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THE BASICS OF THE 3 ASSESSMENT JUMPS

//_SQUAT JUMP
//_COUNTERMOVEMENT JUMP
//_DROP JUMP

TABLE OF **CONTENTS**

INTRODUCTION 3

SQUAT JUMP 4
- What is the Squat Jump (SJ) test? 4
- Application of the SJ 4
- How do you perform the SJ test? 5
- Required equipment 5
- Testing procedure 5
- The process for conducting an SJ test 6
- Tips to effectively improve execution 6
- The SJ phases 6
- How do you assess SJ performance? 7
- Factors to keep in mind before conducting the SJ test 8
- Is the Squat Jump test valid and reliable? 8

COUNTERMOVEMENT JUMP 9
- What is a Countermovement Jump (CMJ) test? 9
- Application of the CMJ Jump 9
- How do you perform the CMJ test? 10
- Essential equipment for the CMJ test 10
- Setting up the test 10
- Conducting the test 10
- Tips that could improve execution and monitoring 10
- The CMJ key phases 11
- How do you assess CMJ performance? 12
- Factors to evaluate before utilizing the CMJ test 15
- CMJ test validity and reliability 16

DROP JUMP 17
- What is a Drop Jump (DJ) test 17
- Application of the DJ 17
- How do you perform the Dj test? 18
- Challenges in DJ testing 18
- How do you assess DJ performance? 20
- Factors to keep in mind before conducting the Drop Jump test 22
- DJ test validity and reliability 22
- Factors affecting validity and reliability 23

REFERENCES 24

INTRODUCTION

The Squat Jump (SJ), Countermovement Jump (CMJ), and Drop Jump (DJ) are foundational exercises within the realm of sports science, strength and conditioning, as well as athletic training. These exercises not only serve as benchmarks for assessing an athlete's explosive power, lower body strength, and plyometric ability, but also as integral components of training programs aimed at enhancing sports performance. This introduction delves into the essence, biomechanics, and applicative significance of these jumps, shedding light on why they are pivotal for athletes across a spectrum of disciplines.

Squat Jump (SJ): The Squat Jump is a pure measure of lower-body strength and explosive power. Starting from a static, semi-squat position, the athlete explodes upwards with full force, striving for maximum vertical lift off the ground. Unlike the Countermovement Jump, the Squat Jump does not involve a preliminary downward movement or "countermovement," hence isolating the concentric phase of the jump. This specificity makes the Squat Jump an excellent tool for assessing the raw power output of an athlete's lower body without the influence of stretch-shortening cycle (SSC) efficiency.

Countermovement Jump (CMJ): In contrast to the Squat Jump, the Countermovement Jump begins with the athlete standing upright, followed by a rapid downward squatting motion before immediately transitioning into an explosive jump. The CMJ exploits the SSC, a physiological phenomenon where a pre-stretch or countermovement leads to a stronger concentric action. This jump is indicative of an athlete's ability to effectively utilize elastic energy stored during the eccentric phase for a more powerful concentric phase, making it highly relevant for sports requiring quick, explosive movements from a standing position.

Drop Jump (DJ): The Drop Jump is a plyometric exercise designed to improve reactive strength and efficiency in utilizing the SSC. Starting from a raised platform, the athlete steps off, lands with both feet, and immediately jumps vertically with minimal ground contact time. The height of the jump and the speed of the movement are key metrics in assessing plyometric ability and neuromuscular efficiency. The Drop Jump is particularly valued for its ability to enhance sports performance through improved ground reaction force, coordination, and the development of fast-twitch muscle fibers.

These jumps are crucial for performance diagnostics and guiding coaches in improving power output. By understanding an athlete's baseline in each jump, coaches can design programs to address weaknesses, optimize strengths, and improve sports-specific performance. For instance, an athlete with a strong Squat Jump but weaker CMJ might focus on improving SSC efficiency. Conversely, an athlete aiming to enhance reactive strength for quick, multi-directional movements might train with Drop Jumps. Through careful assessment and targeted training, these jumps can significantly enhance power, agility, and overall athletic ability, making them essential for sporting excellence.

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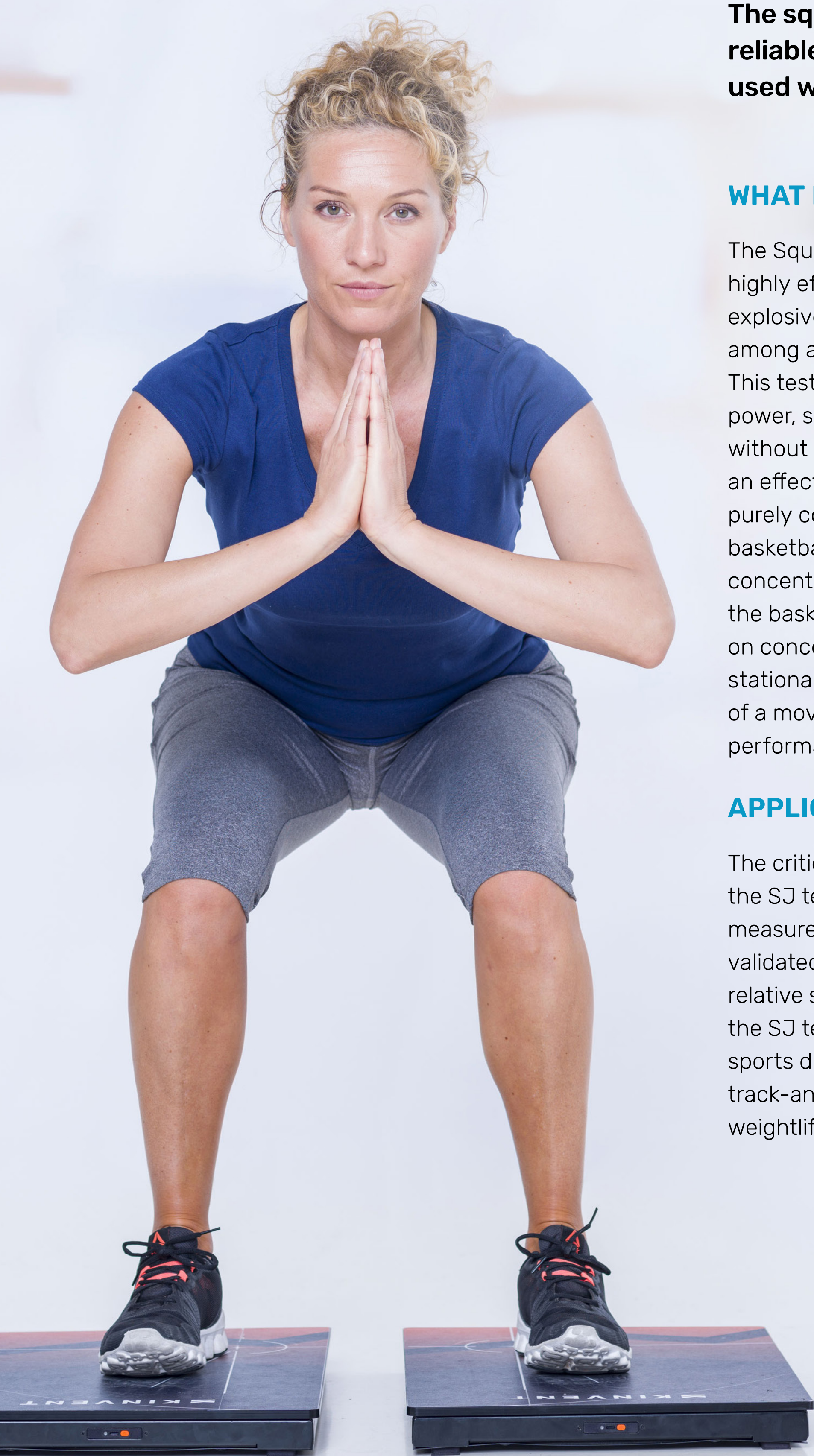


SQUAT JUMP

The squat jump is a simple, practical and very reliable measure of lower-body power, and is used widely by coaches and sports scientists.

