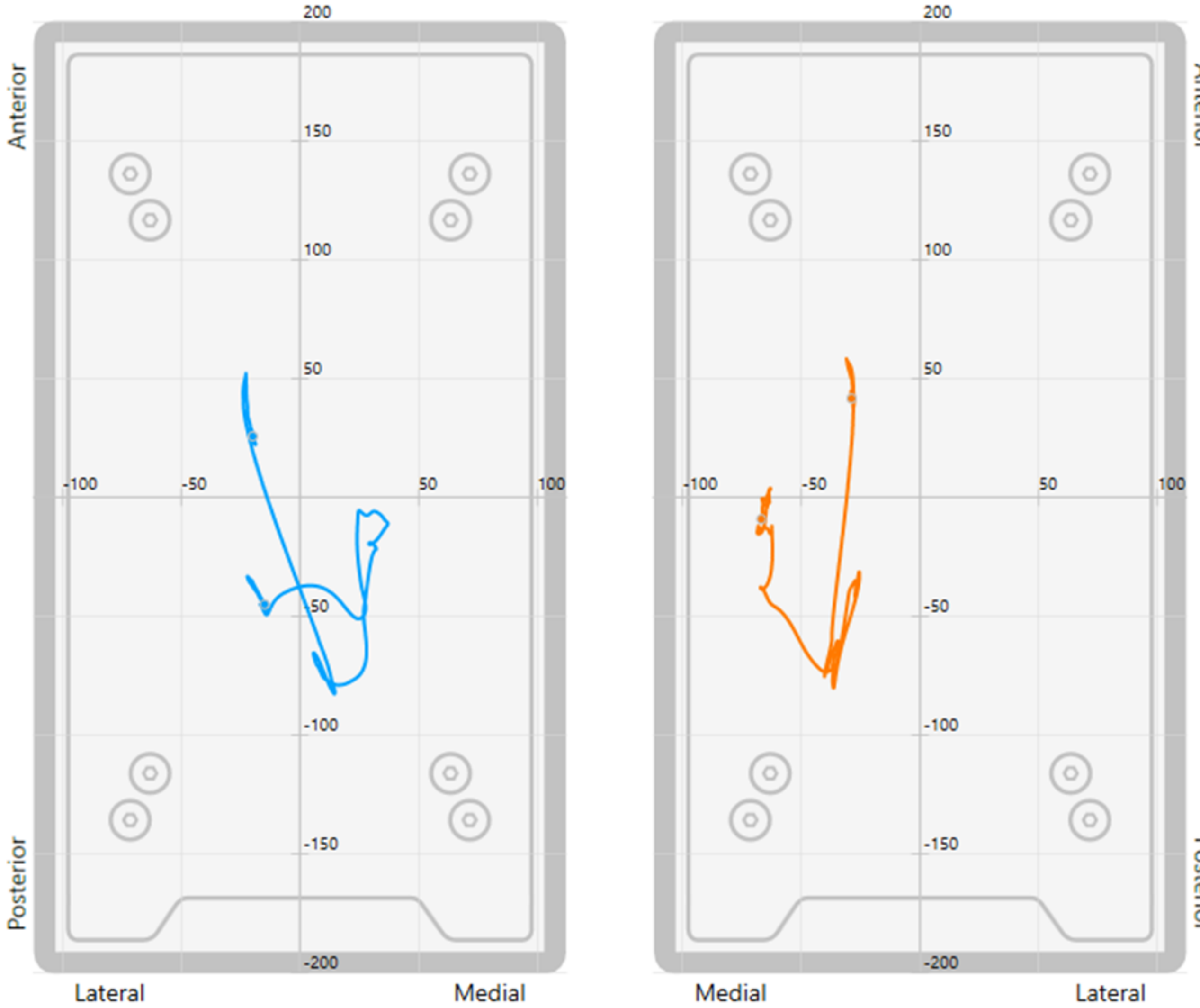
2.8 Quiet Stand (QSB)

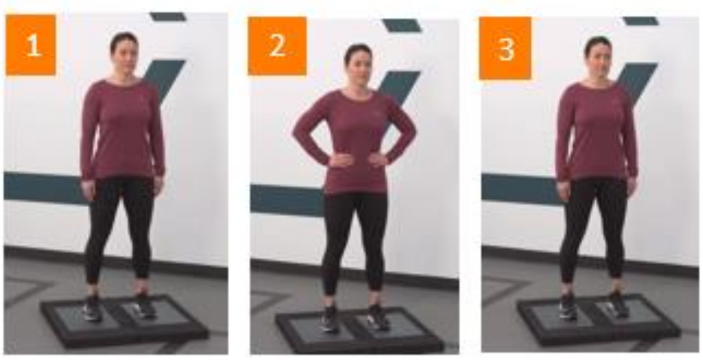
The Quiet Stand (QSB) test assesses an individual's ability to balance and maintain stability under a variety of conditions.

This assessment measures the center of pressure (CoP) of the individual, which goes beyond the typical visual assessments that stability tests are limited to.

The goal of the Quiet Stand test is to stand as still as possible for a set amount of time.

Below is the raw CoP trace of a Quiet Stand test in ForceDecks:





2.8.1 Protocol

To perform a **Quiet Stand** test, follow these steps:

Starting Position:

- Normal Standing Posture
- Hands on hips
- Chest up and looking forward

Protocol:

1. **Confirm exercise length** – Input the desired length of the protocol (in seconds).

2. [OPTIONAL] **Select additional test parameters** – Select if the individual being tested has their eyes closed, is standing on an unstable surface, or is performing a secondary task.

3. **Zero plates** – Zero the plates. Ensure nothing is touching the plates during this step.

4. **Assume starting position** – Ask the individual to assume the starting position on the plates.

5. **Perform test** – Instruct the individual to:

    a. Keep their feet set; then
    b. Stand as still as possible for the length of the exercise.

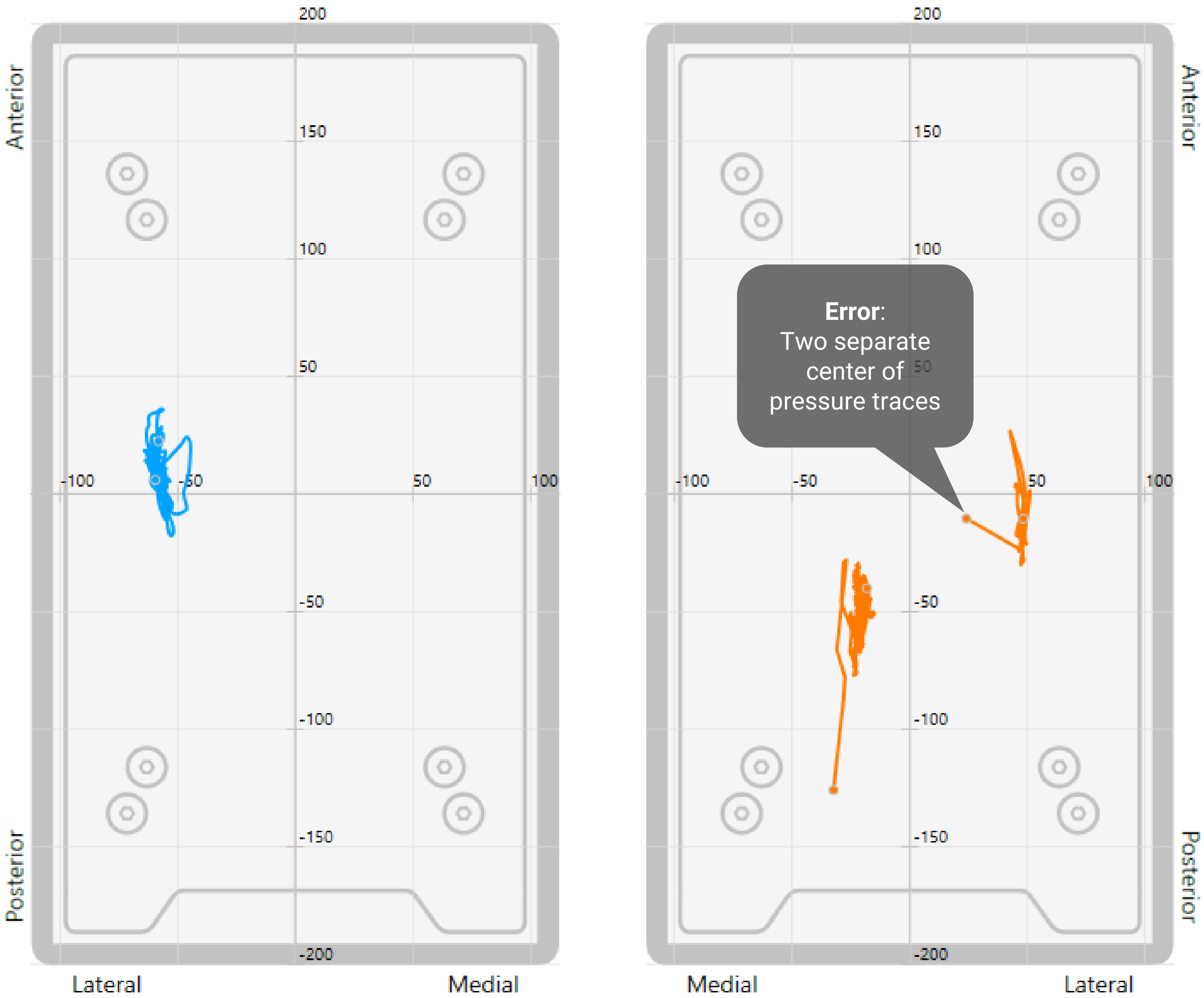
6. **Repeat** – Repeat step 5 to record the desired number of reps.

7. **Complete the test –** Click to stop the recording and check the results.

Common protocol errors include:

Error	Potential Effect(s)
Lifting feet off the plate during the test	The measured centre of pressure will suddenly jump to another part of the plate when the foot is set back down, resulting in larger values for the metrics calculated using it.

Example:



The right plate has two separate center of pressure traces indicating that the right foot was picked up and placed back down during the rep. If this happens the rep should be discarded and reperformed.

2.8.2 Key Moments and Phases

There are no detected key moments or phases in a Quiet Stand test.

In a Quiet Stand test, ForceDecks software calculates and reports 8 metrics on performance and asymmetry.

2.8.3 Commonly Used Metrics

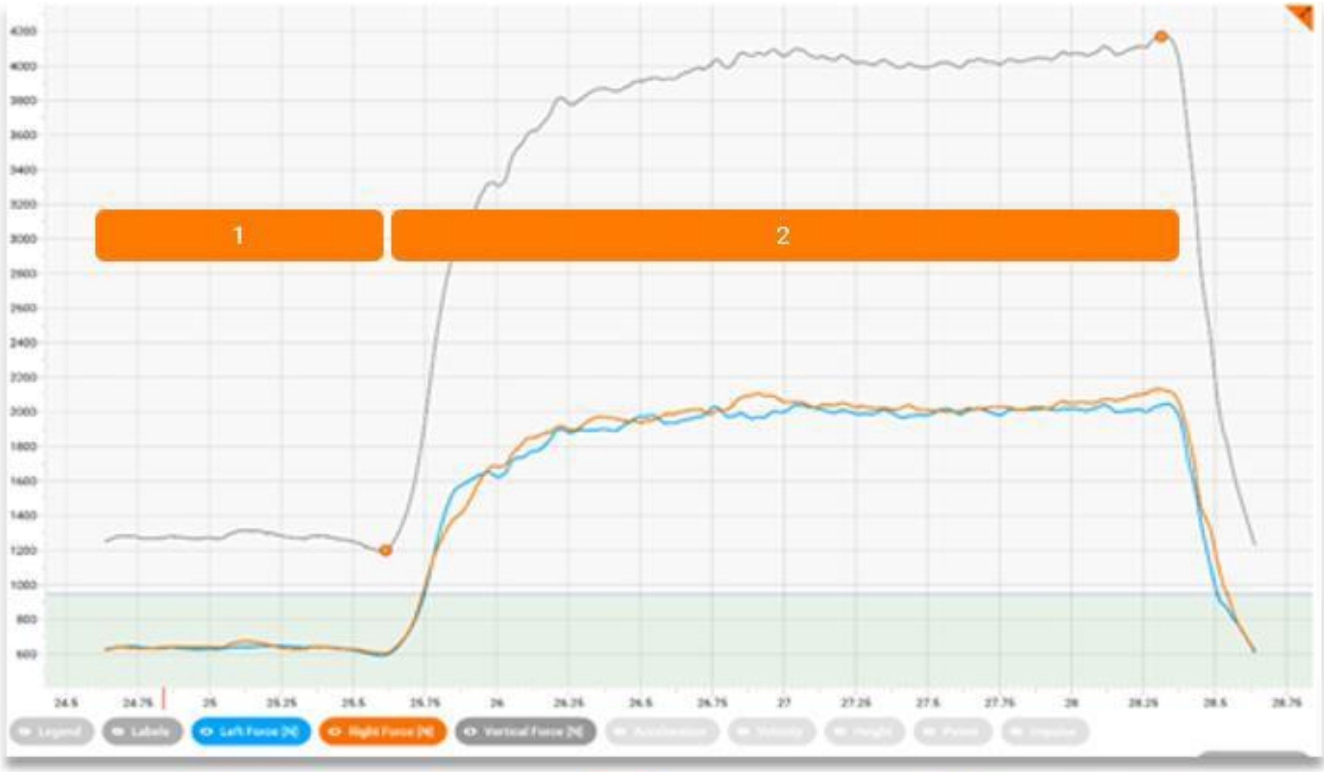
Some of the most commonly used metrics from a Quiet Stand test include:

Metrics	Description	Common Application(s)
Performance Metrics		
CoP Range – Medial-Lateral	The distance between the furthest points in the side-to-side direction	Balance screening, return to play, profiling
CoP Range – Anterior-Posterior	The distance between the furthest points in the front-to-back direction	Balance screening, return to play, profiling
Total Excursion	The length of the center of pressure line during the test	Balance screening, return to play, profiling

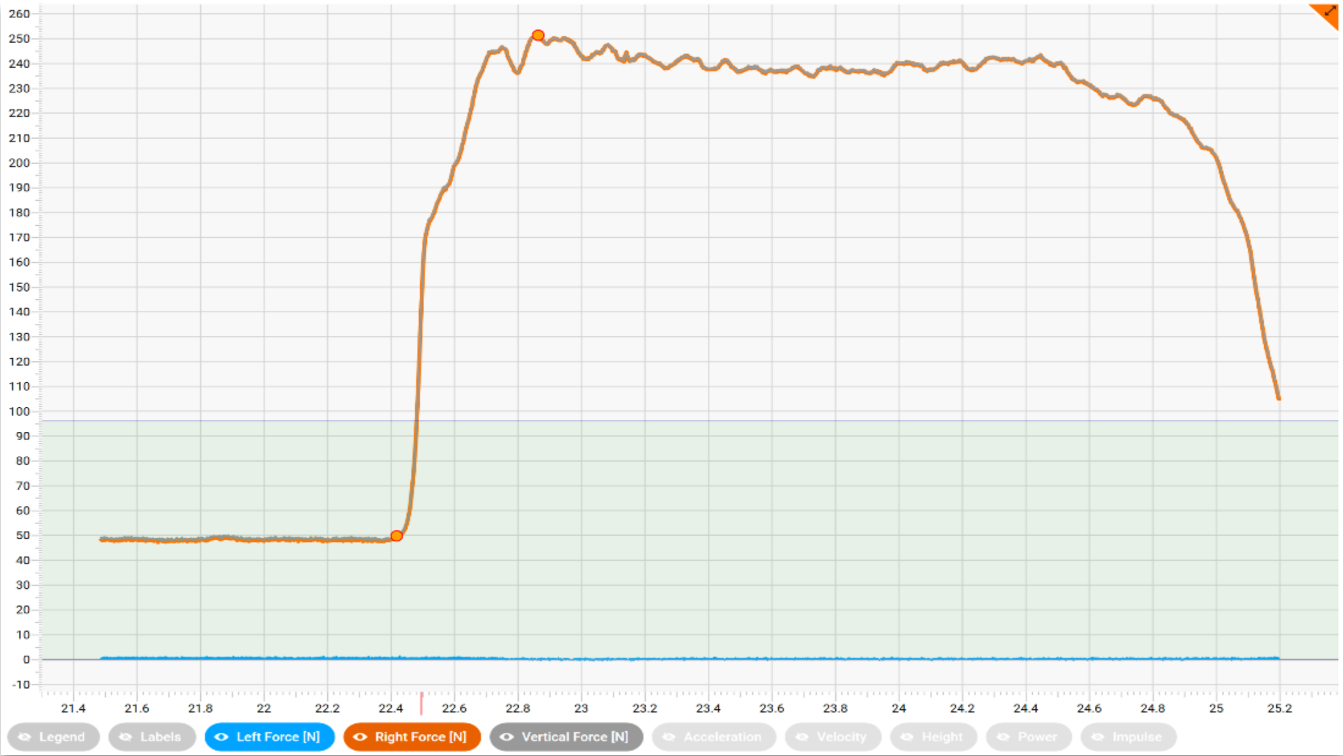
2.9 Isometric Test (ISOT)

Isometric tests (both bilateral and single limb) are an effective way to determine maximum strength output in numerous scenarios. A variety of testing options exist and include the Isometric Mid-Thigh Pull, several hamstring variations, and a comprehensive shoulder series that examines force production at end ranges of motion. Isometric tests will be discussed together in this section since they exhibit common factors, including key analysis metrics and similar asymmetry considerations.

Below is a raw trace of a Bilateral Isometric Test (in this case an Isometric Mid-Thigh Pull test), showing left, right, and total forces:



An example Single Limb Isometric Test (in this example, the right limb only) is shown below:



2.9.1 Protocol

To perform an **Isometric** test, follow these steps:

Starting position:

Starting position varies depending on the isometric test being performed.