WHAT IS THE SQUAT JUMP (SJ) TEST?

The Squat Jump (SJ) emerges as a fundamental, yet highly effective metric for evaluating the lower body's explosive capabilities, holding substantial credibility among athletic coaches and sports science practitioners. This test is important in gauging an athlete's explosive power, specifically their speed-strength capacity without a pre stretch. The Squat Jump test serves as an effective means to assess force application that is purely concentric in nature. Consider this scenario: a basketball power forward employs both eccentric and concentric movements to leap for a rebound beneath the basket, whereas an offensive lineman primarily relies on concentric muscle actions to launch forward from a stationary position. By eliminating the eccentric phase of a movement, the test seeks to evaluate an athlete's performance capability to produce concentric force.

APPLICATION OF THE SJ

The critical role of power in numerous sports underscores the SJ test's relevance as a straightforward, dependable measure of lower limb power output. Its utility is further validated by correlations with sprint speed and back squat relative strength during the 1RM back squat. Consequently, the SJ test is particularly suited for athletes engaged in sports demanding significant lower-body power, such as track-and-field jumping events, rugby, basketball, Olympic weightlifting, and volleyball.

HOW DO YOU PERFORM THE SJ TEST?

The Squat Jump (SJ) focuses solely on the concentric phase, unlike other jump tests that also analyze eccentric phases. It's valuable for assessing an athlete's ability to generate propulsive force but can be more challenging to execute correctly compared to the CMJ. Athletes often unintentionally include a preliminary countermovement, which invalidates the jump by introducing residual elastic energy and thus falsely inflating the jump height. This can significantly reduce the reliability of the data. Proper execution of the SJ is essential for an accurate assessment of concentric force.

REQUIRED EQUIPMENT

There are several ways a practitioner could perform the SJ test. The gold standard still is the force plate which can provide the necessary reliability in the results and also the strategy employed by the athlete to achieve the kinetic outcome (jump height). Required equipment includes:

- Reliable and consistent testing facility
- One of the following: force platform, contact mat, linear position transducer, high-speed video camera and software, or an infrared platform
- Performance recording sheet
- Relevant calculation software

TESTING PROCEDURE

While the SJ test is widely recognized and seemingly straightforward, there's notable ambiguity in both academic and practical circles concerning its execution and procedural standards. For an unloaded SJ, the athlete is required to hold a lightweight wooden dowel across their shoulders, mimicking a back squat stance or alternatively hold his arms in the akimbo position. The athlete must maintain a semi-squat posture for a few seconds before initiating the jump through an upward, concentric action. Regarding the depth of the countermovement or 'pre-stretch' phase prior to the jump, there's no consensus on the optimal depth. Although evidence suggests that greater depths can enhance jump heights and peak power outputs, findings remain mixed, underscoring the need for further investigation. Therefore, it's advisable for test administrators to adopt a specific protocol and consistently apply it in subsequent assessments.

THE PROCESS FOR CONDUCTING AN SJ TEST

1. The athlete positions themselves on the force plates.
2. The athlete assumes a squat position and maintains stability.
3. Following the instructor's signal, the athlete activates their leg muscles to jump straight up, ensuring there is no preliminary countermovement (this is of paramount importance).
4. Upon jumping, the athlete lands firmly on the force plates and remains there until the test concludes.

TIPS TO EFFECTIVELY IMPROVE EXECUTION

Ensuring a period of complete stillness before the jump is initiated is critical for gathering accurate data.

- The athlete should remain as motionless as possible prior to starting the SJ motion.
- The concept of performing a jump with only concentric muscle action is often challenging for athletes to master.
- Successfully executing the test without prior attempts is rare; athletes typically need several attempts to get it right.
- After an unsuccessful attempt, advise the athlete to concentrate on activating their glute and abdominal muscles to begin the jump, avoiding any preliminary downward movement to ensure the focus remains on concentric muscle engagement.
- Maintaining consistent hand placement is essential.
- While hand position is a crucial factor in the CMJ due to its significant impact on results, it also plays a role in the SJ test. It's advised that athletes either keep their hands on their hips consistently throughout the test or allow their hands to rest by their sides, with the option to extend them upwards during the jump.
- However, be cautious; any hand movement during the SJ test often leads to an unintentional countermovement, potentially invalidating the test.
- Ensure the athlete maintains their landing position.
- It's important for the athlete to "stick" their landing post-jump, allowing for the analysis of time to stabilization and landing stiffness, among other metrics. While the test is still valid if the landing is not maintained, lacking this component may result in the omission of certain measurements.

THE SJ PHASES

- **The weighing phase:** This initial stage occurs before the onset of the jump, serving as the moment when the system's weight is established. Its significance cannot be overstated, as the system weight plays a critical role in the calculations performed after the test.
- **The propulsive phase:** Unique to the SJ test for its exclusive focus on concentric action, this phase follows immediately after the quiet phase. During this time, the athlete exerts force against the force plate to launch themselves into the air.
- **The flight phase:** This phase is marked by the athlete's ascent off the plates, during which they are suspended in mid-air.
- **The landing phase:** The final phase occurs as the athlete makes contact with the plate again, concluding the jump.

HOW DO YOU ASSESS SJ PERFORMANCE?

Typically, SJ performance is expressed as either the height of the jump (in centimeters or inches) or the relative peak power output (W•kg-1). The jump height reflects the vertical displacement of the athlete's center of mass, with the most accurate measurements obtained from impulse-momentum data via a force platform [15,17].

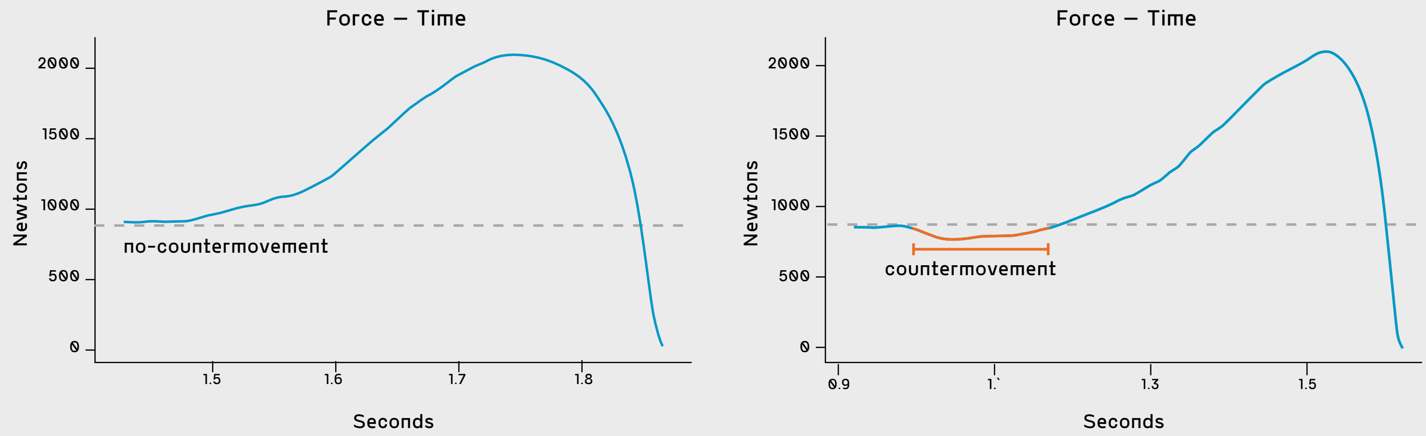


FIGURE 1: SJ force time curves comparison with no countermovement (upper panel) and with countermovement (lower panel)

While additional metrics can be assessed, such as impulse, doing so necessitates specialized equipment like a force platform, making these measurements less common in various settings. Nonetheless, the inclusion of these extra parameters offers a more comprehensive understanding of an athlete's physical capabilities.

- **Peak force (N):** The maximum force an athlete generates during the jump. Measured in Newtons (N), it reflects the athlete's absolute strength and power output at the most intense part of the movement.
- **Relative peak force (N•kg-1):** This adjusts the peak force for the athlete's body weight, providing a measure of how much force they generate per kilogram of body weight. It's a way to compare the performance of athletes of different sizes on a more equal basis.
- **Peak power (W):** The highest rate at which an athlete performs work during the jump, measured in Watts (W). It combines force and velocity, offering a snapshot of the athlete's ability to exert maximum effort in the shortest time.
- **Peak velocity (m•s-1):** The highest speed reached by the athlete during the jump, measured in meters per second (m•s-1). This metric is crucial for understanding the athlete's speed capabilities during the explosive phase of the jump.
- **Rate of force development (N•s-1):** Measures how quickly an athlete can increase force, from the onset of force application to the peak force. It's a critical indicator of explosive strength and the ability to rapidly generate power.
- **Impulse (N•s):** The total change in momentum resulting from the force applied over the time it was applied, calculated as force multiplied by the time duration (Force × Time). It provides insight into the overall effectiveness of the force application through the movement, contributing to the final jump height or distance.

In terms of measuring vertical jump performances, take-off velocity is considered to be the most valid and reliable method for calculating jump height (refs). Flight time can also be used and is simply the total duration the athlete spends in the air with no ground contact. Flight time does not start until the athlete loses contact with the floor, and ends the moment they reconnect with it.

Force platform jump height calculation – Those using a force platform are advised to calculate jump height using the following formula (20):

Jump height = (take-off velocity)^2 / (2 * acceleration due to gravity)

Or

Jump height = 9.81 * (flight time)2 / 8 if flight is to be used

FACTORS TO KEEP IN MIND BEFORE CONDUCTING THE SJ TEST

Before initiating the SJ test, it's crucial to account for several important considerations. These include:

- Individual effort – Sub-maximal efforts will result in inaccurate scores.
- Varying take-off and landing positions.
- Countermovement drop depth.
- Duration of pause if performing the static SJ.
- Flexing on the ankles, knees, or hips during flight.

IS THE SQUAT JUMP TEST VALID AND RELIABLE?

The SJ test is recognized as both a valid and reliable indicator of lower-body explosive strength. Furthermore, it ranks as the second most dependable assessment of lower-body power when compared against other widely used jump tests, including the Countermovement Jump, Abalakov jump, Sargent jump, standing long jump, and the standing triple jump.

COUNTERMOVEMENT JUMP

WHAT IS A COUNTERMOVEMENT JUMP (CMJ) TEST?

The Countermovement Jump (CMJ) is widely used to assess an athlete's explosive power in their lower body. It is a key test for coaches and researchers to gauge lower limbs power indirectly and can be performed with or without swinging the arms. Including an arm swing has been found to enhance jump performance by at least 10%. Various technologies such as contact mats, force platforms, infrared platforms, accelerometers, linear position transducers, and video analysis have been employed to measure the CMJ. Among these, force platforms are regarded as the most accurate measurement tool since they can directly measure the applied forces.

Application of the CMJ Jump

The CMJ test is a versatile tool for evaluating lower-body explosive power, essential for athletes across various sports. Its simplicity, practicality, and reliability make it invaluable for measuring lower limb power, crucial for performance in disciplines like basketball, volleyball, soccer, rugby, Olympic weightlifting, and track-and-field events. The CMJ test is linked to athletic performance, showing correlations with sprinting speed up to 30 meters and dynamic movements like the 1RM squat and power clean. These links suggest that excelling in the CMJ predicts better performance in speed bursts and strength tests. The test is beneficial not only for explosive sports but also for athletes in training or rehabilitation, aiming to enhance or recover lower-body power. It is widely used by strength and conditioning coaches, sports scientists, and physical therapists to monitor progress, customize training, or assess injury recovery. In summary, the CMJ test is a key component for athletes and professionals in sports requiring explosive lower-body power, providing valuable insights into performance and progress.

HOW DO YOU PERFORM THE CMJ TEST?

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

ESSENTIAL EQUIPMENT FOR THE CMJ TEST

- A controlled testing space, such as a gym or laboratory.
- Measurement equipment: This could be a contact mat, force platform, linear position transducer, high-speed camera with analysis software, or an infrared platform.
- A form for recording performances.
- The necessary formulas for evaluating CMJ outcomes.

SETTING UP THE TEST

The setup for the CMJ test varies based on the chosen measurement tool, whether it's a contact mat, force plate, infrared platform, accelerometer, or video analysis.

CONDUCTING THE TEST

- **Arm swing:** Decide in advance if the test will allow arm swings, enhancing performance by over 10%. If disallowed, participants should keep their hands on their hips, and monitors must ensure compliance.
- **Weighing:** Stand relaxed and without any movement in the upright position this critical to obtain accurate mass measurements and clearly detect the onset of the jump (in case of force platform measurement).
- **Countermovement depth:** The depth of the athlete's preparatory dip lacks a standardized optimal level. Deeper countermovements might increase jump height and power, though findings are mixed. It's best to select a protocol and consistently apply it.
- **During the jump:** Athletes should extend their hips, knees, and ankles while in the air to avoid gaining extra height by bending their legs.
- **Jump consistency:** Athletes should aim to land in the same spot they jumped from, avoiding forward, backward, or sideways movement, which can skew results. Marking the take-off and landing spot with tape can help maintain consistency.

TIPS THAT COULD IMPROVE EXECUTION AND MONITORING

- Measure the CMJ score following a five-minute standardized warm-up, before starting the training session.
- Ensure each trial is initiated with uniform instructions delivered in a consistent tone.
- Conduct at least three CMJ trials with the athlete keeping their hands on their hips of with an arm swing, allowing 60 seconds of rest between each trial.
- Analyze the data to monitor changes (recommend using standardized Z-scores).
- Any unexplained variations or declines in CMJ results should prompt a discussion with the athlete.
- Based on the athlete's performance and potential signs of fatigue, consider adjusting the training intensity or volume.
- Monitor CMJ scores over time to prevent overtraining or burnout.