Protocol:

1. **Zero plates –** Zero the plates. Ensure nothing is touching the plates during this step.
2. **Weigh individual –** Measure the individual's weight.

> Important: For isometric tests where the bodyweight is being supported by something other than the plates (e.g., Shoulder ISO-I), only the limb being tested should be weighted.

3. **Assume starting position –** Ask the individual to assume the starting position on the plates.
4. **Stabilize individual –** Instruct the individual to remain completely still, in the starting position for 2-3 seconds before and between each rep in the test.
5. **Perform test** - Instruct the individual to:
    a. Contract as hard and as fast as possible; then
    b. Hold at maximum force output for a minimum of 2 seconds; then
    c. Relax after the contraction; then
    d. Assume the starting position again.
6. **Repeat –** Repeat step 5 to record the desired number of reps.
7. **Complete the test –** Click to stop the recording and check the results.

Common protocol errors include:

Error	Potential Effect(s)
Not taking Individual or Limb Weight Prior to test	This will affect detection of the exercise and report an error message.

Error example:

Limb was not weighed prior to test. Here both limbs should have been weighed in the testing position. One limb should be removed while the other limb is tested. Then pause recordings, switch legs, continue recording, stop and analyze.

Error	Potential Effect(s)
Not utilizing pre-tension prior to the execution of a test	Pretension reduces “Impact Forces” which effect all time-based force values and RFDs. This may also negate true maximal force values if the impact is hard enough.

Error example:

Here you can see a rapid rise of Force, a peak, trough, and another rise in force. This suggests there was no pretension before the pull was commenced, the individual pulled from a “slack” position, “bounced” back, and pulled again. Not only does this effect time metrics but also this “impact” is where peak force is found which is most likely not a real muscular action.

Error	Potential Effect(s)
Using drastically inconsistent levels of pre-tension	This will have impact on all values relating to time. The more pre-tension there is, the higher starting value force you have. For example, Force@200ms will be higher than a lower pre-tension if intent and force rise is equivalent. This makes the data used for monitoring noisier.

Error example:

Above is an example of two isometric tests with drastically different starting forces (892N left, and 1,388N right). Forces reached at 200ms are drastically higher in part due to the "head start" of starting with ~500N more force.

If the same individual were to then start the 3rd trial with closer to 900N of pre-tension again, we may see a decrease in RFD. In practice, such a decrease may be attributable to "noise" in the measure, but alternatively may simply be due to poor standardization of testing protocol.

Name	Max	Mean	2/3/2019 11:31:41 AM Trial 1	1/27/2019 11:14:36 AM Trial 1	SD	CoV	SEM
Performance							
Force at 200ms [N]	3,668	3,317	3,668	2,966	351	10.6%	248
Peak Vertical Force [N]	4,626	4,304	4,626	3,983	321	7.5%	227
Peak Vertical Force / BW	5.58	5.21	5.58	4.84	0.37	7.1%	0.26
RFD - 200ms [N/s]	11,363	10,872	11,363	10,381	491	4.5%	347

2.9.2 Isometric Mid-Thigh Pull Protocol

The Isometric Mid-Thigh Pull (IMTP) test is a type of Isometric Test and is detected and analyzed exactly the same way within ForceDecks. However, given the IMTP is a very commonly used test in its own right, this section covers its specific protocol.

To perform an **IMTP** test, follow these steps:

Setup:

Set your ForceDecks up in a dedicated IMTP rig or with a fixed barbell within a cage or frame.

> ***Note:*** *the equipment used for an IMTP test can make a significant difference to the quality of your results. A dedicated IMTP rig is recommended because it will typically:*
>
> ***a.*** *Allow for the bar height to be finely adjusted to suit different individuals;*
> ***b.*** *Feature a stiffer bar than a traditional weightlifting bar; and*
> ***c.*** *Have no slack between the bar and frame.*
>
> *For recommendations on where to find a local supplier of IMTP rigs for your ForceDecks, please contact info@vald.com*

Starting position:

> ***Note:*** *the individual's body should be in the below position, with roughly 135° of knee flexion, and the feet, hands, and shoulders in vertical alignment* (Kraska, 2009)

2.9.3 Isometric Mid-Thigh Pull Protocol

To perform an **Isometric Mid-Thigh Pull** test, follow these steps:

Starting position:

- Standing position with hip and knees slightly bent
- Bar positioned at mid-thigh
- Gripping the bar with slight pretension

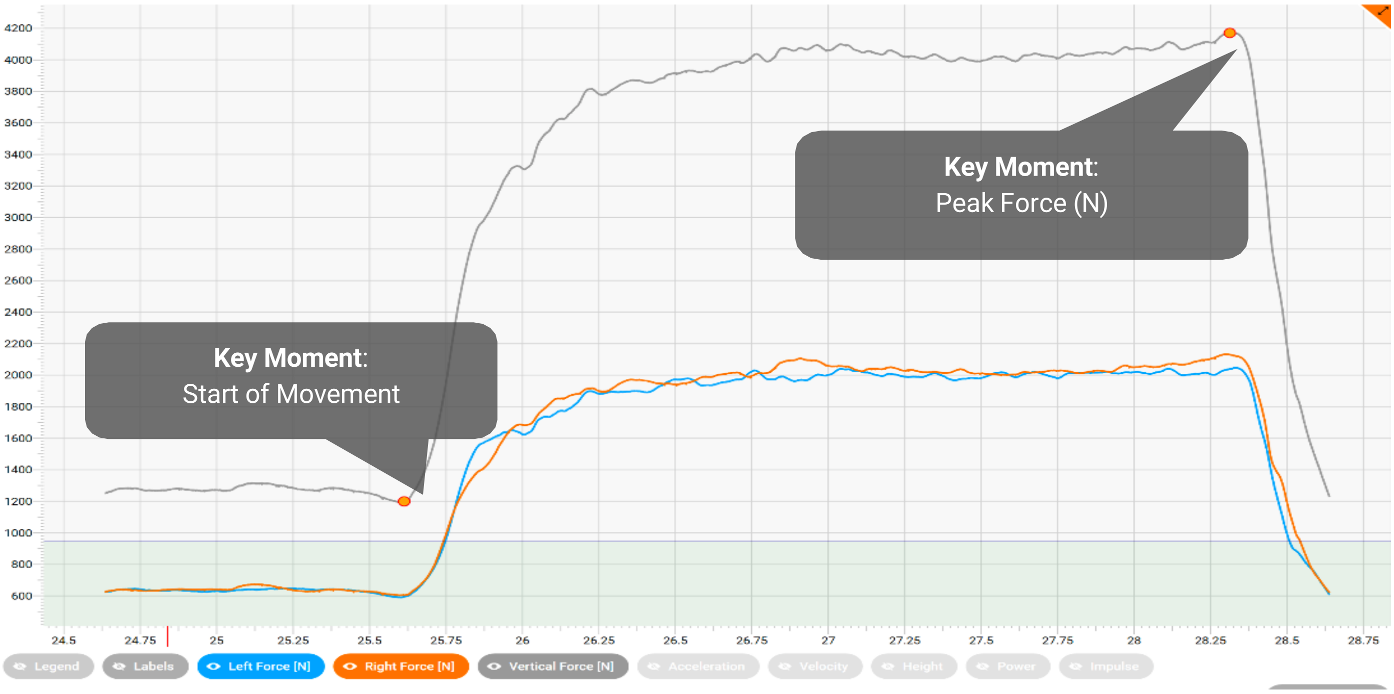
Protocol:

1. **Zero Plates –** Zero the plates. Ensure nothing is touching the plates during this step.
2. **Weigh individual –** Measure the individual's weight.
3. **Assume starting position –** Ask the individual to assume the starting position on the plates.
4. **Stabilize individual –** Instruct the individual to remain completely still, in the starting position for 2-3 seconds before and between each rep in the test.
5. **Perform Test –** Instruct the individual to:
    a. Contract as hard and as fast as possible: then
    b. Hold at maximum force output for a minimum of 2 seconds; then
    c. Relax after the contraction; then
    d. Assume the starting position again.
6. **Repeat –** Repeat step 5 to record the desired number of reps.
7. **Complete the test –** Click to stop the recording and check the results.

2.9.4 Key Moments and Phases

ForceDecks auto-detects the following key moments in an Isometric test.

Key Moments	Description
Start of Movement	Point where exercise commences.
Peak Vertical Force	Greatest force recording through the entire trial.



> ***Note**: there are no distinct phases detected in an Isometric Test.*

From these key moments in an Isometric test, ForceDecks software calculates and reports 44 metrics on performance and asymmetry.

2.9.5 Commonly Used Metrics

Some of the most commonly used metrics from an Isometric test include:

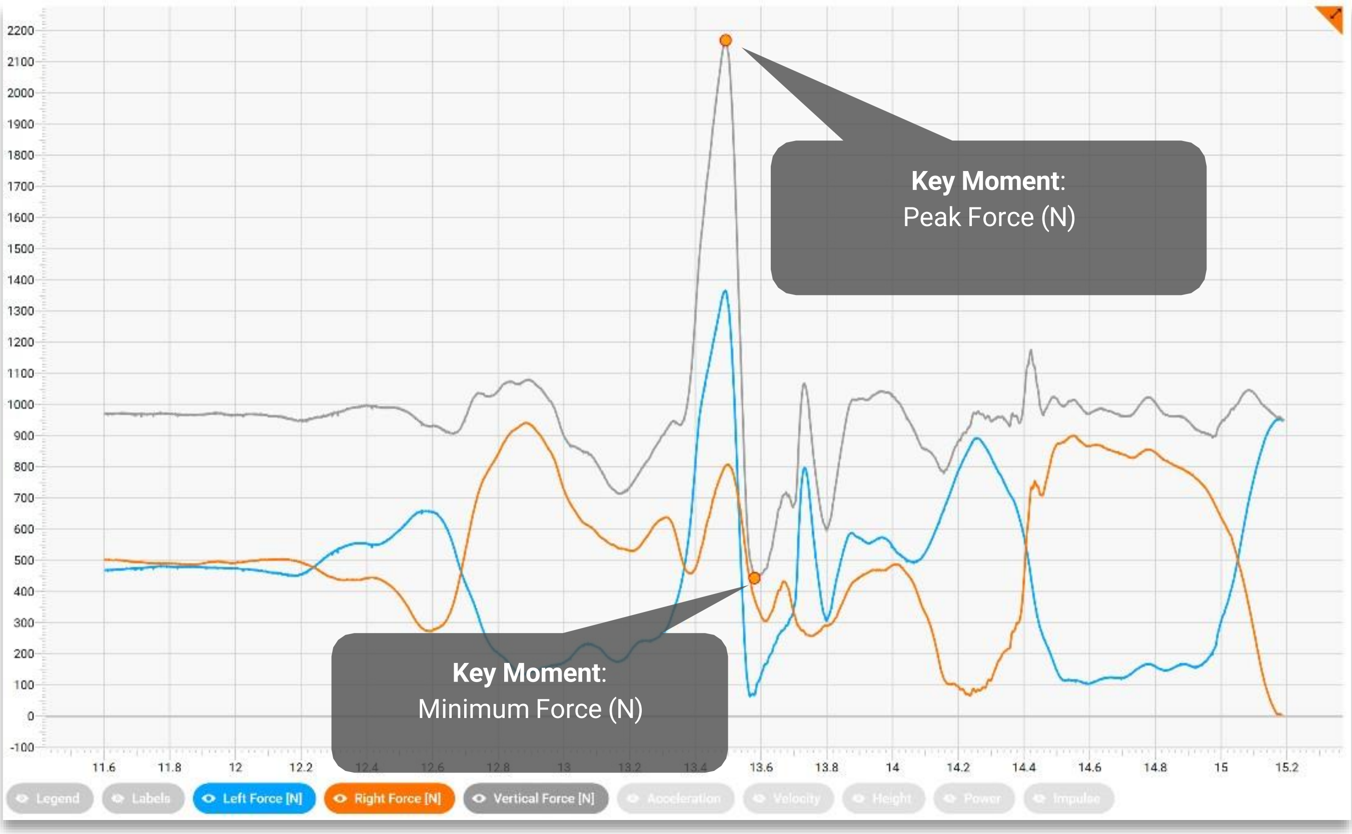
Metrics	Description	Common Application(s)
Performance Metrics		
Peak Vertical Force	Maximal force produced within the trial	Profiling, adaptation monitoring
Absolute Impulse	Total work performed	Profiling, adaptation monitoring
Force @ 100/150/200ms	Depending on the sport, you can select a time epoch that matches the sport demand (example, sprinting GCT of about 100ms)	Fatigue monitoring, adaptation, monitoring, profiling
Rate of Force Development @ time epoch of choice	Similar to F@time point, RFD is found to track explosive strength qualities and fatigue	Individual profiling and adaptation monitoring
Peak Vertical Force/BW	Peak force relative to bodyweight is used for comparison to other individuals	Adaptation monitoring, profiling
Asymmetry Metrics		
Peak Vertical Force Asymmetry	L/R difference between max force produced	Return to play monitoring, Profiling
Absolute Impulse Asymmetry	L/R difference of total work performed	Return to play monitoring, Profiling
RFD Asymmetry	L/R difference in rate of force produced	Return to play monitoring

2.10 General Force-Time Analysis (GFTA)

The General Force Time Analysis is a very different process than other test types that have clear instructions and detection points that allow ForceDecks to auto-detect and auto-analyze.

The GFTA allows the user to record force:time data for any test or exercise they wish. In a GFTA test, there is no defined start of movement (SoM) or eccentric/concentric/landing phases, but ForceDecks does produce simple force related metrics such as peak force and minimum force.

There are countless examples of tests for which GFTA may be used, but one example shown below is a GFTA test being used to analyze a golf swing.



2.10.1 Protocol

To perform a **General Force –Time Analysis** test, follow these steps:

(This test is **available on ForceDecks Windows only**. GFTA is not available in ForceDecks iOS).

> ***Note***: *A General Force-Time Analysis is typically performed for tests and movements which are not automatically detected by ForceDecks Windows. This allows any test to be analyzed at a basic level, even if it is a unique or uncommon protocol or movement.*

General Force-Time Analysis tests yield generic results, which are broadly suitable for most tests, but depending on the test being performed, may not capture all desired metrics for all users.

Starting position:

- As desired

Protocol:

1. **Zero plates –** Zero the plates. Ensure nothing is touching the plates during this step.
2. **Assume starting position –** Ask the individual to assume the starting position on the plates.
3. **Weigh individual –** Measure the individual's weight.
4. **Stabilize individual –** Instruct the individual to remain completely still, in the starting position for 2-3 seconds before and between each rep in the test.
5. **Perform test** - Instruct the individual to perform the desired movement.
6. **Repeat –** Repeat step 5 to record the desired number of reps.
7. **Stop recording –** Click to stop the recording.
8. **Mark reps –** Click "Mark Trial Range", then on the graph, to select the desired range/s to be analyzed.
9. **Complete the test -** Analyze and save the results.

3 Example Applications

This section discusses some of the possible use cases for ForceDecks, using sources taken from:

1. Published literature; and
2. Case studies from current ForceDecks users.

ForceDecks provides a detailed and objective understanding of physical characteristics that relate to sport, work, and/or life tasks that in turn, can help manage general well-being (VALD, 2023). The following section covers common examples of force plate testing, while exploring how resultant data can be used effectively in daily practice. Specifically, we explore why all tests have value, while acknowledging that test types need to be matched with the right context to have maximal value, i.e., ecological validity.

Using ForceDecks helps to better understand and articulate changes in attributes that relate to sports performance, work-related duties, and to guide the progression of injury rehabilitation. In contrast to monitoring progress, it helps to illuminate when physical characteristics are in decline (e.g., fatigue monitoring), which can put performances and the individual at risk, including injury and illness. While these are two distinct considerations (i.e., deciding when to push and when to protect), in practice they work in tandem to ensure healthy performance is maintained.

3.1 General Considerations

3.1.1 Evaluation Stage – Choosing Tests and Metrics

Before thinking deeply about what and when to test, it is important to consider what you want to know from testing and how you plan to use the resultant data, e.g., how will you leverage the information alongside other stakeholders so that programming interventions are successful? The following diagram (Figure 2), underpinned by principles of continuous improvement, offer an example process to help reach your goal(s).

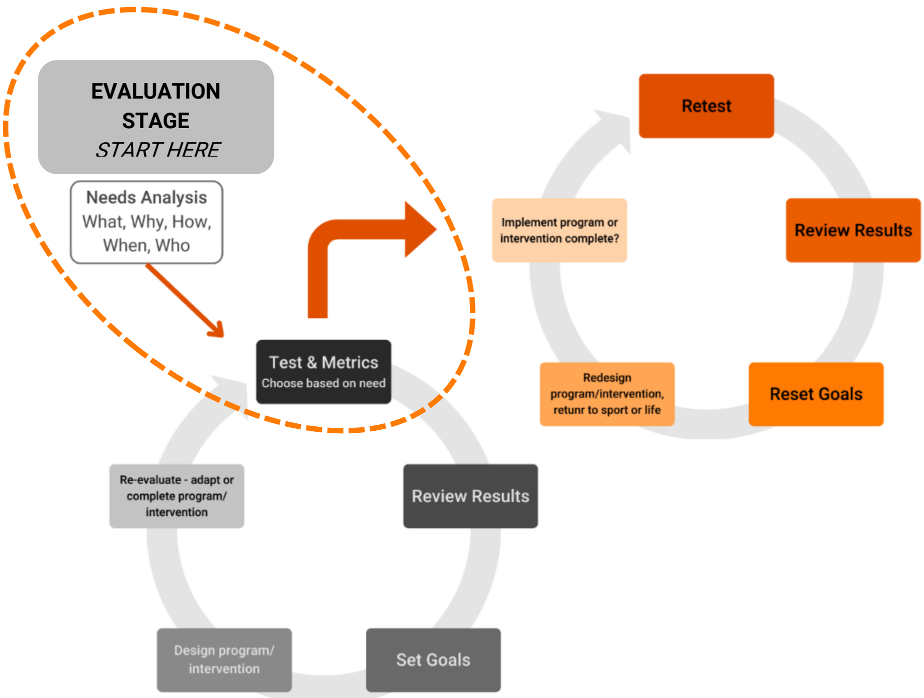


Figure 2. Testing using ForceDecks – considerations for planning, testing, leveraging results, and programming.

For best practice, it is recommended to start with conducting a Needs Analysis, considering the demands of the task and/or sport, and the status of the individual being tested. The structure of the testing session and selected tests should generally meet the following criteria:

1. Tests should relate to a desirable quality in the individual's sport or occupation (for example, the strength capacity of a dog handler in the military or the police).
2. Tests should be repeatable (considering time, set up, access to equipment/space).
3. The individual clearly understands the purpose and goal(s), to ensure that effort and intent are maximal.
4. The data collected will be used to affect exercise prescription and training, where applicable.

Once these have been established, the next step is to select relevant tests and metrics. By quantifying relevant physical capacities, strengths and weaknesses can be determined, guiding targeted training prescriptions to address the revealed deficiencies (James, 2023; Sheppard, 2021). To assist with test selection, ForceDecks users should consider both the individual's immediate and longer-term testing needs, where the choice of tests and metrics are an important first step. For example, as the user, are you looking to assess physical qualities that are important for performance (sport/ job/ life), monitor dose-response/fatigue, or understand progressions during injury rehabilitation? Below are 3 distinct user applications using the CMJ, where ForceDecks can have a significant impact on practice:

PERFORMANCE PROFILING

Purpose:
To assess association with other measures of performance

Metric	What it Assesses
Jump height (cm)	Vertical displacement of the athlete's center of mass
Peak power (W)	Highest rate of doing work during the jump
Concentric mean force (N)	Mean force produced during ascent
Concentric impulse (Ns)*	Product of force and time during ascent

Output metrics, including the metrics above, correspond with physical capabilities that benefit sport performance, including strength, linear speed, and change-of-direction ability.

NEUROMUSCULAR FATIGUE

Purpose:
To detect when neuromuscular fatigue is present

Metric	What it Assesses
Reactive Strength Index (RSI) Modified*	Ratio of output (jump height) to time spent to produce the output (contraction time)
Contraction time (ms)	Total duration from initiation of movement to take-off
Concentric duration (ms)	Time spent during ascent (prior to take-off)
Movement start to peak power (s)*	Amount of time it takes before the greatest amount of power is produced

Time-based metrics, including the metrics above, correspond with acute neuromuscular fatigue (induced by intense physical activity).

RETURN FROM INJURY

Purpose:
To assess post-injury progress and preparedness for return to sport

Metric	What it Assesses
Concentric peak force (N)	Greatest amount of force produced during ascent
Peak landing force (N)	Greatest amount of force produced upon landing from the jump
Landing impulse (Ns)*	Product of force and time during landing from the jump
Asymmetry (%)	Differences in metric outcomes between limbs

Declaration, landing, and inter-limb asymmetry metrics can differentiate between athletes with and without injuries.

*Ensure all component parts are concurrently monitored to understand what is driving any changes in data over time.

NOTE: It is often at times beneficial to evaluate countermovement jump metrics relative to body mass. Above all, the practitioner should be consistent in how they evaluate their data (absolute vs. relative) to appropriately appraise differences between athlete cohorts and changes over time.

Figure 3. A framework to guide practitioners for selecting metrics using the countermovement jump test (*Adapted from* Bishop et al. (2022)

Once the user-case has been established, the next step is to understand how to generate a performance-profile for the individual, where the *ForceDecks Assessment Framework* (see Figure 4) can help to design a suitable testing battery as part of a continuum, where at one end, tests are less demanding and focus on balance and basic function. On the other end of the continuum, test types are more ballistic, and are used to understand plyometric performance. Consequently, each test helps to understand physical characteristics (e.g., strength, speed, and/ or endurance) that are important for enhancing physical performance and is an important first step when designing training and exercise programs. Critically, practitioners need to be mindful that not every individual has to carry out tests at every stage of the *ForceDecks Assessment Framework* (Figure 4), as it is based on need and capability.

For example, elderly individuals might not require and/ or be able to complete high impact and velocity test like, Drop Jumps, but they do require strength and balance to execute daily tasks like, squatting to pick a bag from the floor, or to get out of a chair. In this example, supporting practitioners need to consider whether tests other than balance, functional movement patterns, and isometric strength are safe and relevant to the client's need.

Conversely, military personnel and athletes might require a high degree of elastic reactive strength for aggressive change of direction, jumping from a run up, or running at speed, where Drop Jumps or the 10/5 Repeated Hop Test offer relevant test solutions.

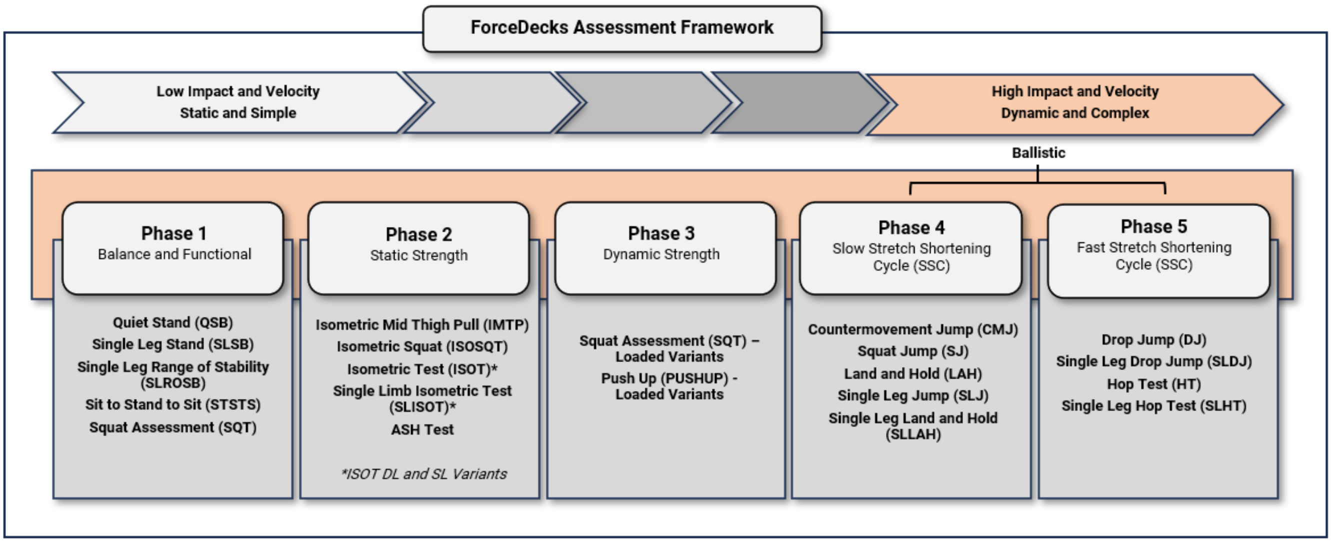


Figure 4. The ForceDecks Assessment Framework assists practitioners when selecting test types based on the individual's need and as part of a continuum.

3.1.2 Individualization: Personalizing the Assessment based on Need

It is important to consider if the goal of your testing is to determine one of the following:

1. What is the individual's capability and capacity - personal best efforts/outcomes across relevant metrics, how they compared to normative standards, and how you can leverage their results to improve the individual's status?

2. What is the individual's average and/or standard deviation of their effort and outcome?
3. What do the individual's effort/outcomes look like under adverse conditions, e.g., during peak levels of fatigue?

The above may seem like a relatively minor distinction but can have a significant impact on the interpretation of any data collected. For example, when testing an individual, consider the differences between:

a. Optimal status; and
b. Normal daily demands.

Below are examples applications that ForceDecks users encounter, providing details of the client/athlete, test, and metrics:

Profile	Metrics
22 yr old Basketballer Start Preseason Testing Testing: Leg Power • CMJ • Hop Test	The aim is to discover the status of the player, while understanding how the player has returned from an off-season break. More-over, the coaching and support staff are aiming to understand longer-term impact of their programming and competition, as it helps to guide the player for the next stage of preparation and competition. Metrics: **CMJ** Jump Height (cm) ~ brings everyone onto the same page. Eccentric and Concentric Impulse (Ns) ~ provides understanding of the breaking and propulsive phases of the jump. Countermovement Depth (cm) ~ provides helpful information about the depth at the bottom of the movement – consistent or inconsistent? **10/5 Repeat Hop Test** RSI Best (Flight Time / Contact Time) ≤ 1.5 requires work > 2.5 is advanced. Jump Height (cm) ~ Higher is better. Contact Time (milliseconds) ~ Lower is better.
73 yr old Woman 4 Weeks Post-Knee Replacement Surgery Testing: Mobility • Quiet Stand • Sit-Stand-Sit	Testing balance and sit-to-stand function after knee replacement surgery is an integral part of postoperative (and preoperative) care. It helps ensure patient safety, monitors rehabilitation progress, and guides the development of targeted interventions to optimize functional outcomes. Metrics: **Quiet Stand (QSB)** Total Excursion (mm) ~ total distance travelled by the CoP. Mean Force (Asymmetry) [% L, R] ~ mean force imbalance between involved vs uninvolved limbs. **Sit to Stand to Sit (STSTS)** Mean (and/or Peak) Standing Force (Asymmetry) [% L,R] ~ mean vertical force asymmetry over sit-to-stand phase, giving insights into involved vs uninvolved force contributions to the standing phase. Time to Stand (s) ~ time between start of standing and stabilized in standing position, insights into rate and time-based components of functional standing task.
39 yr old Soldier Annual Testing Testing: Strength and Leg Power • IMTP • CMJ	Unlike in many sports, military personnel must be available for operational duties at any time, and not necessarily in peak condition. Testing should identify core physical capacities (e.g., strength and endurance), and identify potential injury risk. Metrics: **IMTP** Peak Vertical Force / BM (N/kg) ~ helps to identify systematic full body strength relative to the weight of each individual. Net Peak Vertical Force Asymmetry (%) ~ is the soldier favoring one side more than the other? **CMJ** Jump Height (cm/ inches) ~ gives an overall indication of performance. Eccentric Impulse (Ns) ~ capacity to apply braking forces before the concentric phase of jumping. Concentric Impulse (Ns) ~ capacity to apply braking forces before the concentric phase of jumping. Peak Landing Force (N) ~ helps to identify landing loads and asymmetries, which can be problematic with repeated jumping and landing.

Practical Implications – when to test?

Example comparison: In a typical week, a military Sergeant and basketball player might experience high workloads in their respective jobs, which can have negative implications on their ForceDecks testing performances. Therefore, we might expect sub-optimal performances, unless their training is adjusted to accommodate (typically reduced) for associated acute fatigue to subside. Understanding the need to control physical status in the lead in to testing (time of day, day of week, stage of program, level of fatigue, etc.) is an important consideration when collecting data that is both valid and reliable (Issurin, 2010).

Time of day is also an important consideration when testing. The impact on results is known to vary due to the natural circadian rhythm and the body's fluctuation in alertness, hormonal status, and internal body temperature (Thun, 2015; Atkinson, 1996; Bourreau, 2015). If it is not possible to test-retest at a similar time of day, you can use "Attributes" to delineate results.

In ForceDecks, you can assign "tags", to help classify similar tests that have different constraints. For example, if CMJ is tested in the morning or the evening, it will help the practitioner decide whether the fluctuation in data is due to actual changes in neuromuscular status or simply due to variation in the time. Similarly, attributes can be used in the same manner to delineate differences in physical status (Zarrouk, 2012).

3.2 Profiling

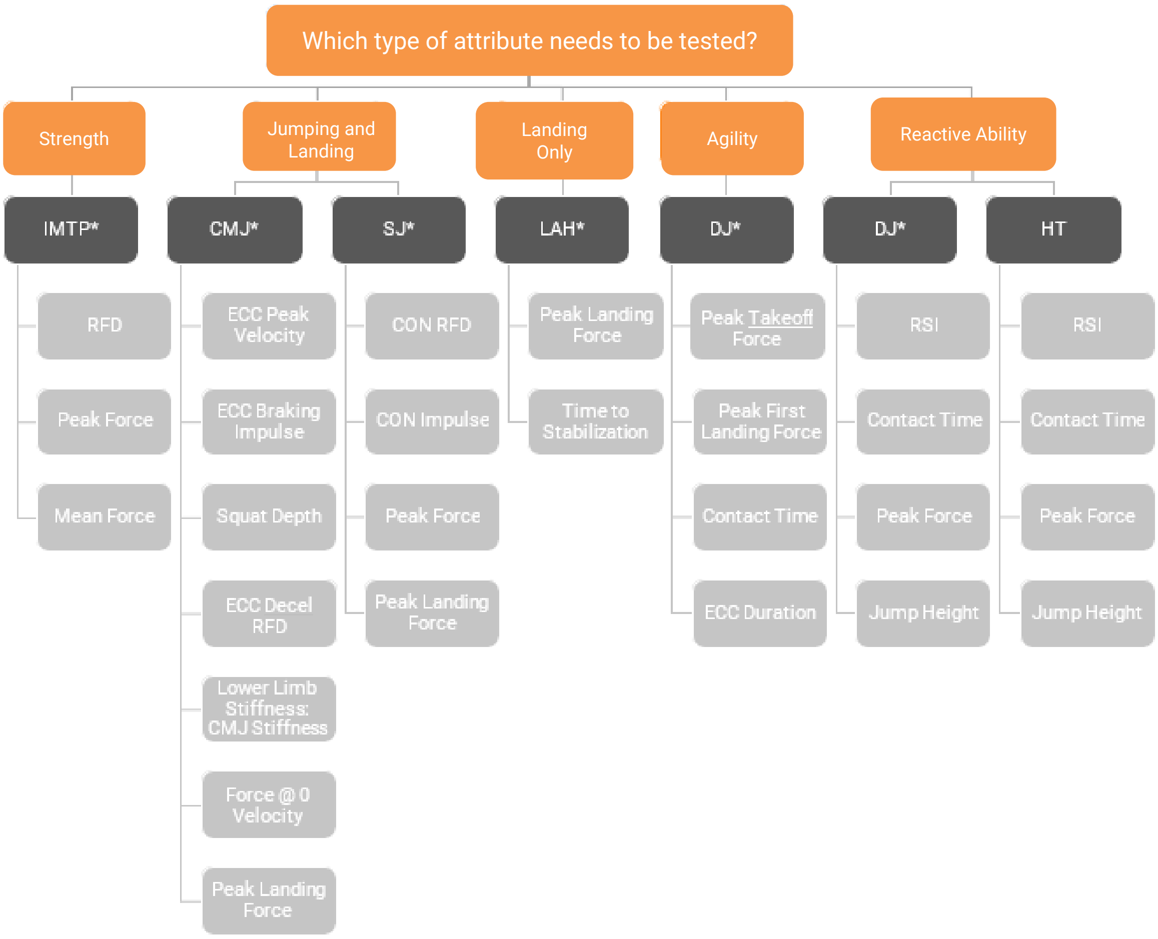
Purpose	Establish a baseline for an individual, relative to: • Their peers (for immediate intervention) • The individual (for future monitoring and intervention)
Objectives	Establish a reliable measure of what is typical for the individual, using criteria that is: • Reliably monitored over time • Directly related to their goals
Common tests	Tests should be easy to perform reliably with minimal familiarization, while gathering as much data as possible, such as (but not limited to): • CMJ • SQT (loaded or unloaded) • Isometric Tests
Frequency of testing	Typically, just once, at start of a discreet period: • During first visit to clinic • Based on timeline needs – e.g., start of program/season/course • Start of new exercise program • Pre/post-surgery
Key considerations	• Is the individual familiarized enough or physically capable enough to make their data reliable? • Would improvement in the aspects being measured mean progress towards their goals? • Can the analysis be consistently performed again in the future to test the same aspects?

Profiling is an important part of understanding programming for performance and injury rehabilitation. The general goal of profiling is to take a "fingerprint" of the individual, to answer questions such as:

- What are their strengths?
- What are their outputs in given tests/metrics?
- What are their weaknesses and imbalances?
- What do their normal outcome measures (e.g., jump height) look like?
- What do their normal strategies (e.g., countermovement depth, contraction time, etc.) look like?
- What do they do on a consistent basis that may be beneficial or detrimental to their sport or their health?

With this in mind, understanding how results in multiple assessments relate to each other can help to improve your understanding of an individual's "fingerprint" and personalize their exercise prescription accordingly (Turner, 2019).

Below is an example of how relevant test/s and variable/s may be selected to form part of profiling.



These tests may instead/also be performed in single limb variants where appropriate.

Note: These are attributes that are relevant for rapid change of direct movements and agility.

For the purpose of this User Guide, our discussion focuses on neuromuscular assessment. Other common areas of profiling such as: 3D movement analysis, speed, endurance, blood panels and cognitive testing are out of the scope of this User Guide but may still form a part of the profiling and monitoring process and may add value to neuromuscular assessment results.

The following section discusses profiling of both performance and asymmetry.

3.2.1 Profiling for Improved Performance

To establish a well-rounded profile for the individual, it is important to consider using different test types. Developing a well-rounded performance profile requires results from multiple test types, each offering details about different attributes. If time and resources allow, the best approach is to examine various test results to identify similarities and relationships. Trends will begin to emerge and that will help support informed decision-making for training and exercise. For example, consider the following tests and the data they most accurately report:

- **CMJ:** precise information regarding slow Stretch Shorten Cycle (SSC) ability and easily administered for ongoing monitoring.
- **DJ:** provides relevant information for fast Stretch Shorten Cycle (SSC) ability, that relates to jumping from a run up, rapid change of direction, and running at speed.
- **SJ:** isolates an individual's ability to generate force during movement without any elastic contribution.
- **Lower Limb ISOT:** a reliable method to determine lower body maximum force production.