THE CMJ KEY PHASES

- **Weighing phase:** The weighing phase is self-explanatory, but its importance may be less obvious, and it is therefore likely to be overlooked by practitioners. When performing a countermovement jump, the weighing phase (or stance phase) is the first thing done during the assessment. The athlete must stand as still as possible for at least 3 seconds during this phase. System weight is calculated during this time before the movement begins. There are several reasons why accurate bodyweight (BW) computation is necessary. Some of them are: 1) it is used to determine an onset threshold to determine movement initiation, 2) BW is included in a series of calculations of important variables obtained from the force signal, 3) obtained values are often used in relevance to BW in order to be comparable across different time periods (a person's BW can fluctuate significantly from time to time) or with a database of other individuals.
- **Unweighting phase:** The unweighting phase begins at the onset of movement which is usually identified as the instant at which BW is reduced below a set threshold value of force. The threshold value of force used is when force is reduced by 5 times the standard deviation of BW (calculated on the weighting phase). The unweighting phase continues from the start of the movement through to the instant at which the force returns to the body weight and the individual is essentially in an accelerating-fall. The instant when force returns to BW coincides with the instant at which peak negative COM velocity is achieved. Plotting the velocity-time curve alongside the force-time curve is visually useful for checking the duration of the specific phase. Ineffective execution in this phase is usually related to less efficient braking/decelerative capabilities.
- **Braking phase:** The braking phase commences from the instant of peak negative COM velocity, through to when COM velocity increases above zero. This coincides with the bottom of the CMJ (the peak negative COM displacement/deepest part of the downward movement). The braking phase has also been called the stretching phase. The leg extensor muscle-tendon unit is thought to be actively stretching to decelerate body mass. This phase can provide information for the practitioner so he could understand how capable is the athlete or patient to decelerate his/her body. If inefficiencies are detected in the braking phase in relation to similar population, then combined with clinical reasoning this could tell the practitioner to target those type of muscle contractions and qualities.
- **Propulsive phase:** The propulsive phase (or push-off phase) starts when the COM velocity becomes positive, identified at 0.01 m/s. This phase involves forceful extension of the hips, knees, and ankles to propel the COM vertically. The transition from braking to propulsion and the force platform's sampling frequency determine if an amortization phase (brief isometric period when velocity is zero) is identifiable. The force at the start of propulsion depends on the force at the end of braking, minus any force lost during amortization. The propulsion phase continues until take-off. Plotting the displacement-time curve here shows vertical COM displacement becoming positive. Athletes with a smoother transition from braking to propulsion (less time in amortization) are more efficient at transferring momentum, crucial for maximizing jump performance and improvement potential.
- **Flight phase:** The flight phase commences at the instant of take-off when the force falls below a set threshold. A threshold of force equal to 5 times the standard deviation of flight force (when the force platform is unloaded), taken over a 300-ms portion of the flight phase, has been successfully used to identify take-off. The flight phase ends when the athlete contacts the force platform again and the force rises above 5 times the standard deviation of flight force.
- **Landing phase:** It is the final CMJ phase, whereby the participant applies a net impulse to decelerate the COM from the velocity at which it contacts the force platform. The landing phase ends when the force stabilizes between ±5% of body weight for one second. This instant is referred as the time to stabilize.

HOW DO YOU ASSESS CMJ PERFORMANCE?

The CMJ assessment can answer questions like, “Was the athlete quick? Are they slow but powerful? Was the jump shallow or deep?” It provides insights not only from the jump height but also from the jump execution. Questions addressed include, “How fast was the movement completed?”, “How long did the lowering and propulsion phases take?”, “What was the deepest point the COM reached?”, and “Is the athlete relying more on force or timing?”. These insights help understand the strategies athletes use to achieve jump height. While jump height is a key metric summarizing total output, it’s not the only one. Before takeoff, various factors determine jump height. CMJ performance is often reported as jump height (cm) or relative peak power output (W•kg-1). Other variables, like those measured by force platforms, provide additional data requiring specialized equipment.

Some of the most used key performance indicators (KPI) are listed in more detail, below in table 1.

Table 1: Detailed description of the most used metrics to assess CMJ performance

KPI	Description
Jump height (cm)	Jump height is defined as the maximal vertical displacement reached by the participant’s COM in relation to initial position and it can be accurately calculated using the impulse momentum theorem. It can be also calculated from flight time but less accurately. ***Jump height from velocity at take-off (impulse momentum):*** **Jump height = Velocity@takeoff²/(2*g)** ***Jump height from flight time:*** **Jump height = 1/8*(g*Flight_time²)**
Peak force (N)	Peak force is defined as the maximal value of force produced by the individual during ground contact
Peak power (W)	Peak power is defined as the maximum value of power generated by the participant during ground contact
Peak RFD (N/s)	Peak RFD is defined as the maximum value of RFD obtained at 30ms intervals during the braking phase of the jump.
Total impulse (N•s)	Total impulse is defined as the area under the curve of force it can be calculated from the movement initiation until take off.
Concentric (Upward) impulse (N•s)	Concentric (Upward) impulse is defined as the area under the curve of force during the concentric (push-off) phase of the jump.
Eccentric (Downward) deceleration Impulse (N•s)	Eccentric (Downward) impulse is defined as the area under the curve of force during the braking phase of the jump.

Table 1: Detailed description of the most used metrics to assess CMJ performance	
KPI	**Description**
Rate of Force Development (maximum or average) (N/s)	Rate of Force Development (RFD), is the first time-derivative of the applied force, or **RFD= dF/dt**. Typically in a CMJ, RFD is evaluated in the braking phase which shows how quickly an athlete can generate deceleration force. This reflects both neuromuscular and coordination skills in a multi-joint motion like the CMJ. It does not depend on the athlete's mass, muscle size, or dimensions and is not necessarily related to power output (force multiplied by velocity).
Eccentric (Downward) duration (ms)	Eccentric duration represents the duration of COM trajectory from jump onset until it reaches the deepest point.
Eccentric (Downward) peak braking Force (N)	The maximum value of Force during the braking phase.
Eccentric (Downward) peak Power (W)	The maximum value of Power during the braking phase.
Concentric (Upward) duration (ms)	Concentric duration represents the duration of COM trajectory from the deepest point of the counter-movement until take off.
Concentric (Upward) peak Force (N)	The maximum value of Force during the concentric (push-off) phase.
Concentric (Upward) peak Power (W)	The maximum value of Power during the concentric (push-off) phase.

In the table below there is a guide on how to select metrics depending on the use case.

Table 2: CMJ for performance assessment, neuromuscular fatigue monitoring and injury-rehabilitation testing

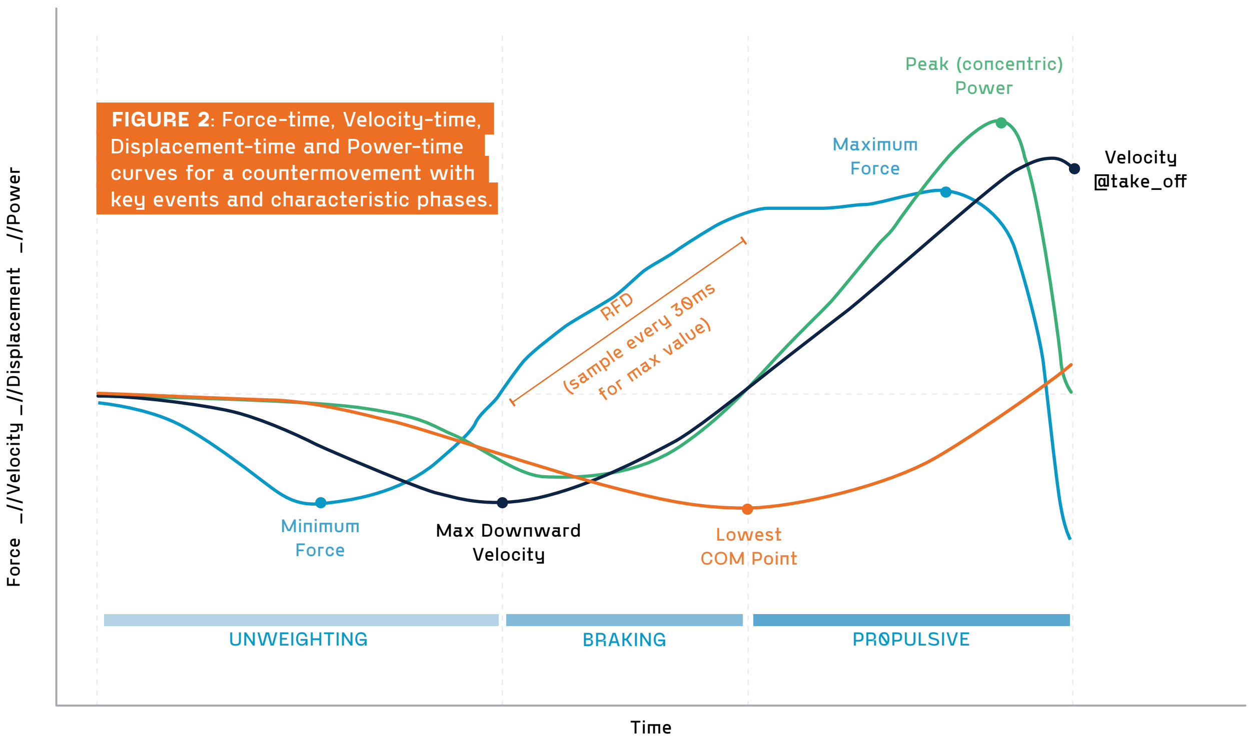
Performance assessment		**Neuromuscular fatigue**		**Injury – rehabilitation**	
PURPOSE: To test and assess correlations with other physical capacity measures		**PURPOSE:** To detect neuromuscular fatigue		**PURPOSE:** To assess progress after injury and inform decision for return to play actions	
KPI	**Scope of usage**	**KPI**	**Scope of usage**	**KPI**	**Scope of usage**
Jump height (cm)	Vertical Displacement of the body's Center of Mass	**Propulsive phase duration**	Duration of upward movement of the jump	**Peak propulsive force (N)**	Maximum force value produced in the propulsive phase of the jump
Peak power (W)	Highest work rate during the jump	**Time to take off (s)**	Time spent from the jump onset until the jumper leave the ground	**Peak landing force (N)**	Maximum value of applied force during landing
Mean propulsive force (N)	Mean force value produced in the propulsive phase of the jump	**Time to peak power (s)**	The amount of time needed for power to reach its maximum value	**Landing impulse (N*s)**	Product of force and time during landing from the jump
Propulsive impulse (N*s)	Product of force and time in the propulsive phase of the jump	**Reactive strength index (RSI) *modified**	The proportion between Jump Height and Contraction Time (time spent to produce the output)	**Asymmetry (%)**	Differences in measure outcome between the lower limbs

Bishop, Chris PhD1; Jordan, Matt PhD2; Torres-Ronda, Lorena PhD3; Loturco, Irineu PhD4; Harry, John PhD5; Virgile, Adam MS6; Mundy, Peter PhD7; Turner, Anthony PhD1; Comfort, Paul PhD8. Selecting Metrics That Matter: Comparing the Use of the Countermovement Jump for Performance Profiling, Neuromuscular Fatigue Monitoring, and Injury Rehabilitation Testing. Strength and Conditioning Journal, January 9, 2023. | DOI: 10.1519/SSC.0000000000000772

***Key points:** It is imperative to monitor several KPIs at the same time since humans are highly variable systems in order to understand what is actually driving the observed change or even further use multivariate analysis to reduce your data in new meaningful dimensions. The above KPIs are just the most used in the literature and produced acceptable correlations with outcomes of interest. This does not mean that another metric could not be used or be meaningful.

Concentric peak power (**P**$_{PEAK}$), defined as the maximum power output achieved during the concentric (muscle shortening) phase of a movement, stands as a critical metric in athletic profiling. This parameter's significance is rooted in its consistency across repeated assessments and its correlation with performance across a broad spectrum of physical tasks. Not only does **P**$_{PEAK}$ offer a snapshot of an athlete's explosive strength and power at a given moment, but it also plays a pivotal role in longitudinal evaluations, helping to track and analyze long-term adaptations to training. Moreover, **P**$_{PEAK}$, alongside the average power output during the concentric phase (**P**$_{MEAN}$), is instrumental in developing a comprehensive performance profile for athletes. This dual analysis allows for a nuanced understanding of an individual's power capabilities, facilitating tailored training interventions aimed at enhancing specific aspects of athletic performance. The utilization of **P**$_{PEAK}$ and **P**$_{MEAN}$ in profiling provides a foundation for informed decision-making in training program design, enabling a strategic approach to optimizing athletic development and achieving peak performance levels.

FIGURE 2: Force-time, Velocity-time, Displacement-time and Power-time curves for a countermovement with key events and characteristic phases.



FACTORS TO EVALUATE BEFORE UTILIZING THE CMJ TEST

Before initiating the countermovement jump test, it's crucial to account for various elements to ensure accurate results. These include:

- The necessity of maximum effort from participants, as anything less can lead to unreliable scores.
- Consistency in the positions from which individuals take off and land.
- The decision to include or exclude arm movements during the jump.
- The depth of the initial dip prior to the jump.
- Maintaining straight legs versus bending at the ankles, knees, or hips while in the air.

CMJ TEST VALIDITY AND RELIABILITY

The CMJ test is acknowledged as both a valid and dependable tool for assessing lower-body explosive strength. It has been found to be the most consistent indicator of lower-body power when compared to other common jump assessments, including the squat jump, Abalakow's jump, Sargent jump, standing long jump, and the standing triple jump.

While the CMJ test can be accurately conducted using various equipment, the force platform is regarded as the premier choice for achieving the highest degree of accuracy. These include:

- Contact mats
- Force platforms
- Infrared platforms
- Accelerometers
- Linear position transducers
- High-speed video cameras coupled with specialized analysis software

This broad range of measurement tools underscores the test's adaptability and reliability across different settings and equipment, with the force platform standing out for its exceptional precision.

DROP JUMP

WHAT IS A DROP JUMP (DJ) TEST

A drop jump is a type of plyometric jump designed to assess an athlete's explosive power, specifically targeting the fast stretch-shortening cycle (SSC) of muscle contractions. In this jump, an athlete starts by stepping off a platform or box of a predetermined height and immediately upon landing, executes a vertical jump as quickly and as high as possible. The key aspect of the drop jump is the minimal time spent on the ground between the landing and the subsequent jump, known as the ground contact time. This rapid transition is crucial for effectively utilizing effectively the SSC, which involves a rapid stretch of the muscle followed by an immediate shortening, generating greater power during the jump.