However, this is by no means a comprehensive list of options. For example, a Hop Test can replace the DJ; Single Limb Jump and Isometric tests may help with single limb versus double leg abilities (possibly highlighting deficiencies or asymmetry variations). Lastly, Squat Assessment and/or Loaded CMJs can be used to create a Force:Velocity Profile or again, help to determine how external load influences asymmetry profiles. Beyond using single tests, it is also possible to cross-reference different test types such as an IMTP and CMJ to derive a Dynamic Strength Index (DSI), or to look at the difference in CMJ and SJ performance in order to better understand the relationship between strength capacity and Stretch Shorten Cycle (SSC) ability.

Index	Equation	Description	Common Values
Dynamic Strength Index (DSI)	CMJ Peak Force / IMTP Peak Force	Determines the percentage of maximum isometric force (i.e., from an IMTP) that an individual expresses during a ballistic movement (i.e., a CMJ).	A low DSI (e.g., < 0.6) suggests jump or plyometric training may be beneficial. A moderate DSI (e.g., 0.6 - 0.8) may indicate that both power and maximum strength should be trained concurrently. A high DSI (e.g., > 0.8) may indicate that additional maximum strength training would be useful to increase performance. Caution should be used with deconditioned individuals.

Elastic Utilization Ratio (EUR)	SJ Jump Height / CMJ Jump Height	Determines the contribution of the stretch/shorten cycle (i.e.: elastic properties) to overall jump performance.	The CMJ uses the eccentric phase to develop elastic potential and quickly transfers that energy to the force generated during the concentric phase. The SJ removes that elastic potential by requiring the individual to jump from a paused squat position. Determining the difference between the two jump heights may identify the contribution of elastic potential to jump performance. The larger the difference, the more the individual may rely on elastic properties to jump.
CMJ Upper Body Contribution	CMJ Jump Height / Abalakov Jump Height	Determines the contribution of an arm swing movement to overall jump height.	The CMJ protocol requires that the hands of the subject stay on their hips during the entire test. This restricts the upward momentum generated by the upper body and, in some cases, may expose deficits in jump strategy. These factors reduce final vertical jump height. Testing an individual with and without arm swing will determine the additional contribution (if any) of upper body. Some individuals may display stronger single limb results than when both limbs are testing simultaneously.
Bilateral Strength Deficit	IMTP Bilateral Max/(IMTP Left Max + IMTP Right Max)	Identifies if the summed unilateral force produced is greater than in the bilateral testing condition.	Testing bilaterally and both limbs individually may demonstrate if and by how much single limb force output differs. A result of >1.0 means that bilateral force is higher, while <1.0 means that summed unilateral forces are higher. Such results may guide programming choices and inform practitioners of how asymmetries in bilateral movement patterns differ from single limb performances.

There are many options for creating a profile. The following principles are recommended for establishing priorities:

1. Determine the performance and/or physical demands for the individual, and assess what extent of testing can be tolerated;
2. Identify the general attributes that match the response(s) to question 1, such as, CMJ performance for a basketball player or single leg ISO strength for a soldier;
3. Select tests that return unique results rather than ones that examine similar aspects and yield redundant conclusions. Consider logistics such as time, equipment availability, and individual experience when selecting certain tests over others within a category; and
4. Use the results to establish a baseline, identify areas of performance excellence, and aspects in need of improvement.

Finally, it is worth considering how you will present the data in an understandable way. On that topic, the paper “Total Score of Athleticism: Holistic Athlete Profiling to Enhance Decision Making” by Anthony Turner

(2019) may provide some guidance.

3.2.2 Controlling Test Protocols

As stated earlier, the importance of applying a standardized protocol is fundamental to test validity and reliability, where the following examples need careful consideration:

- A **steady weigh-in period** is measured immediately prior to start of movement;
- A **steady period of at least 3 seconds in squat position**, before movement occurs;
- **Preventing a countermovement/sudden dip** at start of movement of a Squat Jump;
- When assessing a Drop Jump, the individual steps off the box and maintains hip height before dropping;
- Setting **bar height and joint angles in consistent positions** for each individual; and
- **Capturing an accurate system weight** (i.e., bodyweight plus any external load) in a loaded Squat Assessment.

These factors (along with others mentioned throughout this document) are the cornerstones in the usage of force plates. Executing correct, repeatable protocols should be considered a critical precursor to selecting and analyzing force plate data.

3.2.3 Defining Best Results

For any test that involves multiple trials, it is important to consider if data will be considered from all trials (repetitions) or from the "best" trial only. Results can then be filtered by the maximum, minimum, or average of trials (intra and inter-session).

For example, a profile can be built from a single "best trial" (e.g., the repetition with the best jump height, the shortest contact time, the lowest interlimb asymmetry, etc.) for key metrics of interest, such as, Jump Height, Peak Power, Eccentric Deceleration RFD, Eccentric Peak Power, etc. Alternatively, you may prefer to use multiple trials within a testing session. For example, consider a subject performs 5 trials in a CMJ test, and registers the following:

Best Jump Height	in Trial 1
Best Peak Power	in Trial 4
Best Eccentric Deceleration RFD	in Trial 2
Best Eccentric Peak Power	in Trial 1

The above outlines a test set, where the "best result" for each variable can occur in different repetitions or trials. For this reason, it might be preferable to use all trial/session data, as this single trial will be able to be better analyzed for both strengths and weaknesses. Thus, in this example, one may opt to analyze and filter results through the "maximum' of trials.

It's normal to see inter-trial variation. ForceDecks then allows us to analyze multiple trials as an average or mean of trials, along with its respective standard deviation and coefficient of variation, to help us better understand this variability and compare changes within various testing sessions.

3.2.4 Frequency of Testing

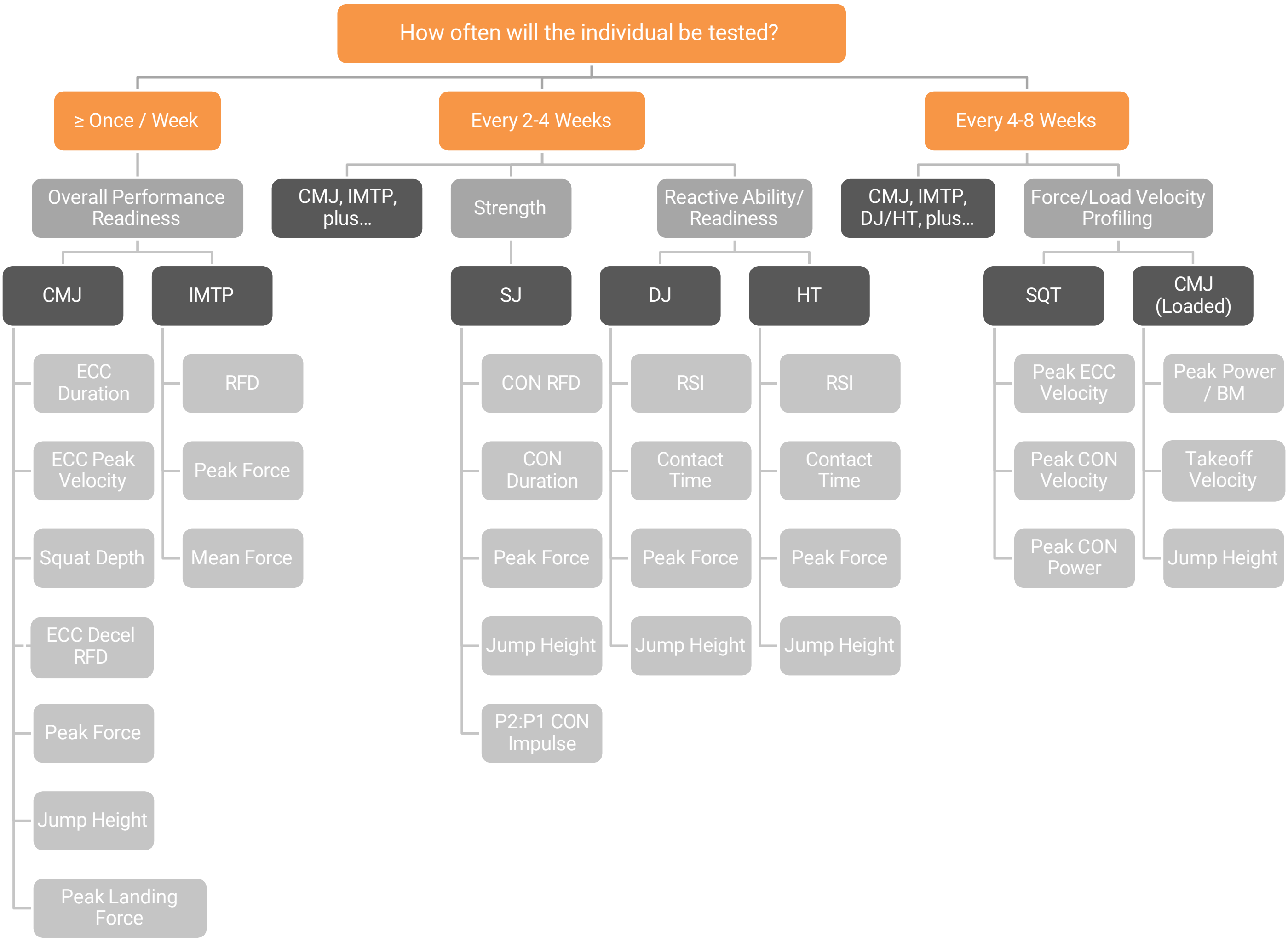
Contextual needs and constraints are important considerations when setting testing frequency. In sport, for example, testing alongside known benchmarks and past results are often used to set training direction at the start of preseason; assess physical progress during and/or at the end of preseason training; before using testing sparingly during the in-season and off-season phases to monitor and manage physical status, i.e., dose-response relationship.

Compare this to private practice physiotherapy, where practitioner-client interactions are less frequent, testing frequency will be lower. In these circumstances, the practitioner needs to consider time constraints and how the test results will be applied to guide rehabilitation, while engaging the client optimally.
Therefore, an important consideration is frequency of testing, which changes depending on the desired outcome of the test. For example, fatigue monitoring will be conducted more frequently than testing the effectiveness of an intervention.
Below are some important considerations for selecting an appropriate frequency:

1. Familiarization: it is prudent to allow enough trials to build familiarization and consistency in results. The rate of familiarization can vary depending on the experience of the individual and the complexity of the test (Bishop, 2022; Knezevic, 2014; Henry, 1967; Haugen, 2016).
2. With less data collected, it is more difficult to identify the difference between outliers and "good" or "bad" performances. The more consistently data is collected, the easier it becomes to spot and clean poorly performed tests, resulting in more reliable data.
3. Frequent testing helps visualize the normal trends that occur in each time, such as over the course of an exercise program, during a normal week of training, or during a rehabilitation journey.

For example, when trying to understand dose-response, if an individual is only tested fortnightly, it is difficult to determine how well that individual is progressing. Ideally, measures would be taken more frequently to get a better understanding (Bailey, 2019; Cormack, 2008). However, in contrast to testing healthy populations, frequent testing during rehabilitation interventions might not allow adequate time to highlight meaningful change but demonstrates normal daily variation of status. Therefore, practitioners need to adopt a plan and schedule for testing frequency that meets their individual's set of circumstances.

Below is an example of how appropriate test types and metrics may be selected based on time constraints and need.



Note: test choice is at the discretion of the practitioner based on the individual being tested.

3.2.5 Standardizing Test Protocols – Checklist before starting

Standardizing test protocols for testing is essential to ensure consistency and reliability in the measurements obtained. Outlined below are steps to improve standardization of test protocols for force plate testing:

1. **Define Objectives:** Clearly outline the objectives of your testing. What specific physical capacities or qualities are you measuring? What information are you trying to gather?
2. **Review Relevant Literature:** Familiarize yourself with existing research and standards related to force plate testing. This can help you understand best practices and inform your protocol.
3. **Define Subject's Instructions and Tester's Cueing:** Clearly communicate instructions/cueing to participants to ensure consistent testing conditions – includes all relevant instructions that might influence results.
4. **Control for Variability:** Minimize external factors (e.g., task constraints) that could introduce variability in the measurements. Emphasize reliable and consistent testing conditions, e.g., footwear, fatigued vs non-fatigued, etc.
5. **Consider Order Effects:** If your testing involves multiple trials or conditions, consider the order in which they are presented to the subject. Randomize or counterbalance the order to minimize order effects when needed.

By following these steps, you can establish a standardized and reliable protocol for testing in your specific application. Keep in mind that the details of the protocol may vary based on the specific goals of your testing.

3.2.6 Test Delivery Considerations

Test delivery considerations during ForceDecks testing are crucial to ensure accurate and reliable data collection. Below are key considerations to keep in mind:

1. **Cueing and Instructions:** Ensure a protocol is clearly laid out, allowing all involved to understand every step in the process, and ensuring those being tested can perform the test to their full capabilities, e.g., acutely fatigued due to poorly administered warm up.

2. **Familiarization:** Include a set of familiarization trials to allow participants to become accustomed to the testing environment and tasks. This helps reduce potential learning effects that could impact data validity.

3. **Order of Testing:** Tests must be ordered to allow for the participant to perform optimally, without the negative effects of the previous tests affecting subsequent tests.

4. **Rest Periods in Between Trials and Subsequent Tests:** These must be appropriate for the same reasons as delineated above.

5. **Task Repetition:** Determine the number of repetitions or trials for each task. Consistency in the number of repetitions helps ensure that the data collected is representative of the participant's performance.

6. **Task Complexity:** Be mindful of the complexity of the task participants are asked to perform. Ensure that tasks are appropriate for the participant's ability level and that they can be consistently replicated.

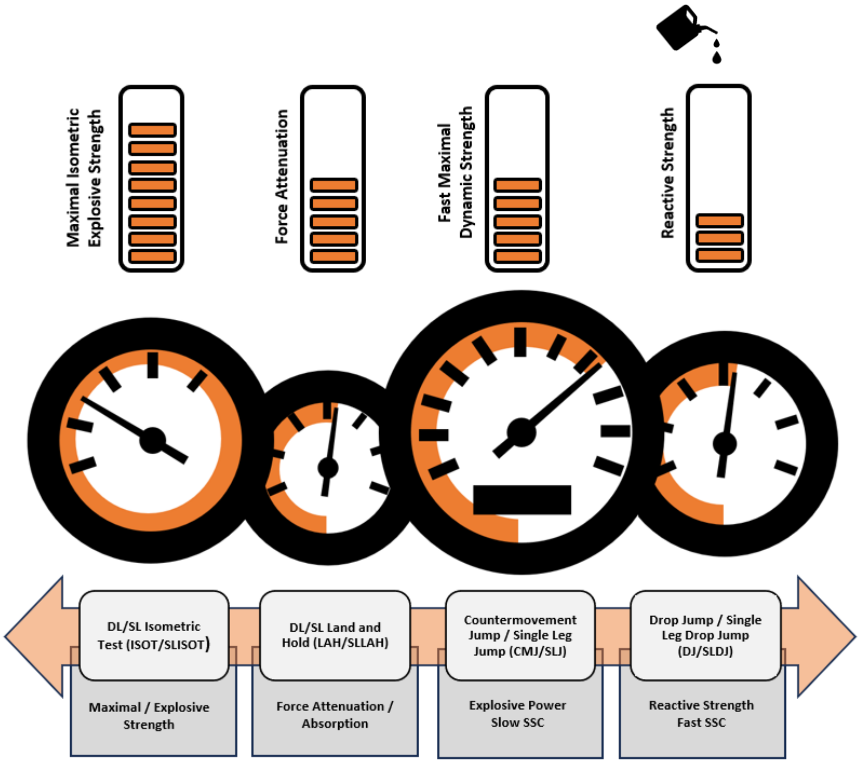
7. **Real-time Feedback:** Consider providing real-time feedback to participants during testing, especially if the follow up involves intervention or training. This can help participants adjust their performance and maintain consistency.

8. **Monitoring Participant Compliance:** Continuously monitor participant compliance with the testing protocol. Address any deviations promptly to maintain consistency in data collection.

By carefully considering these factors, you can enhance the reliability and validity of testing, ensuring that the data collected accurately reflects the demands of the individual’s needs – sport, work, and/or in life.

3.3 Reviewing Results: Key considerations

Once testing has been successfully completed, it is important to understand the participant’s strengths and weaknesses relative to benchmarked standards or previous healthy results, for programming and training/exercise prescription to meet the individual’s needs. In exercise science, the principle of Specificity is fundamental to adaptation and the successful transfer to real-world situations, e.g., prescribing exercises that help with heavy lifting from the ground (McGuigan, 2014). By choosing the right tests and metrics, it helps us consider wider implications of programming and/or recommendations, e.g., prior training history, current physical status, expected demands of role (sport or job), daily tasks, etc.



For example, the diagram on the left (Figure 5) shows results for several strength tests and associated variables, illustrating varying degrees of output success (i.e., strengths and weaknesses).

In this example, while isometric performance is good (see dial on the far left), jumping performance – landing and propulsive qualities were moderate (see all other dials).

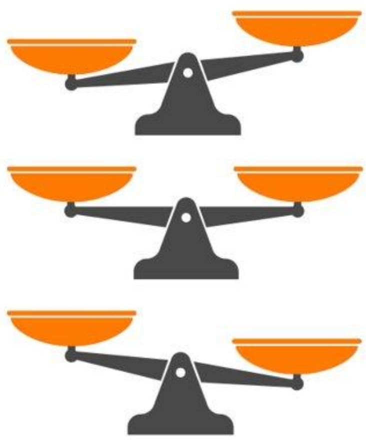
Therefore, where jumping and landing is required, as is the case here, the goal might be to improve the transfer of developed strength to more explosive actions, like high-speed running, aggressive change of direction, and/ or jumping after a run up.

Figure 5. An example lower limb test battery looking at different strength qualities for performance athletes and personnel.

It is also prudent to consider the individuals intrinsic injury risk profile (Joyce, 2015). Joyce & Lewindon (2015) suggest that intrinsic risks may include past injury, age, reduced range of motion, and muscle weakness. If the individual is exposed to extrinsic risk factors, they become more susceptible to injury. Extrinsic risk factors are those that are applied to the individual, such as, sports training, workplace hazards and regular physical activity, weather, and the nature of the expectations of the sport, job, or activity. As consequence, testing results help us understand risk factors, e.g., structural imbalances and asymmetries.

3.3.1 Balance vs. Asymmetry Profiling

When assessing physical asymmetries (structural and functional) from a scientific standpoint, it remains somewhat unclear about what constitutes as meaningful, or a “risky” magnitude of asymmetry. There are many factors that influence what is meaningful. Key to this are the characteristics of the individual and their environmental requirements (Coutts, 2015). Therefore, physical asymmetries should only ever be considered a risk indicator and never a predictor of injury. Despite this, there is a large amount of empirical evidence investigating asymmetries and their implications on performance (Eagle, 2019; Helme, 2021; Hewit, 2012).



Before considering the significance of asymmetries and how they trend over time, it is important to understand what they look like under normal conditions and more extreme circumstances. It is important to note, there is no clear-cut rule on when an asymmetry is significant. Consequently, it is recommended that when assessing movement performance and asymmetries, peak and mean values drawn from ForceDecks reporting helps to gain a broader understanding of functional capability and capacity. Furthermore, these metrics can be further dissected, looking into the differences between the performance of each limb (e.g., Left side = 1200 N/Right side = 1340 N).

Common questions practitioners seek to answer when considering the implications of asymmetries include:

Does the individual exhibit a compensatory movement strategy?
Is that strategy of a large enough magnitude to justify intervention?
Are there phase-specific asymmetries that warrant greater attention (*e.g., left-dominant in eccentric phase, but right-dominant in concentric phase)?*
Is there any history of injury that warrants more scrutiny?
Is there any movement variability that would signal cause for greater or lesser concern?

It is reasonable to expect to see asymmetries in certain populations over others, due to the demands of their occupation or sport (e.g., Tennis players, NFL Defensive Linesman, Dog Handlers, or Construction workers). Therefore, the goal of profiling is to highlight individuals that predominantly fall into one of three categories:

a. They fall outside of what would be considered normal for their population;
b. Have an undisclosed history of injury (Hart, 2019).
c. Disease or neuromuscular disorder; and/or,
d. Even when satisfying **a., b., or c**., results fall outside the desired bounds to achieve their goals.

Analyzing asymmetries can be a complicated process, and understanding key concepts can help to create a flexible and straightforward system. Below are *6 considerations* to help you understand asymmetry analysis for effective decision-making:

1. Magnitude of Asymmetry
2. Change in Magnitude of Asymmetry
3. Influence of Previous Injury on Asymmetry
4. Sport/Occupation/Life Stressors
5. Consistency of Inter-Phase Asymmetries
6. Consistency of Inter-Trial Asymmetries

The learn more about asymmetries and their implications on practice, refer to Appendix A.

3.4 Program Design/Intervention

The development of effective programming in performance environments, health and fitness, or rehabilitation is an intricate process (Wing, 2018; Issurin, 2010). Often there are multiple physical capacities and capabilities that need addressing, while other technical and tactical tasks are being trained or executed concurrently, resulting in high volumes and intensities. To best understand the effects of training and exercise, ForceDecks offers a sophisticated solution for practitioners in all contexts to assess the effects of their programming interventions through regular monitoring.

ForceDecks is a valuable tool when returning injured athletes and general populations to full function. In sport, this is broadly termed as, Return to Sport/Play/Participation rehabilitation.

3.4.1 Return to Play/Full Function

Return to play/participation measurement and monitoring is one of the most popular applications for force plate technology, and a common starting point for new users. This is likely due to the acute nature of injuries, which often creates a need for measurement and monitoring that may not have existed or was not able to be prioritized previously.

In multidisciplinary team (MDT) settings, it is common for Doctors, Physiotherapists, Strength and Conditioning Coaches, Exercise Physiologists, and Coaches to collaboratively implement a plan that incorporates sophisticated processes to aid progression of the individual towards full function or return to playing their sport safely (see Figure 6) (Mujika, 2018).

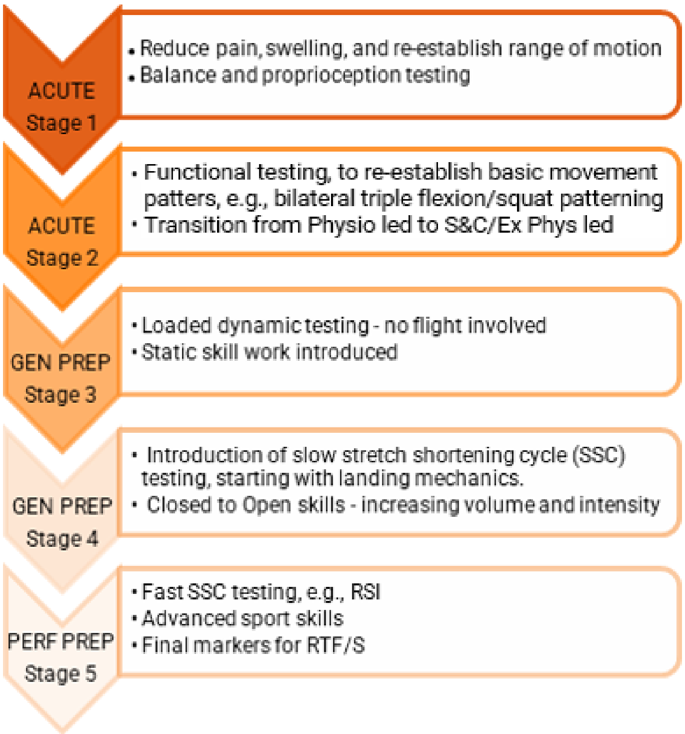


Figure 6. Example of Return to Sport/ Play MDT process

Using the following principles below, practitioners can decide how best to adopt and apply ForceDecks testing for their circumstances:

Purpose	Use reliable metrics to determine: • How quickly (or slowly) an individual is recovering from injury • When the individual's rehabilitation program should progress (or regress) • Finally, if the individual is ready to return to their sport, work, or other activity
Objectives	Perform reliable testing at logical timepoints to: • (If pre-injury data exists) determine how far the individual has been set back by the injury • Set goals for rehabilitation progress and outcomes • Monitor progress, and if needed, alter rehabilitation programs accordingly • Set measurable thresholds to be used for clearance for return to play/participation
Common tests	Rehabilitation tests will vary widely based on the injury and stage of rehabilitation, for example: • Lower limb injury, early rehabilitation: SQT (unloaded) • Lower limb injury, mid-rehabilitation: CMJ • Lower limb injury, late rehabilitation: DJ

Frequency of testing	Regularly throughout rehabilitation, however often less regular than in fatigue monitoring, such as: • Once per fortnight • During each in-clinic appointment • At the end of each rehabilitation stage or exercise program
Key considerations	• How will progress be measured? • Are the tests being performed commensurate with the stage of rehabilitation? • What will the threshold(s) be for return to play/participation? • Force plate metrics are usually not enough in isolation to determine that someone is "rehabilitated". How will these results be cross-checked?

3.4.2 Pre-Injury Baseline Data

One of the most valuable assets in implementing a return to sport/play/participation strategy is having pre-injury data that provides a baseline for what may constitute "healthy" or "normal" for the individual.

Baselines for return to play/participation are typically not collected discretely, given that practitioners do not plan for injuries to occur, but rather simply try to be prepared for them. Instead, return to play/participation baselines are often drawn from data collected previously for profiling, fatigue monitoring or adaptation monitoring purposes. In this regard, the participant's data can be used for several different purposes if the context around the test (discussed previously) is known and has been fully considered (see Figure 7 below):

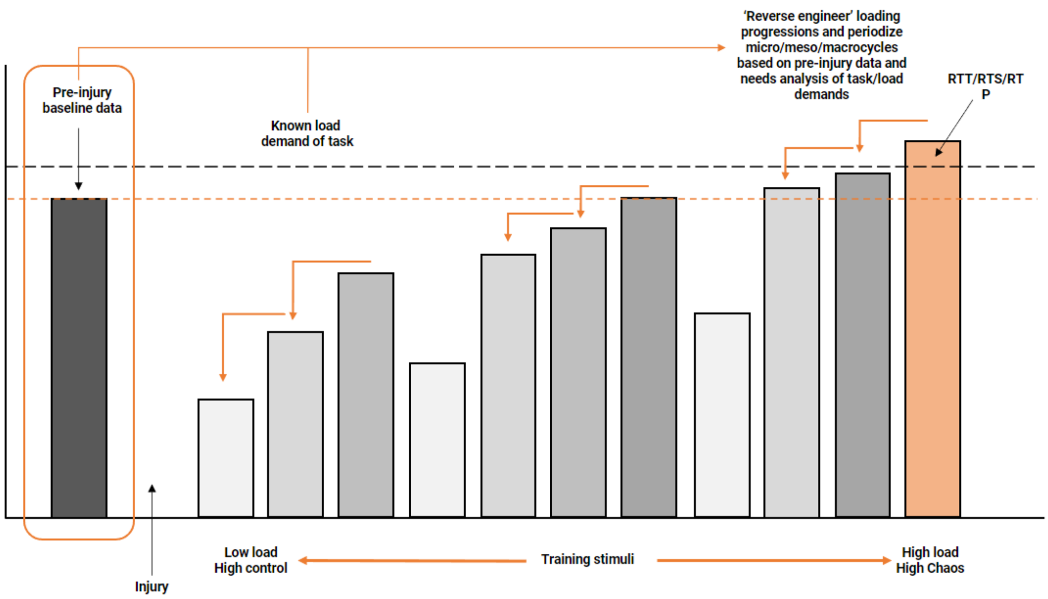


Figure 7. Using pre-injury/matched-control normative data to 'reverse engineer' and 'backward design' transferable and context specific programming. It can roughly be broken down into 4 stages: (1) define the return to performance goal, (2) determine the key performance indicators (KPIs), (3) assess current performance, (4) plan and program rehabilitation appropriately (Chia, 2022).

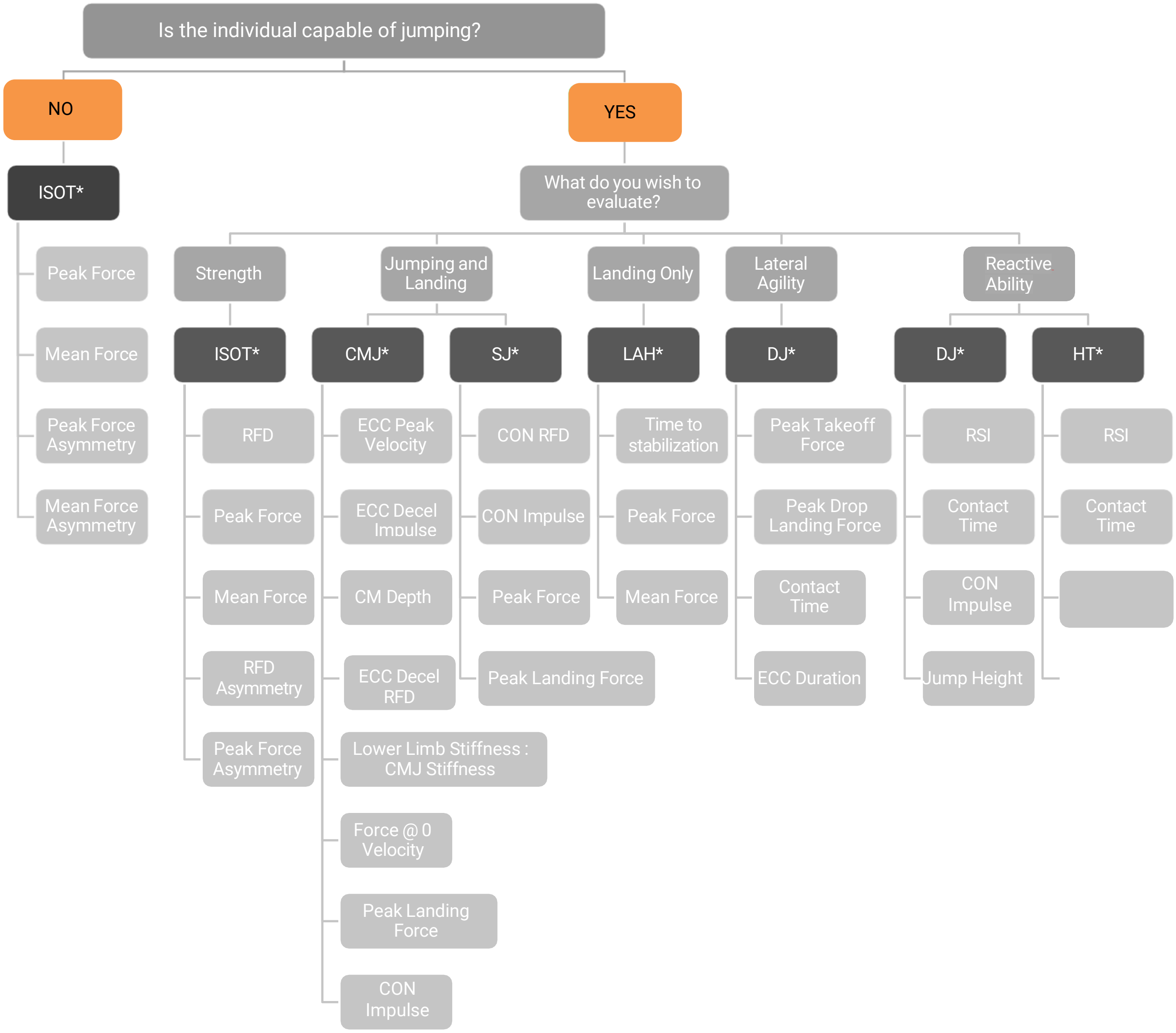
However, when a return to play/participation strategy becomes necessary (i.e., after an injury occurs), it is too late to establish such baselines. This often means that the program must use alternative options for establishing goals for return to play/participation clearance.

For example, other options for return to play/participation goals may reference:

- Data from research literature; or
- Means from comparable individual populations.

Ultimately, the circumstances of return to play/full function are often imperfect, as the individual's status is inherently compromised, and there are often a multitude of other personal, emotional, and social influences which may introduce additional pressure or urgency to the process. This is why, whenever possible, establishing data-driven baselines, robust reference points and goals for individual to strive for can assist in directing focus onto modifiable factors (rather than non-modifiable factors) and removing potentially detrimental distractions.

Therefore, as a starting point, it is important to ask some fundamental questions that assist with choosing test types and associated metrics. For example, does your participant need to jump in the sport or work, and if so, which tests are most applicable and safe during the early stages of rehabilitation? Below is an example framework that helps to make these decisions.



Particularly in return to play/participation applications (i.e., often even more so than in profiling and monitoring applications), practitioners would commonly monitor these tests' **asymmetry metrics as well.*

Once decided, the next step is to consider how you will progress testing to reflect the loading (load impact and velocity) required to move to the next stage of rehabilitation. Below is another example framework (Figure 8) where objective testing is performed to inform decision-making throughout the rehabilitation-performance continuum – part of an ongoing process of testing, applying load stimulus, re-testing, and assessing response:

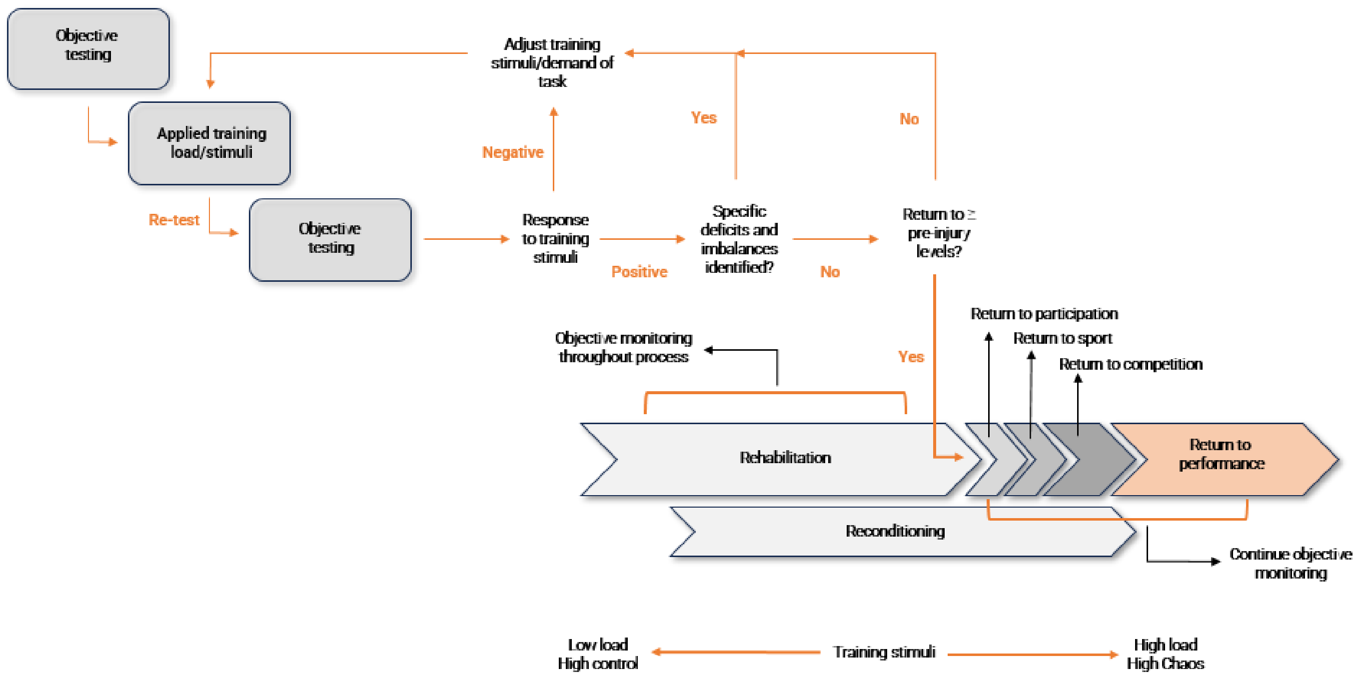


Figure 8. Example RTS/RTP framework using a criteria-based objective approach to inform the decision-making process (Taberner, 2020; Ekizos, 2023; Rebelo-Marques, 2019).