APPLICATION OF THE DJ

The application of the DJ in assessing athletes is multifaceted:

- **Evaluating plyometric and explosive strength:** The DJ is particularly valuable in sports requiring rapid force production, such as basketball, volleyball, track and field, and soccer. It helps in determining an athlete's explosive strength and plyometric capability, which are critical for sprinting, jumping, and rapid changes of direction.
- **Monitoring training progress:** Regularly incorporating the DJ test in an athlete's training regimen can track improvements or declines in reactive strength and explosive performance over time, guiding adjustments in training intensity, volume, or focus.
- **Injury risk Assessment:** The DJ can also aid in identifying potential risk factors for lower limb injuries. Athletes displaying longer ground contact times and lower jump heights may have inefficiencies in their SSC, potentially increasing injury risk.
- **Tailoring training programs:** By assessing the reactive strength index (RSI) through the DJ test, coaches can customize plyometric and strength training programs to enhance an athlete's performance specifically. Athletes with lower RSI may require targeted interventions to improve their SSC efficiency and overall plyometric performance.
- **Sport-specific conditioning:** The insights gained from DJ tests can help in designing sport-specific conditioning programs that address the unique demands of an athlete's sport, focusing on improving the SSC efficiency that translates directly to better performance in competitive situations.

HOW DO YOU PERFORM THE DJ TEST?

The general guidelines for performing a DJ are the following:

- **Preparation:**
  - Equipment needed: A box/platform for jumping (the height can vary depending on the athlete's experience and the test's purpose, commonly ranging from 30 to 60 cm).
  - The athlete should perform a thorough warm-up, including dynamic stretching and some plyometric exercises to prepare the muscles for the explosive activity.
- **Performing the test:**
  - The athlete stands on top of the box with feet shoulder-width apart.
  - They step off the box (not jump down) to land on the ground with both feet, attempting to minimize the ground contact time and immediately jump vertically as high as possible.
  - It is crucial to ensure the athlete does not jump off the box but simply steps off to ensure the fall's impact causes the stretch-shortening cycle.
  - Arms can be used to aid in the jumping motion.
- **Safety and considerations:**
  - Ensure the landing area is safe and clear of any obstructions.
  - The height of the box should be chosen based on the athlete's experience and ability. Higher boxes increase the difficulty and the impact forces upon landing.
  - Athletes should be familiar with plyometric exercises and have a good strength base to minimize the risk of injury.
- **Repetitions and variations:**
  - The test can be repeated multiple times to ensure consistency and reliability of the results.
  - Variations can include different box heights to assess how the athlete copes with different levels of SSC demand.

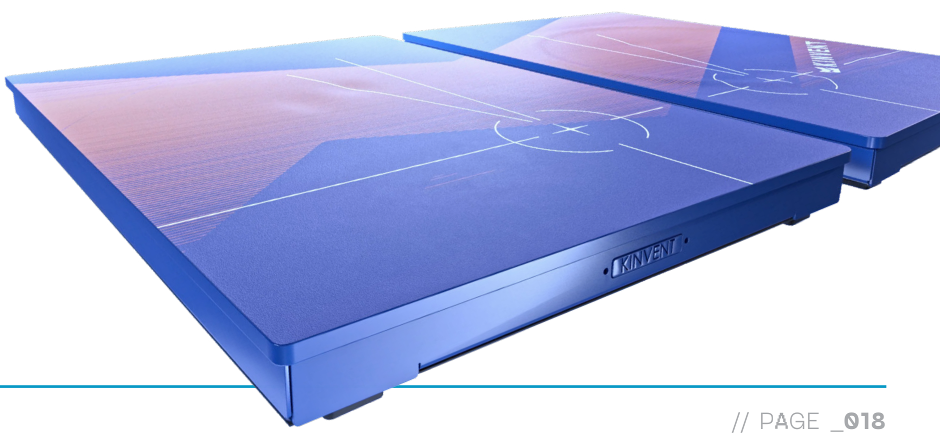
CHALLENGES IN DJ TESTING

Accurately knowing the drop height is critical when calculating force-derived and jump height variables in the context of a DJ test, especially if the drop jump is derived from the impulse momentum theorem. The calculation of force derived variables such as displacement and power during the contact phase rely heavily on precise initial conditions, which include the drop height. When only the nominal value is used in the calculation of the drop height, there is substantial error in the calculation of the landing velocity.

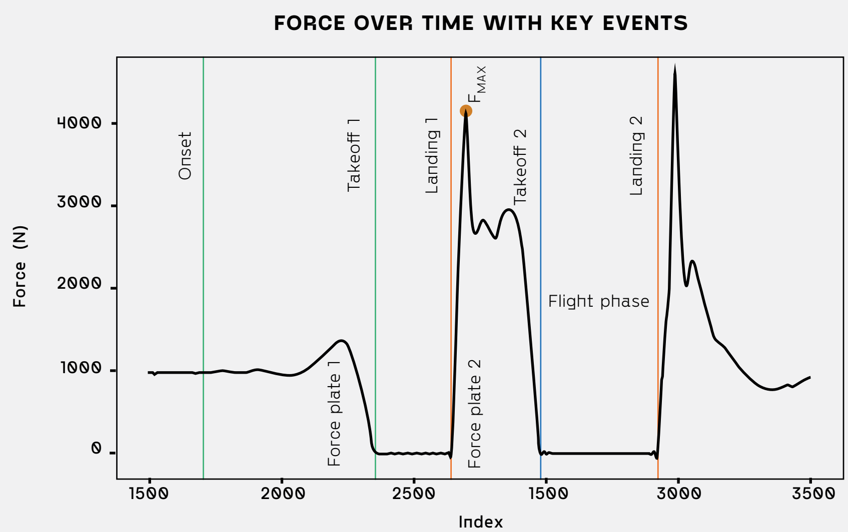
Drop Jump key phases

1. **Starting position:** The athlete begins on top of a box or platform. The height of the box can vary depending on the athlete's experience, the objective of the test or training, and the specific demands of their sport. The athlete stands with feet shoulder-width apart, preparing to step off the box.

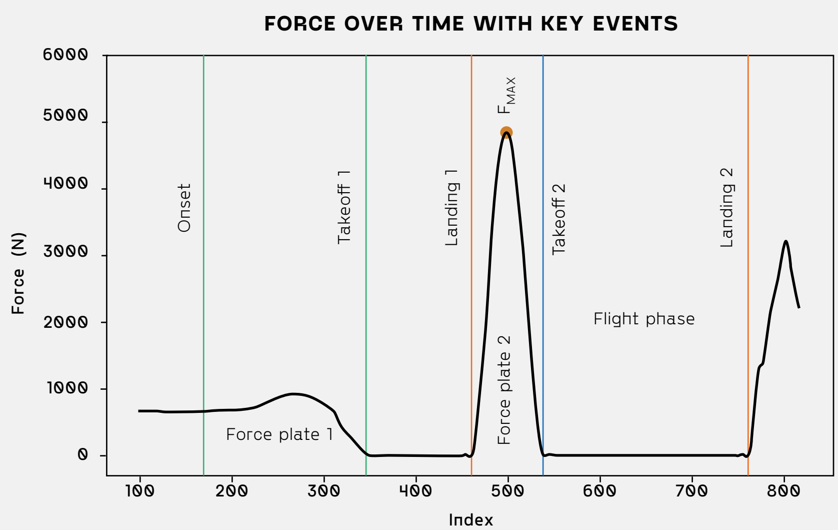
2. **Initial drop:** The athlete steps off the box to initiate the drop. It's important that the athlete steps off rather than jumps off to ensure that the drop height is controlled and consistent (in case of one force platform is used). The body should be aligned, with the arms prepared to assist in the landing and subsequent jump.