A progression/regression framework can then be created to identify the appropriate entry-point for intervention and objective assessments. The image below (Figure 9) depicts a relative progression within a continuum of tests that can be utilized throughout the rehabilitation course to assess various qualities and physical capacities:

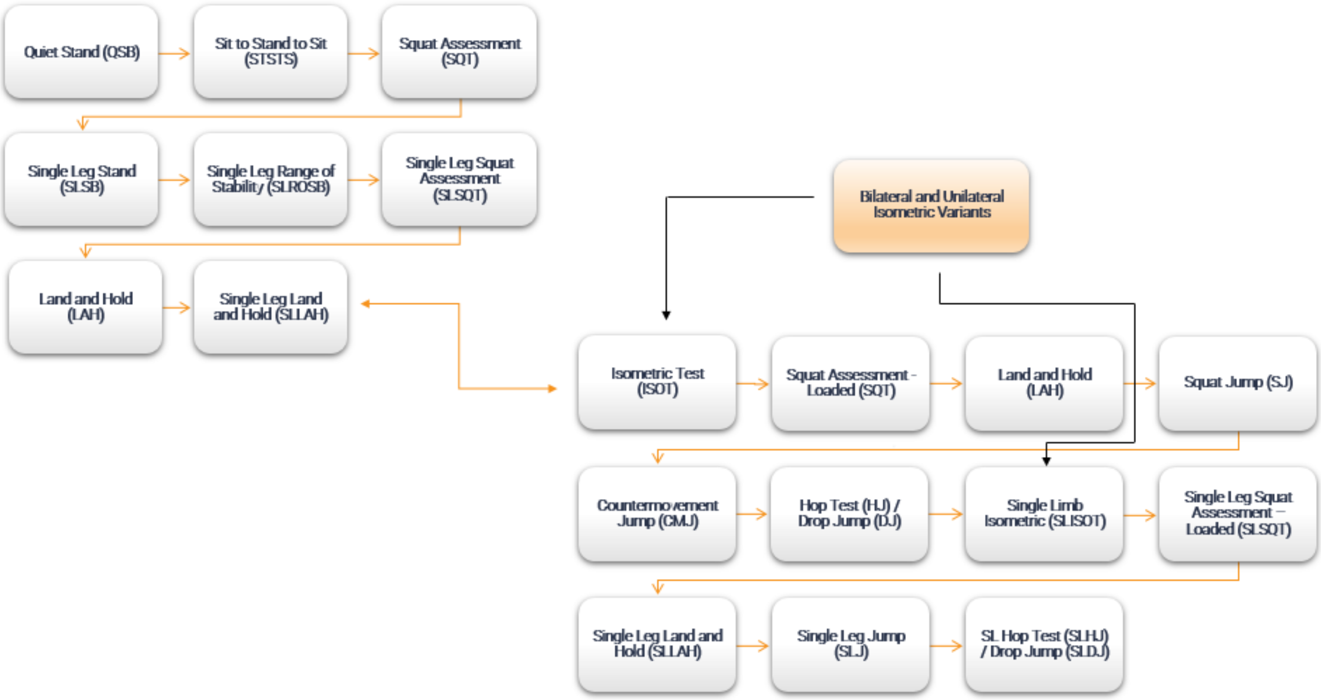


Figure 9. Example progression/regression framework, based on relative intensity/demand.

We can then zoom in further into the left side of that continuum, which at times can be referred to as the **'early phase'** of the spectrum (figure 10), where tasks are considered to be of relative low load/velocity, non-ballistic/low impact in nature. Task constraints/conditions can then be manipulated to either increase or decrease task demands, based on the subject's current function and capabilities.

If we were to take for example, a patient status post total knee arthroplasty (TKA), one may start early on within the rehabilitation process assessing static balance and weight distribution in standing with the Quiet Stand (QSB) test, and possibly measuring bilateral subphase force capacities and interlimb asymmetries with the Sit to Stand to Sit (STSTS) test. Once the patient demonstrates acceptable outputs and qualities within those initial tests, one might progress now into an unsupported bilateral Squat Assessment (SQT) and look to assess unilateral static and dynamic balance/stability with the Single Leg Stand (SLSB) and Single Leg Range of Stability (SLROSB) tests. The patient can then be progressed to a Single Leg Squat Assessment (SLSQT) to assess unilateral submaximal dynamic strength and range of movement asymmetry, along with landing force attenuation capabilities from progressively higher stair riser heights comparable to daily functional demands.

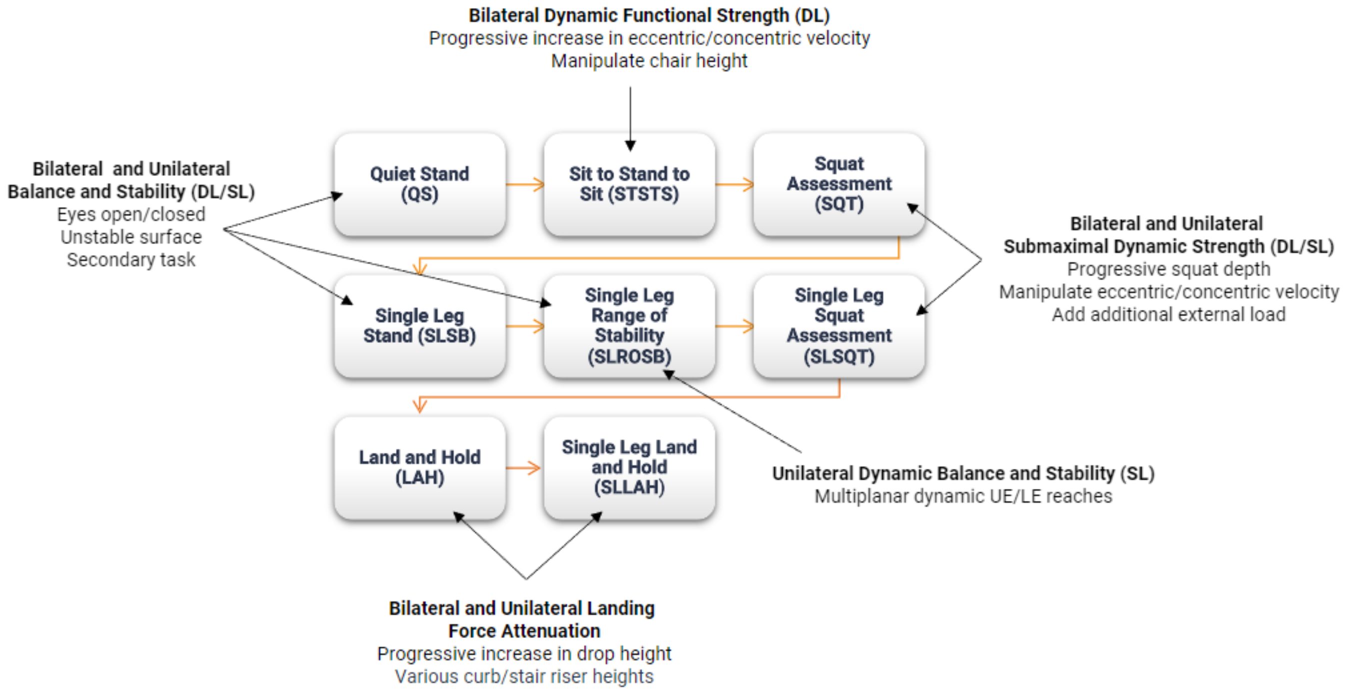


Figure 10. Example of 'early phase' objective testing progression/regression framework for the lower limb.

A similar approach can then be applied to the right side of the continuum, where we can zoom in and dissect the **'mid to late phase'** (Figure 11), where higher load demands are placed within the various tissues and systems. Following a similar approach to the 'early phase', pending preset goals and functional demands, emphasis can then be placed on a progressive increase in the demand of the stimuli, moving from a bilateral submaximal/maximal isometric strength test (ISOT), like the Isometric Squat (ISOSQT), all the way to a unilateral reactive strength-based test like the Single Leg Drop Jump (SLDJ). Various physical qualities and capacities can then be assessed from bilateral to unilateral tasks, manipulating task constrains to either increase or decrease task demand.

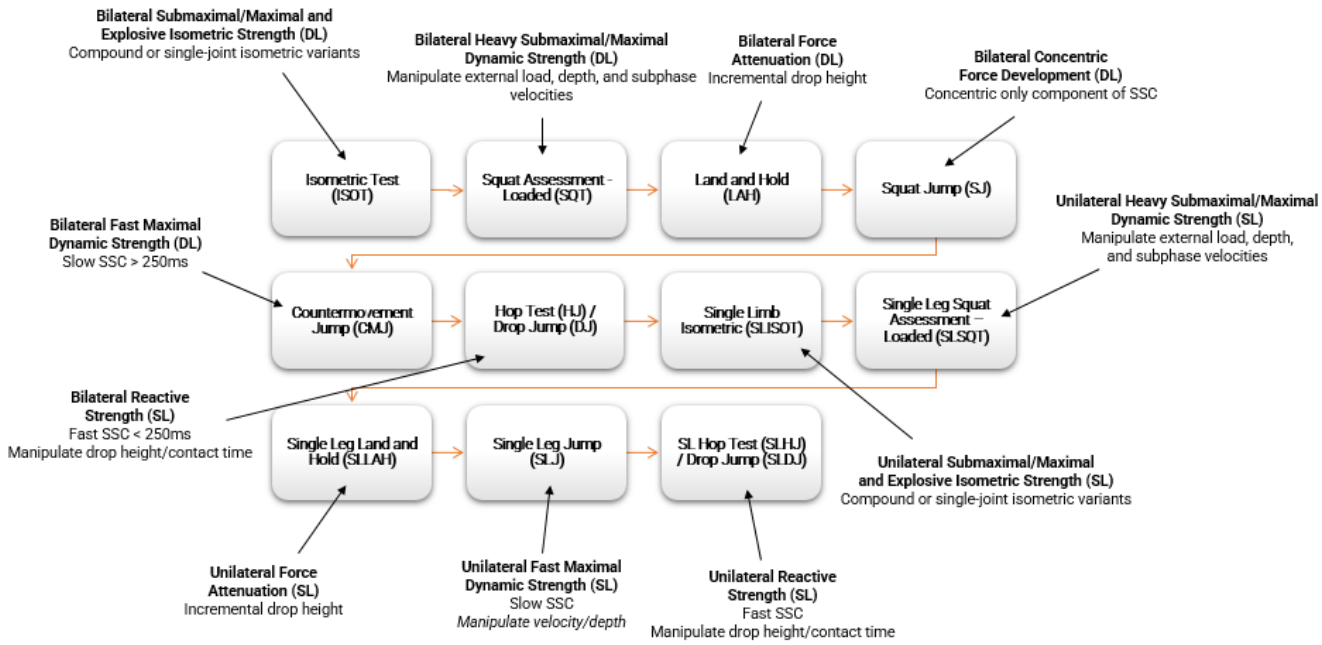


Figure 11. Example 'mid to late phase' objective testing progression/regression framework for the lower limb.

In a very simplistic manner, return to play testing can be disseminated into 4 'main' specific buckets of physical capacities or qualities (Figure 12), looking to guide and optimize programming and decision-making:

1. How strong are they?
2. How well can they absorb landing force?
3. How 'explosive'/dynamic are they?
4. How reactive/elastic are they?

In the absence of pre-injury data, the uninvolved limb should be monitored throughout the rehabilitation process (including from initial onset of injury), and both limbs should reach matched-control normative values (Kotsifaki, 2023).

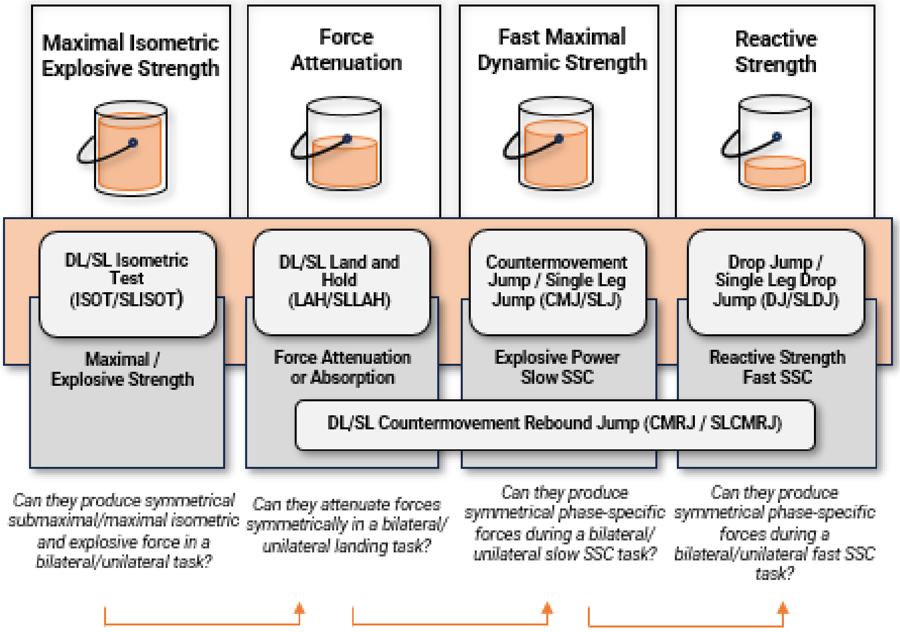


Figure 12. Physical qualities and capacities within the RTS/RTP process for the lower limb.

Lastly, the image below (Figure 13) is an example of **'mid-to-end stage'** testing after a medial meniscus knee injury looking at specific qualities and capacities as delineated above, including some possible 'key metrics' for initial analysis and interpretation:

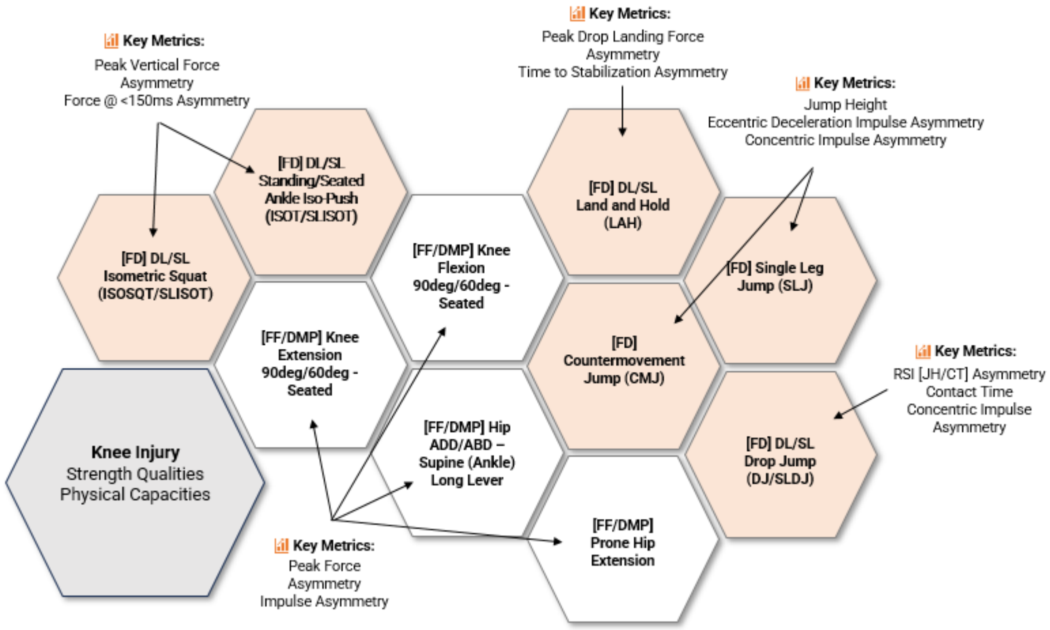


Figure 13. Example objective testing for RTP post 'knee injury'.

3.5 Monitoring

The body seeks to maintain a state of homeostasis and constantly aims to adapt to stress (physical and mental) from its environment (Soligard, 2016). Regular exercise and work challenge this homeostatic state and the use of ForceDecks provides a sophisticated solution to better understand the physical effects, within and between training bouts, i.e., examining the dose-response relationship. Choosing valid metrics that look at neuromuscular responses/fatigue, acute and chronic, are relevant when trying to understand over-reaching and over-training.

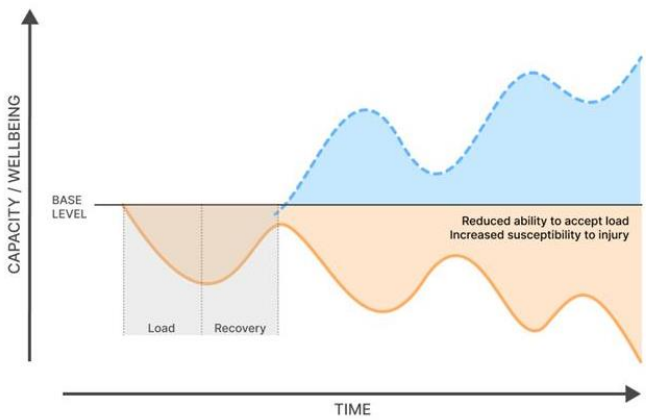


Figure 6. Biological maladaptation through cycles of excessive loading and/ or inadequate recovery *(Adapted from Soligard et al., 2016)*

The Supercompensation Theory (see Figure 6) is a phenomenon that explains how the body responds to stress (physical and mental), leading to improvements in performance over time. The theory suggests that after a period of training, the body undergoes a cycle of stress, fatigue, recovery, and if training is structured appropriately, Supercompensation occurs. Inappropriate training stimulus (too much, too often) can have the opposite effect and causes the individual to be more susceptible to loss of performance, and susceptible to injury and illness, as they have a reduced ability to recover/ return to homeostasis.

It's essential to tailor the monitoring approach to the individual's needs and goals, considering factors such as age, fitness level, and specific sport or activity. Regularly monitoring, reviewing, and adjusting programming is key to long-term success and avoiding potential issues related to overtraining or inadequate adaptation. Using the following guidelines below, practitioners can decide what and how to monitor physical responses to training, competition, and job demands.

3.5.1 Monitoring Training Adaptations

Purpose	Use comparable metrics, measured at specific timepoints to determine if: • The individual is improving • The exercise program is having the intended effect
Objectives	Perform reliable testing at logical timepoints to: • Measure changes in metrics directly related to the individual's goals • Determine level of progress relative to expected progress • Make decisions to tailor upcoming programs accordingly
Common tests	Tests that are easy to perform quickly and reliably to ensure compliance over time: • CMJ • SQT (Loaded) • ISOT
Frequency of testing	At least at the beginning and end of (and often at interim time points within) an exercise program or training block such as: • Start and end of preseason • Start and end of a 12-week training block • Start and end of an exercise intervention
Key considerations	• What are the individual's goals for the exercise program? • Is the exercise program likely to yield measurable results? • Which metrics can be measured that are most closely related to the Individual's goals?

Adaptation monitoring is quite different when compared to fatigue monitoring, as it proactively anticipates change, rather than waiting for and reacting to change. For this reason, adaptation monitoring typically involves less frequent testing – albeit still pre-planned – than fatigue monitoring. This application is commonly used in performance environments.

Turner et al. (2019) suggests that adaptations should be measured at the end of each training block or exercise program to assess whether the desired outcomes were achieved, and to confirm or adapt plans for the next program.

For example, consider an American Football Wide Receiver (a position requiring extreme speed, agility, and coordination) and an Offensive Lineman (a position requiring extreme strength and power). In this scenario, both individuals play the same sport, however positionally, they likely have significantly different goals.

The Lineman may need to be as maximally strong as possible, possess as much relative power as possible, and need to overcome a static start explosively. Meanwhile, the wide receiver may need to be powerful, fast, quick to accelerate and elastic, and all these metrics may need to be improved while minimizing weight gain.

Both Individuals will perform tests that assess common traits that both require, such as:

IMTP

CMJ

The Lineman will then perform tests tailored to the demands of their position, such as:

SQUAT JUMP

EXPLOSIVE PUSH UP

Likewise, the Receiver will perform different tests tailors to their position, such as:

DROP JUMP

SINGLE LEG JUMP

The purpose of this example is to explain the rationale that, while all tests have merit, tests need to be carefully selected for every individual, pathology, or person.

With initial data collected, a first block/ program of training can be constructed to target general and specific qualities that are relevant to the individual and their sport and job. At the end of the program, re-testing (along with other agreed performance measures) will allow the effectiveness of the program to be judged as successful or not.

For example, the Lineman could show poor Peak Vertical Force in the IMTP but good RFD at 100 ms, and high peak power in the CMJ and SJ. This, in turn, might help steer the next training block/ program towards strength development as the key performance indicator.

On the other hand, the receiver might have improved in all categories except elastic qualities as measured CMJ and DJ, and under further inspection, showed he gained body mass over the course of the program, which was considered a contributing factor. This case may suggest that a subsequent program target more plyometric training, while reducing body mass.

The overarching principle of adaptation monitoring is to allow assessment and adaptation to occur more quickly and reliably.

3.4.2 Monitoring Fatigue

Using ForceDecks, we can also measure the response to training, including fatigue. Most commonly, the CMJ and DJ have been used to assess athletic populations and provide insights into neuromuscular fatigue, focusing on explosive leg power and is considered relatable for high-speed running, jumping, and change of direction.

Monitoring fatigue typically requires frequent testing, and in turn, requires consistency and repeatability in testing procedures to ensure that any data collected is reliable enough to be acted upon. The following recommendations can be used to help ensure monitoring data is collected reliably:

1. Where possible, schedule testing for the same time of day (or as close to the same time of day as possible). This limits the effect that natural body/circadian rhythms have on both neural and hormonal outputs. Evidence suggests that, on average, outputs can be expected to be better in the afternoon than in the morning (Jordan, 2017; Bishop, 2022)

2. Review and "clean" your data and be willing to discard data that does not meet a satisfactory quality standard. Elements that can affect data quality can include incorrect bodyweight measurements, unstable periods prior to start of movement and sub-maximal efforts in maximal tests. These elements can lead to inaccurate dependent metrics, such as contraction time, flight time and displacement which can in turn drastically alter means, CVs, and SDs (Stone, 2019; Cohen, 2020)

3. Apply a consistent statistical method that suits the data you collect. This may involve always using the mean of a certain number of trials and applying the Smallest Worthwhile Change, Standard Deviation change, or another pre-set threshold considered to be important (Gorard, 2015; Bailey, 2019; Wing, 2018).

Overall, time-based metrics are more sensitive to change (and therefore more suitable for fatigue monitoring) than outcome-based metrics [citation]. Below are brief example summaries of commonly used time-based CMJ metrics that have been shown to be useful in fatigue monitoring:

a. <u>Flight Time: Contraction Time (FT:CT</u>) – FT:CT is a commonly-used assessment ratio for monitoring neuromuscular fatigue, originally popularized in Australian Rules Football (Cormack, 2008). Subsequent research has supported these conclusions for FT:CT (Gathercole R. S., 2015) along with other duration-based metrics such as RSImod (Martinez, 2016). Common logic suggests this may be due to metrics such as Flight Time (or Jump Height) typically being more stable than the time it takes to jump (Contraction Time). Therefore, while Jump Height is a very reliable and stable measure, FT:CT may provide a more sensitive measure of change, due to fluctuations in Contraction Time.

b. <u>Eccentric Duration</u> – Another time-based measure, Eccentric Duration is the time spent in the Eccentric Phase of the jump (this phase is also referred to as "Unweighting Phase" plus "Braking Phase" in some literature (McMahon, 2018). This is another metric shown by Gathercole to be a sensitive measure of Neuromuscular Fatigue (Gathercole R. S., 2015; Gathercole R. J., 2015), which follows logic given that Eccentric Duration makes up a portion of Contraction Time (discussed above), again suggesting that a lengthening of time may indicate the presence of neuromuscular fatigue.

While many other metrics can also be used in a fatigue monitoring program, the metrics discussed above are some of the most-used and most-supported by research.

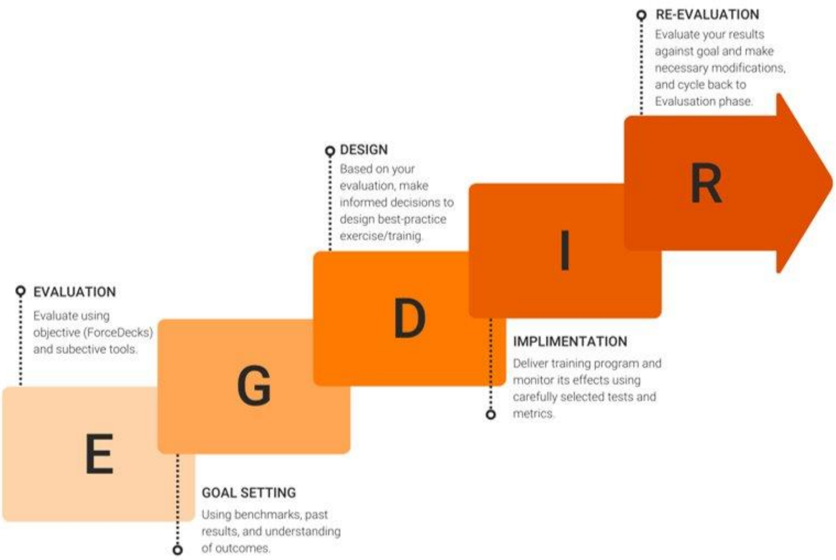
Jump Height is also a useful indicator of fatigue, and can be an easy variable to collect, i.e., using a jump mat (despite their limitations in measurement) (Whitmer, 2015). However, the reliability of Jump Height must not be confused with sensitivity. While decrements in Jump Height are likely indicators of fatigue, and is a very reliable measure, it may also be less sensitive to change than some time-based measures. This means that a decrease in Jump Height may happen later than some of the time-based metrics discussed above (RSImod, FT:CT, ECC Duration) making it less suitable for fatigue monitoring (Cormack, 2008).

As our industry of exercise science evolves and becomes more analytics-driven, many organizations now employ dedicated data analysts, data scientists, and machine learning specialists, for the purposes of performing significantly more robust analysis than has been common in the past. It is highly likely that, as these professions develop, more and more metrics will be proven (and perhaps disproven) as being valuable in contexts such as fatigue monitoring.

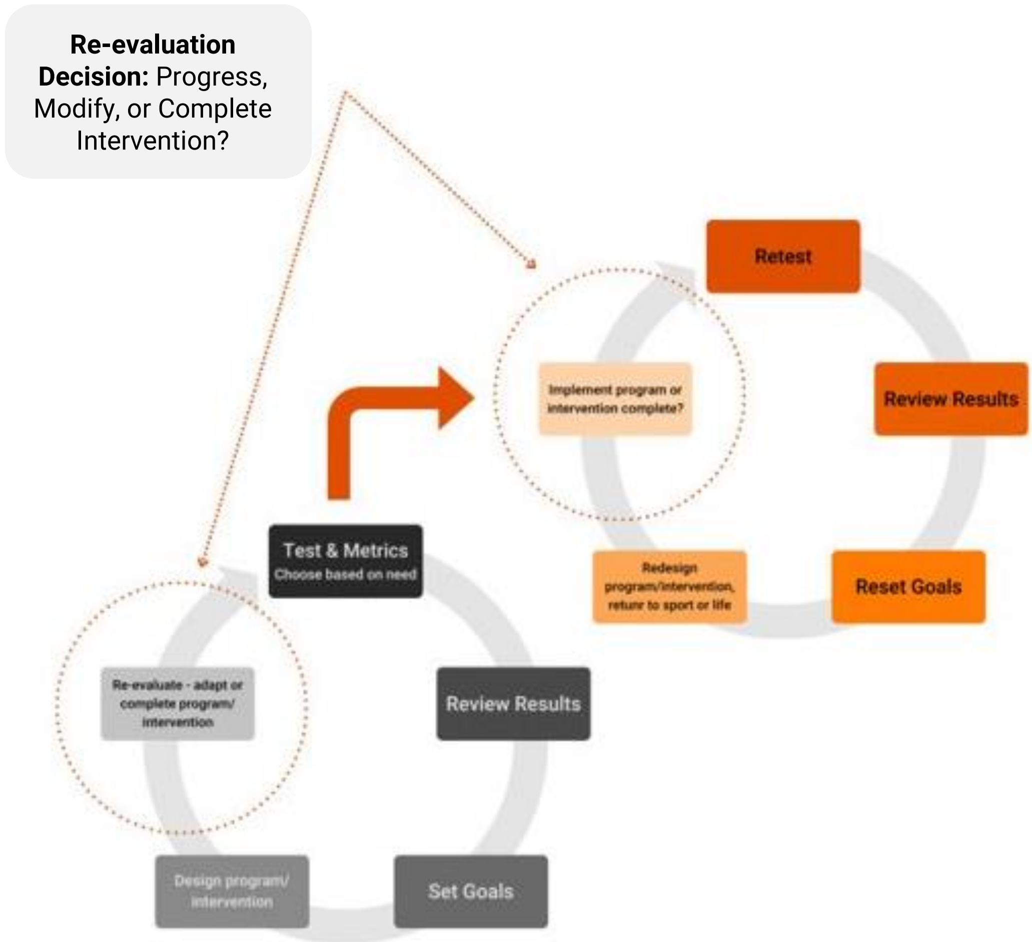
Purpose	Use comparable metrics, measured over time to determine if: • The individual is fatigued • This fatigue poses a risk • A program modification might be appropriate (if any)
Objectives	Perform regular testing to provide results that are: • Reliable • Sensitive to fatigue • Support informed decision making through targeted interventions
Common Tests	Tests that are easy to perform quickly and reliably to ensure compliance over time: • CMJ • SJ • DJ • ISOT
Frequency of Testing	As often as possible when fatigue is an important consideration, at consistent time points, such as: • Every week, 48 hours after competition • Twice per week, once 48 hours after competition and once 24 hours before competition • Every weekday, when first arriving at training • At the start of each appointment
Key Considerations	• Are the metrics being measured sensitive to fatigue? • If so, are they being measured at consistent times, with the individual in consistent states of fatigue, that will show if the performance is different from typical results? • If the results are different, is it feasible to modify the training program to account for the fatigue and prevent injury or other issues from occurring?

3.6 Re-evaluate Progress or Completion of Intervention?

The value of assessing the responses to exercise/training and rehabilitation lies in the ability to use valid and reliable data to effectively manipulate future training bouts [8]. The success of a program is likely to be the highest with the use of minimally invasive tools and without requiring a specific session devoted to data collection.



Whether it be Performance or Health environments, it is recommended that practitioners use a combination of objective and subjective information to formulate their action-plan. In doing so, all stakeholders can be better informed, while communicating with confidence that their intervention(s), individual and collectively, has best practice impact for the athlete/client/worker



Glossary

Force plate terminology can be confusing, so we have compiled an alphabetical glossary of terms you'll see commonly used both in this guide and in other force plate literature.

Term	Definition
Asymmetry	Inequality or imbalance between left and right. In reference to force plate testing, asymmetry refers to the difference in output or strategy between left and right limbs.
Auto-Analysis	ForceDecks software uses algorithms to "Auto-Analyze" results immediately after a repetition and/or test is completed. This means that after a rep or test is completed, up to 200 summary metrics are calculated and displayed immediately and automatically, without requiring any further post-processing or analysis work from the user.
Auto-Detection	ForceDecks software uses algorithms to "Auto-Detect" what type of movement is being performed, as well as when it starts and ends. This means that ForceDecks can detect a movement, highlight it on-screen and categorize it as the correct type of movement (e.g., CMJ, DJ, ISOT), all without any manual input from the user. Most (but not all) tests that can be Auto-Analyzed can be Auto-Detected.
Biofeedback	A process whereby electronic monitoring of a normally internalized bodily function (such as the expression of force) is used to provide real time or near-real time feedback on performance. Biofeedback is typically used to train the subject to improve their understanding - and subsequently their performance - of that function/movement.
Centre of Mass (CoM)	The precise point within the pelvic/torso region at which an applied force will move the body in a linear direction without creating any rotation movement. This point is generally located between the naval and the sacrum. It is often used as a reference for vertical jump height and squat depth changes in biomechanics.
Concentric (CON)	Describes a muscle contraction that produces force as it shortens, during either flexion or extension of a specific joint. In terms of jump analysis, the concentric phase represents the time period between the lowest point of the CoM depth and take off from the force plates. This is the upward phase or triple extension component of a jump.
Contact Time	The time spent in contact with the force plates during a rapid single jump after landing or a repeat jump test (measures each contact individually). The most prominent examples are the Drop Jump and Hop Tests, respectively.
Contraction Time (CT)	Total measured time from the Start of Movement until Takeoff. For a movement such as a Countermovement Jump, this encapsulates both eccentric and concentric phases.
Countermovement	The downward movement of the body performed in preparation for a vertical jump. The intention of this initial movement is to accelerate the body mass downward and use eccentric muscle force to decelerate the body, thus generating elastic potential for the jump.
Derivative	A number (or Metric) based on the calculations from other such numbers. In the context of force plate analysis, Force and Time are used as the basis for calculating a range of different derivates such as power, velocity, displacement (height) and impulse.
Drop Landing	In a Drop Jump, this is the first landing impact on the force plates after the drop, prior to jumping.
Eccentric (ECC)	Describes a muscle contraction that produces force as it lengthens, during either flexion or extension of a specific joint. In terms of jump analysis, the eccentric phase represents the time between the start of the movement and the lowest point of the CoM depth. This is the downward phase that generates/builds elastic energy for use during the concentric phase (i.e.: stretch shorten cycle).
Elastic	Ability to rapidly resume the original state spontaneously after contraction.