3. **Braking phase:** Almost immediately upon touching down on the plate following the initial descent, the athlete enters the braking phase. This period is also commonly known as the “deceleration” phase. During deceleration/braking the athlete stretches the leg muscles (eccentric) to prepare for the next phase (concentric).
4. **Propulsive phase:** The propulsive phase starts as the athlete’s velocity hits zero and persists until they lift off from the ground.
5. **Flight phase:** The phase is defined as the time the athlete spends airborne.
6. **Landing:** After flight phase, the athlete begins the descent back to the ground, preparing for a controlled landing.



- Drop height: 0.32m
- Jump height (V_{TOFF}): 0.25m
- Jump height (Flight time): 0.23m
- Contact time: 0.351sec
- Flight time: 0.445sec
- Vertical stiffness: -100.45N/m
- P_{MAX}: 50.72W
- Eccentric phase duration: 0.182sec
- Concentric phase duration: 0.093sec
- Max negative displacement: -0.27m
- $F_{MAX\_RELATIVEBM}$: 29.54N/kg



- Drop height: 0.32m
- Jump height (V_{TOFF}): 0.35m
- Jump height (Flight time): 0.33m
- Contact time: 0.181sec
- Flight time: 0.524sec
- Vertical stiffness: -427.79N/m
- P_{MAX}: 98.4W
- Eccentric phase duration: 0.0866sec
- Concentric phase duration: 0.093sec
- Max negative displacement: -0.17m
- $F_{MAX\_RELATIVEBM}$: 71.12N/kg

FIGURE 3: DJ force-time curve with 2 force plates with the respective phases.
Top panel: a force time curve with a high impact early in the jump (not optimal).
Lower panel: a force time curve from a well executed jump.
Side panel: results from some exemplary calculated metrics.

HOW DO YOU ASSESS DJ PERFORMANCE?

Assessing your DJ performance involves measuring several key variables that reflect your explosive strength, reactive ability, and the efficiency of your stretch-shortening cycle (SSC). Here are the primary steps and metrics to consider when evaluating your DJ performance:

- **Jump height (cm):** The vertical distance achieved in the jump following the drop. Higher jumps suggest greater explosive power and effective use of the energy stored during the eccentric phase.
- **Ground contact time (GCT):** The time spent on the ground between landing from the drop and initiating the jump. Shorter ground contact times are indicative of better reactive strength and a more efficient SSC. This is often measured using a force plate or contact mat.
- **Reactive strength index (RSI):** Calculated by dividing the jump height by the ground contact time (**RSI = Jump height / GCT**). The RSI is a useful composite measure that evaluates how effectively an athlete can convert the energy absorbed during landing into explosive power for the jump. Higher RSI values indicate better plyometric performance.
- **Stiffness (N/m):** In the context of a DJ, "stiffness" refers to the body's ability to resist deformation in response to the impact forces experienced upon landing and to rapidly generate force for the subsequent jump.

$$k = \frac{F}{\Delta x}$$

Stiffness (k) is measured in Newtons per meter (N/m).

Force (F) is the peak force exerted on the ground during the landing phase, measured in Newtons (N).

Displacement (Δx) is the change in length or compression of the leg's musculoskeletal system under the load, measured in meters (m). This can be seen as the change in height of the center of mass during the landing and take-off phases.

It's a measure of how effectively the muscles and tendons can absorb and then quickly release energy. Higher stiffness levels are associated with a more efficient stretch-shortening cycle (SSC), allowing for quicker and more powerful jumps. Essentially, an athlete with higher leg stiffness will have a shorter ground contact time and potentially higher jump heights, reflecting better plyometric performance. This stiffness is not just about rigidity; it's about the rapid and controlled response of the neuromuscular system to the demands of the drop jump, enabling maximal performance with minimal energy loss.

- **Peak force (N):** The maximum force an athlete generates during the jump. Measured in Newtons (N), it reflects the athlete's absolute strength and power output at the most intense part of the movement.
- **Relative peak force ($N{\bullet}kg^{-1}$):** This adjusts the peak force for the athlete's body weight, providing a measure of how much force they generate per kilogram of body weight. It's a way to compare the performance of athletes of different sizes on a more equal basis.
- **Peak power (W):** The highest rate at which an athlete performs work during the jump, measured in Watts (W). It combines force and velocity, offering a snapshot of the athlete's ability to exert maximum effort in the shortest time.
- **Peak velocity ($m{\bullet}s^{-1}$):** The highest speed reached by the athlete during the jump, measured in meters per second ($m{\bullet}s^{-1}$). This metric is crucial for understanding the athlete's speed capabilities during the explosive phase of the jump.
- **Rate of force development ($N{\bullet}s^{-1}$):** Measures how quickly an athlete can increase force, from the onset of force application to the peak force. It's a critical indicator of explosive strength and the ability to rapidly generate power.
- **Impulse (N•s):** The total change in momentum resulting from the force applied over the time it was applied, calculated as force multiplied by the time duration (Force × Time). It provides insight into the overall effectiveness of the force application through the movement, contributing to the final jump height or distance.

In terms of measuring vertical jump performances, take off velocity is considered to be the most valid and reliable method for calculating jump height (refs). Also flight time can be used and is simply the total duration the athlete spends in the air with no ground contact. Flight time does not start until the athlete loses contact with the floor, and ends the moment they reconnect with it.

Force platform jump height calculation – Those using a force platform are advised to calculate jump height using the following formula (20):

Jump height = (take-off velocity)^2 / (2 * acceleration due to gravity)

Or

Jump height = 9.81 * (flight time)2 / 8 if flight is to be used

In the DJ, accurate jump height calculation is challenging. Calculating jump height from take off velocity requires very robust and accurate calculation of the drop height, since drop height will dictate the landing velocity which is required to have an accurate take off velocity. Due to the significant errors (8-20%) that could contaminate the results it is worth to take some time to explain the chain of dependency if the jump height is calculated with the force integral and why it is important to define accurately the initial conditions:

Drop height and landing velocity:

The drop height directly influences the landing velocity due to gravitational acceleration. The higher the drop, the greater the velocity at which the athlete hits the ground. This is based on the principle of conservation of energy, where potential energy (due to height) is converted into kinetic energy (motion).

Accurately calculating the drop height is essential because it allows for a precise estimation of the initial kinetic energy present during contact phase and, thus, the landing velocity using the formula $\sqrt{(v=2gh)}$ where **v** is velocity, **g** is the acceleration due to gravity, and **h** is the height of the drop.

Landing velocity and take-off velocity:

Now knowing the landing velocity will not overestimate or underestimate the vertical velocity due to incorrect drop height estimation and the force integration will produce the correct result. Jump height now can be accurately calculated from the take-off velocity involves using the formula derived from the conservation of energy principles or kinematic equations, $h=\frac{v^2}{2g}$, where **h** is the height, **v** is the take-off velocity, and **g** is the acceleration due to gravity.