Flight Time (FT)	Total measured time spent in the Flight Phase (time from Takeoff until Landing).
Flight Time: Contraction Time (FT:CT)	A simple ratio of jump performance to preparation time needed. In a sporting context, it is desirable for an individual to achieve significant vertical jump performance (i.e.: elevated flight time, power output, and peak velocity) with the least amount of time required. Increases in this ratio are due to improved jump ability and/or reduced preparation time (defined as from start of movement to take off).
Force: Velocity (F:V) Profile	A comparative, multi-stage jump testing protocol intended to determine if an individual is more proficient in force production or movement velocity. Several loads are used, (based on a specific weight (20kg, 40kg etc.), a % of body weight or %'s of 1RM), and a maximal CMJ is performed with each. Results are calculated and can be compared to ideal power output equations using participant biometrics.
Impulse (Imp)	The action of a force over a period which leads to a change in momentum (velocity) of the individual. Impulse reflects the area under the Force-time curve. ForceDecks splits impulse into phases such as braking, deceleration, concentric denoting the effect of the force application in different phases of jumps.
Isometric (ISO)	Related to or having no change in muscle-tendon length or joint angles during force production. This is achieved by maintaining the exact position of involved joints at the onset of contraction until the end of the repetition. Common tests include the Isometric Squat, IMTP, the ASH Test, and numerous hamstring variations.
Jump Height	The net displacement of the CoM from the instant of take-off to the peak displacement (as a result of the net concentric impulse generated on the ForceDecks in the preceding movement). This can be measured from impulse-momentum equations or from flight time.
Key Moment	A single key time point within a movement. E.g., Start of Movement.
Load	Amount of force applied to the individual and their bodily structures. Can also refer to the 'additional' load in the form of extra weights on a bar for loaded jumps.
Load: Velocity Profile	A comparative, multi-stage testing protocol intended to determine the ideal external load for producing peak performance in one or more metrics. One common example is performing a Squat Assessment using different weights to identify CON Peak Power and Velocity.
Neuromuscular Fatigue	Any (usually but not exclusively exercise-induced) decrease in a muscle's ability to develop force or power.
Phase	A period of movement within a test, typically bound by 2 key moments (e.g.: Eccentric Phase).
Pre-Tension	The amount of force applied to a bar (or other immovable setup) prior to a maximum effort isometric test. Pre-tension is intended to remove elastic give from key body segments, thus creating a truly isometric testing condition and safely preparing the individual for larger amounts of force production.
Profiling	The recording and analysis of a person's neuromuscular characteristics, for the purpose of categorizing or triaging. In large cohorts, profiling is typically done to assist with grouping similar subjects together to streamline exercise programming or treatments.
Rate of Force Development (RFD)	The change in force applied as a function of time (i.e.: N/s). This can be 'instantaneous' (I.e., every 0.001s for a 1000Hz sample frequency), or 'average' (between specific key moments within a movement, e.g., SoM to peak force).
Reactive Strength Index (RSI)	A commonly used Drop Jump metric, RSI is Flight Time divided by Contact Time.
Reactive Strength Index Modified (RSImod)	A commonly used Countermovement Jump metric, RSImod is Jump Height divided by Contraction Time.
Return to Play (RTP)	The process of returning to play/compete a given sport or exercise after injury.

Stable Period	The baseline BW readings immediately prior to the onset of movement
Start of Integration (SoI)	Key moment at which Force and Time begin being calculated together to produce new “derivatives” or metrics such as displacement or power.
Start of Movement (SoM)	Key moment where the individual begins to move. In ForceDecks, for the CMJ, this is a 20N threshold change from bodyweight.
Stiffness	The extent to which an object resists deformation (such as muscle lengthening) in response to an applied force, calculated by Peak Force / displacement.
Strategy	In the context of this manual – strategy refers to the idiosyncratic way in which an individual completes a task (jump/isometric/squat). For example, a subject’s strategy in a CMJ may be to consistently exhibit a long eccentric phase with large asymmetry.
Stretch Shorten Cycle (SSC)	A muscle action where active muscle lengthening is immediately followed by active muscle shortening (e.g., demonstrated in a countermovement jump but not in a squat jump)
System Weight	Depending on the test being performed, system weight is the total weight of the subject, partial subject and/or any additional load that will be directly on the force plate/s during a test. For example: • For a CMJ, system weight is simply the individual’s bodyweight; • For a Loaded Squat Assessment, system weight is the individual’s bodyweight, plus, the external load they are holding/carrying; or • For a Single Limb Isometric Test where part of the individual will rest on the floor (i.e., not on the force plates), such as a posterior chain or shoulder I/Y/T isometric test, system weight is the weight of the individual’s limb* *While precise bodyweight measurements are critical for jumping tests, precise measurements for limb weights in Single Limb Isometric Tests are less critical, as these tests typically rely less on relative force measurements and more on absolute force measurements.
Test	For the purposes of this document, “test” refers to a single ForceDecks test recording, of a single test type, which may involve one or more trials.
Test Type	For the purposes of this document a “test type” is a single type of movement, able to be auto analyzed by ForceDecks software. For example, CMJ, DJ and SQT are all test types.
Time Series	Sequence of data taken in equally spaced points in time. ForceDecks collects time series data on force, at a default sampling rate of 1,000 Hz (samples per second).
Trial	Synonymous with “rep” or “repetition”, a trial is one rep of a test.
Triple Extension	The actions that describe the proximal to distal sequencing of joint movements across the ankle, knee, and hip joints during the CON phase of a jump. Although the ankle is technically performing plantar flexion, it assists in raising the CoM upward just as knee and hip extension do. The term expresses these three coordinated joint actions in displacing the body away from the ground.
Zeroing	To “Zero” a force plate (also known as “taring”) means to reset the point of zero weight. Zeroing is used to cancel out any errors in starting measurement, which may be introduced by factors such as the weight of the force plates themselves, any external fixings, and/or any sensor drift over time. For example, if you have a force plate that registers 2kg despite having no weight applied, performing a test could be expected to produce downstream measurement and calculation errors. Zeroing the platform will perform an offset, adjusting the starting reading to 0kg and in turn ensuring that downstream data is more accurate.

References

Atkinson, G. &. (1996). Circadian Variation in Sports Performance. *Sports Med, 21*, 292-312.

Bailey, C. (2019). Longitudinal Monitoring of Athletes: Statistical Issues and Best Practices. *Journal of Science in Sport and Exercise, 1*(3), 217-227.

Bishop, C. T. (2022). A framework to guide practitioners for selecting metrics during the countermovement and drop jump tests. *Strength & Conditioning Journal, 44*(4), 95-103.

Bourreau, P. Y. (2015). Circadian Rhythm in Heart Rate Variability Contributes to the Increased Cardia Sympathovagal Response to Awakening in the Morning. *Chronobiology International* , 1-12.

Chassé, E. T.-B. (2019). Factors affecting performance on an army urban operation casualty evacuation for male and female soldiers. *Military Medicine, 184*, 11-12. doi:e856-e862

Chia, L. T. (2022). Beginning With the End in Mind: Implementing Backward Design to Improve Sports Injury Rehabilitation Practices. *journal of orthopaedic & sports physical therapy, 52*(12), 770-776.

Cohen, D. D.-S. (2020). Single v double leg countermovement jump tests; not half an apple. *Aspetar Sports Med Journal, 9*, 34-41.

Cormack, S. J. (2008). Neuromuscular and endocrine responses of elite players during an Australian rules football season. *International journal of sports physiology and performance, 3*(4), 439-453.

Coutts, A. &. (2015). Monitoring training load. In *Sports Injury Prevention and Rehabilitation: Integrating Medicine and Science for Performance Solutions* (pp. 380 -391). Routledge.

Eagle, S. R. (2019). Bilateral strength asymmetries and unilateral strength imbalance: predicting ankle injury when considered with higher body mass in US special forces. *Journal of athletic training, 54*(5), 497 - 504.

Ekizos, A. &. (2023, June 12th). Biofeedback-based return to sport: individualization through objective assessments, 14, 1185556. *Frontiers in Physiology, 14*, 1185556.

Gathercole, R. J. (2015). Effect of Acute Fatigue and Training Adaptation on Countermovement Jump Performance in Elite Snowboard Cross Athletes. *J Strength Cond Res, 29*, 37-46.

Gathercole, R. S. (2015). Alternative Countermovement-Jump Analysis to Quantify Acute Neuromuscular Fatigue. *International Journal of Sports Physiology and Performance*(10), 84–92.

Gorard, S. (2015). Introducing the mean absolute deviation ‘effect’size, . *International Journal of Research & Method in Education, 38*(2), 105-114.

Hart, L. M. (2019). Previous injury is associated with heightened countermovement jump force-time asymmetries in professional soccer players. *Translational Sports Medicine, 2*(5), 256.

Haugen, T. &. (2016). Sprint running performance monitoring: methodological and practical considerations. Sports Medicine. (46), 641-656.

Helme, M. T. (2021). Does lower-limb asymmetry increase injury risk in sport? A systematic review. *Physical Therapy in Sport, 49*, 204-213.

Henry, F. M. (1967). “Best” versus “average” individual scores. Research Quarterly. *American Association for Health, Physical Education and Recreation, 38*(2), 317-320.

Hewit, J. C. (2012). Multidirectional leg asymmetry assessment in sport. *Strength & Conditioning Journal, 34*(1), 82-86.

Issurin, V. B. (2010). New Horizons for the Methodology and Physiology of Training Periodization. *Sports Medicine, 40*, 189-206.

James, L. P. (2023). Strength Classification and Diagnosis: Not All Strength Is Created Equal. *Strength and Conditioning Journal, 45*(3), 333-341.

Jordan, M. J. (2017). Asymmetry and thigh muscle coactivity in fatigued anterior cruciate ligament–reconstructed elite skiers. *Medicine & Science in Sports & Exercise, 49*(1), 11-20.

Joyce, D. &. (2015). *The injury risk profiling process. In Sports Injury Prevention and Rehabilitation .* London: Routledge.

Knezevic, O. M. (2014). Asymmetries in explosive strength following anterior cruciate ligament reconstruction. *The Knee, 21*(6), 1039-1045.

Kotsifaki, R. S. (2023). Performance and symmetry measures during vertical jump testing at return to sport after ACL reconstruction. *British Journal of Sports Medicine*, 1.

Kotsifaki, R. S. (2023, June). Performance and symmetry measures during vertical jump testing at return to sport after ACL reconstruction. *British Journal of Sports Medicine, 0*, 1-8. doi:10.1136/bjsports-2022-

106588

Kraska, J. M. (2009). Relationship between strength characteristics and unweighted and weighted vertical jump height. *International journal of sports physiology and performance, 4*(4), 461-473.

Martinez, D. (2016). FROM THE FIELD - DIRECTED TOPIC | THE USE OF REACTIVE STRENGTH INDEX, REACTIVE STRENGTH INDEX MODIFIED, AND FLIGHT TIME: CONTRACTION TIME AS MONITORING TOOLS. *Journal of Australian Strength and Conditioning* , 1-83.

McGuigan, M. (2014). *Evaluating athletic capacities. High-performance training for sports.* United States: Human Kinetics.

McMahon, J. J. (2018). Understanding the Key Phases of the Countermovement Jump Force-Time Curve. *Strength and Conditioning Journal, 40*(1), 96-106.

Mujika, I. H. (2018). An integrated, multifactorial approach to periodization for optimal performance in individual and team sports. *International journal of sports physiology and performance, 13*(5), 538-561.

Rebelo-Marques, A. A.-M. (2019). Return to Play (RTP). *The Sports Medicine Physician*, 149-169.

Sheppard, J. M.-N. (2021). Performance diagnostics. In Strength and Conditioning for Sports Performance. 208-221.

Soligard, T. S. (2016). How much is too much? (Part 1) International Olympic Committee consensus statement on load in sport and risk of injury. *British journal of sports medicine*, 1030-1041.

Stone, M. H. (2019). The use of the isometric mid-thigh pull in the monitoring of weightlifters: 25+ years of experience. UKSCA Journal: Professional Strength and Conditi. *UKSCA Journal: Professional Strength and Conditioning*, 10-15.

Taberner, M. V. (2020). Physical preparation and return to performance of an elite female football player following ACL reconstruction: a journey to the FIFA Women's World Cup. *BMJ Open Sport & Exercise Medicine, 6*(1), e000843.

Thun, E. B. (2015, October). Sleep, circadian rhythms, and athletic performance. *Sleep Med Review, 23*, 1-9. doi:10.1016

Turner, A. N. (2019). Total score of athleticism: Holistic athlete profiling to enhance decision-making. *Strength & Conditioning Journal, 41*(6), 91-101.

VALD. (2023). *VALD Performance*. Retrieved from https://valdperformance.com/forceDecks/

Whitmer, T. D. (2015). Accuracy of a vertical jump contact mat for determining jump height and flight time. *The Journal of Strength & Conditioning Research, 29*(4), 877-881.

Whitmer, T. D. (2015). Accuracy of a vertical jump contact mat for determining jump height and flight time. *The Journal of Strength & Conditioning Research, 29*(4), 877-881.

Wing, C. (2018). Monitoring athlete load: Data collection methods and practical recommendationsl. *Strength & Conditioning Journal, 40*(4), 26-39.

Zarrouk, N. C. (2012). Time of day effects on repeated sprint ability. *International journal of sports medicine*, 975-980.

Appendices

A. Asymmetries

1. Magnitude of Asymmetry

Magnitude simply refers to the size of an observed asymmetry, without consideration for the direction of asymmetry. At 0% asymmetry for a given metric, it could be safely assumed that the individual is not favoring one limb over the contralateral limb. However, if magnitude of asymmetry is greater than 0%, further consideration of whether an asymmetry is problematic or not, is far less clear-cut. A typical asymmetry for a cohort is unlikely to be indicative of all the populations, and therefore, results must be interpreted with caution.

In large, diverse organizations, cross-disciplinary analysis can help create magnitude rating systems, such as ranking asymmetry ranges from low to moderate to high concern. However, this is not possible in all organizations, and some practitioners must instead rely on intra-subject asymmetry monitoring alone.

2. Change in Magnitude of Asymmetry

Changes in asymmetry can be a powerful factor to monitor, given that asymmetry may be influenced by fatigue and/or ongoing adaptations to physical stimulus. Consider an individual who typically averages 10% asymmetry for a given test and selected metrics. The same individual is tested the day after heavy exercise or a demanding working day, registering a 25% asymmetry for the same tests and metrics. This might suggest that when in a fatigued state, the individual’s asymmetry is magnified and may be interpreted as the individual is at an increased risk of injury. Therefore, timing of testing needs to be carefully considered.

Similarly, changes in magnitude over time can help identify improvements or warn practitioners of a developing problem. For example, if an individual displays a 5% asymmetry on day 1 of testing (multi-day/high frequency testing) and the magnitude of asymmetry is amplified as days pass, this may indicate an issue is developing. Conversely, if a client recovering from ACL reconstruction begins their rehabilitation at 40% asymmetry, but consistently reduces this asymmetry over time, this may indicate positive progress.

Often, these changes are imperceptible to the individual. However, using dual force plate measurement, we can identify changes magnitude and intervene earlier than would otherwise be possible with subjective analysis only.

3. Influence of Previous Injury on Asymmetry

Following an injury, movement mechanics and force production capacity may be altered immediately (i.e., acute responses), leading to obvious asymmetries in many metrics.

Further, the effects of an injury may go on to affect an individual’s asymmetry indefinitely (i.e., chronic adaptations). Depending on the chronic nature of the injury, there may be limits with the amount of improvement possible. Examples of this are observed commonly following severe injuries such as ACL rupture.

In general, an asymmetry analysis should consider how previous setbacks may still affect the individual and how that may change the goals of their exercise program.

4. **Sport/Occupation/Life Stressors**

Aside from injury events and/or the influence of chronic overuse, asymmetries can also develop naturally in response to repetitive actions and may not necessarily be cause for concern. Take for example, a Tennis player exhibits significant asymmetries due to the physical demands of repetitive training and playing where forces are constantly being channeled through their dominant side, whereas road cyclists and weightlifters move more symmetrically. While a Tennis player shows substantial asymmetries between their arm used for a forehand shot, linking to their back, hip, and leg, this does not necessarily mean that they will experience injuries, as there are multiple factors that influence the player's response. Cormack and Coutts (2015) argue that the practitioner needs to consider the combination of physiological and psychological traits and issues related to the specifics of the player's training and competition environment, and not focus on the test alone. Therefore, if the tennis player is generally healthy - physically, mentally, and emotionally, and their magnitudes of asymmetry do not fluctuate greatly over time with good management, any asymmetry can be deemed within acceptable limits,

5. **Consistency of Inter-Phase Asymmetries**

Asymmetries can occur within any given metric, whether it is a singular point (e.g., peak takeoff force), a value of force over time (e.g.: eccentric braking impulse), or a rate of force applied (e.g., eccentric deceleration rate of force development).

To thoroughly understand asymmetries, it is important to analyze an entire movement, looking for similarities and differences across phases and/or key moments. For example, consider the three major phases of the CMJ test:

- Eccentric;
- Concentric; and
- Landing.

It is common for an individual to exhibit minimal or no asymmetry in one or more phases (e.g., concentric phase), while showing significant asymmetry in other phase/s (e.g., eccentric and landing phases).

Such a phenomenon may be explained by several different factors. For example, the individual may be subconsciously "protecting" one limb from:

- *Rapid movements* (which may manifest in RFD and peak force asymmetry metrics); and/or
- *Heavy loading* (which may manifest in higher average force or impulse asymmetries).

In either case, the specific phase or variable can provide significant insights for the practitioner about asymmetries while their athlete/client, or staff member executes a movement.

6. **Consistency of Inter-Trial Asymmetries**

Performing several repetitions of a jump or movement often yields asymmetry results of significantly different magnitudes and directions.

For example, consider someone who performs 5 Drop Jump (DJ) tests and registers a consistent asymmetry of 15% right-dominance across a variety of metrics and phases. Although this might not be cause for concern in isolation, the fact that the individual consistently stresses one limb more than the other may warrant greater investigation.

Conversely, compare this to someone else who performs the same test and has similar results (e.g., average jump height and RSI). These individual exhibits asymmetries that vary between 2% - 40%, randomly alternating between left and right sides. Although peak asymmetry magnitudes appear higher on this occasion, average relative asymmetry (i.e., factoring in direction of imbalance) may be closer to 0%.

This large variance may be completely normal, resulting from variations in movement strategies (e.g., poor jump technique) from trial to trial, suggesting the participant might be comfortable in accepting load and producing force on both limbs equally. Therefore, while these results seem highly variable, this client's performance profile might be protective, showing they may be well-prepared to tolerate variable loading on both limbs.