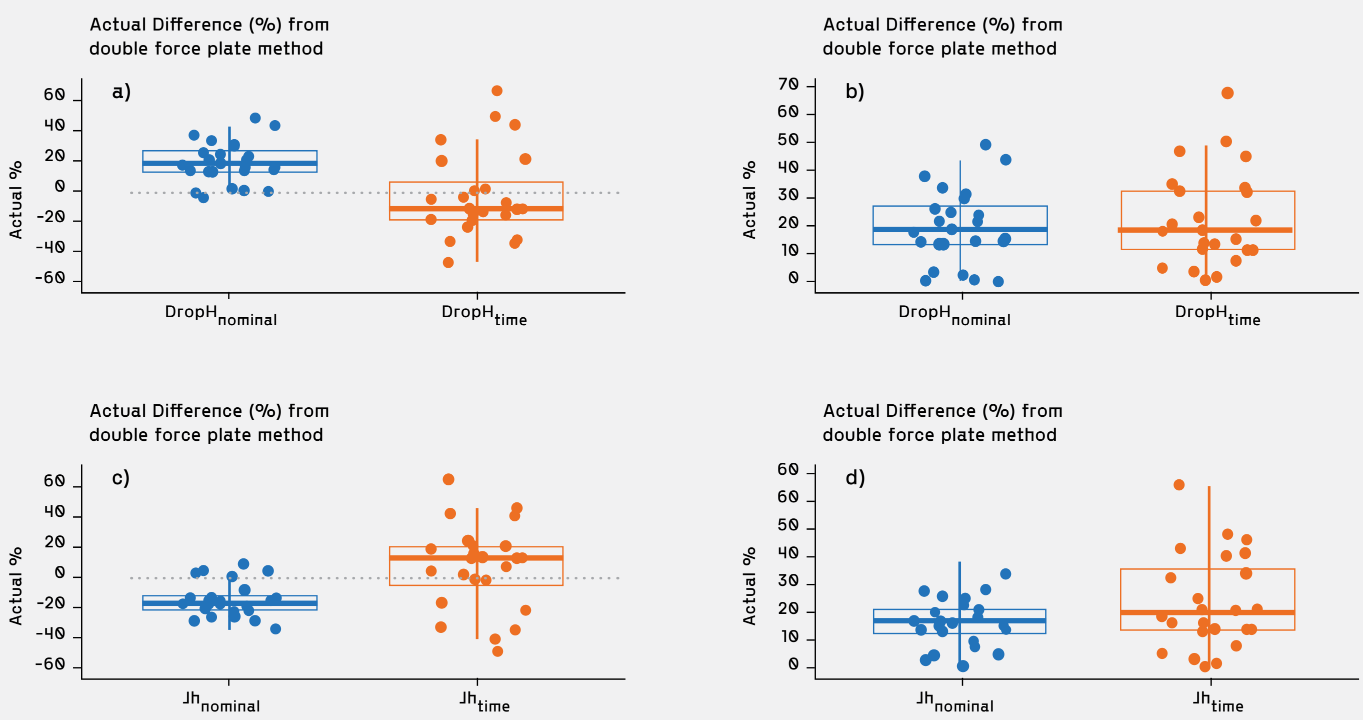


FIGURE 4: Example differences (%) for the examined analysis methods compared to the reference double force-plate method (n = 24). Top panel: a) and b) present the calculated deviations of the drop height estimation in percentages and absolute percentages, respectively. Bottom panel: c) and d) depict the calculated deviations of the vertical jump height estimation in percentages and absolute percentages, respectively. Note: DropH: effective drop height, Jh: jump height; nominal: single force-plate method; time: drop time method; flight: flight time method.

FACTORS TO KEEP IN MIND BEFORE CONDUCTING THE DROP JUMP TEST

Before initiating the DJ test, it's crucial to account for several important considerations. These include:

- Individual effort – Sub-maximal efforts will result in inaccurate scores.
- Varying take-off positions from the box will be problematic if you are using a force plate with nominal drop height.
- Slow contact times.
- Flexing on the ankles, knees, or hips during flight and landing.

DJ TEST VALIDITY AND RELIABILITY

The DJ test is widely regarded as both valid and reliable for assessing plyometric performance, specifically in measuring an athlete's explosive leg power and the efficiency of the stretch-shortening cycle (SSC). However, the validity and reliability of the DJ test can depend on several factors, including the protocols used, the equipment for measurement, and the population being tested. Here's a breakdown of its validity and reliability:

VALIDITY

- **Construct validity:** The DJ test has strong construct validity for measuring the specific athletic qualities it intends to measure, such as reactive strength, SSC efficiency, and explosive power. These attributes are crucial in many sports, and the test's ability to quantify them through measurable outcomes like jump height and ground contact time supports its validity.
- **Ecological validity:** The DJ test replicates movements and demands similar to those found in various sports activities, such as basketball, volleyball, and soccer, thereby offering high ecological validity. It assesses the athlete's ability to perform under conditions that mimic real-world sports performance.

RELIABILITY

- **Intra-subject reliability:** The DJ test shows high intra-subject reliability when the same subject performs the test under similar conditions across different sessions. Consistency in performance metrics (e.g., jump height, ground contact time) suggests that the test can reliably measure changes in an athlete's performance over time.
- **Inter-rater reliability:** With standardized protocols and objective measurement tools (such as force plates or motion analysis software), the DJ test exhibits high inter-rater reliability. This means that different testers should be able to obtain similar results when testing the same athlete using the same procedures.

FACTORS AFFECTING VALIDITY AND RELIABILITY

- **Standardization of procedures:** Variability in test protocols, such as differences in drop heights or measurement techniques, can affect the test's validity and reliability. Ensuring strict adherence to standardized protocols is crucial.
- **Measurement tools:** The accuracy and precision of the measurement tools (e.g., force plates, motion capture systems) significantly impact the reliability of the results. High-quality equipment tends to increase both validity and reliability.
- **Athlete's familiarity:** An athlete's familiarity with the test procedures can also influence the results. Providing adequate instruction and allowing for practice jumps can help mitigate learning effects and improve reliability.
- **Physical condition:** The physical condition and readiness of the athlete on test days can introduce variability. Consistent testing conditions, including time of day and pre-test warm-up routines, are important for reliability.

In conclusion, when administered with proper protocols and equipment, the DJ test is both a valid and reliable method for assessing key aspects of athletic performance related to plyometric ability and explosive power. However, attention to the factors that can affect its validity and reliability is essential for obtaining accurate and consistent results.

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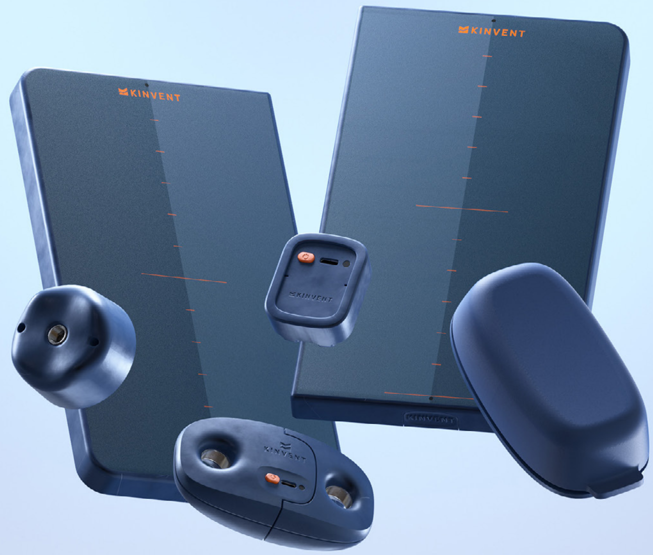

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