Review article

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Comprehensive assessment and individualized training guidance in vertical jump performance: from force–velocity profiling to neuromuscular diagnostics

Abstract

The vertical jump (VJ) serves as a crucial indicator of explosive power in sports like volleyball, basketball, and track and field. Yet, evaluating jump height alone does not sufficiently capture the complex neuromuscular and biomechanical factors that influence performance. This narrative review explores the essential performance metrics and modern assessment techniques that allow for deeper analysis of VJ mechanics and more personalized training approaches. A central focus is placed on force–velocity (F–v) profiling, which dissects jump output into theoretical maximum force (F_0), maximum velocity (V_0), and peak power (Pmax). Additional assessments—including comparisons between squat and countermovement jumps, the eccentric utilization ratio, rate of force development (RFD), reactive strength index (RSI), and kinetic data analysis—help identify specific strengths and limitations in athletes. Integrating these insights enables practitioners to categorize athletes as force-deficient, velocity-deficient, or balanced, guiding tailored interventions to enhance jump performance. Practical recommendations are presented for translating these diagnostics into effective, targeted training plans, thus bridging the gap between assessment and individualized performance development.

Keywords: vertical jump performance, force–velocity profiling, neuromuscular assessment, reactive strength index, individualized training

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Introduction

The vertical jump (VJ) is a fundamental motor skill widely used in sport performance evaluation, particularly in disciplines requiring explosive lower-limb actions such as volleyball, basketball, handball, and track and field. Beyond serving as a simple marker of lower-limb power, the vertical jump is a complex, multidimensional motor task influenced by strength, velocity, coordination, and neuromuscular efficiency.[1] Consequently, effective analysis of vertical jump performance requires more than just measuring jump height; it demands a detailed understanding of the underlying mechanical variables contributing to jump output.

In recent years, biomechanical models have evolved to offer more comprehensive assessments of jump performance. Among the most influential frameworks is the force–velocity (F–v) profiling method, as developed and validated by Samozino et al.[2,3] which allows practitioners to deconstruct jump performance into its mechanical components: theoretical maximal force (F_0), velocity (V_0), and maximal power output (Pmax). This method, which combines anthropometric data with simple jump tests under different loads, provides not only reliable and valid insight into an athlete's neuromuscular profile but also quantifies force–velocity imbalance—a key factor in personalizing training interventions.[4]

Beyond F–v profiling, additional variables such as the eccentric utilization ratio (CMJ/SJ), rate of force development (RFD), and reactive strength index (RSI) have gained importance for identifying specific performance qualities and deficits.[5,6] Force plate data, linear encoders, and mobile apps such as MyJump2 have further enhanced the accessibility of advanced jump analysis, enabling more individualized athlete monitoring.[7]

This review aims to provide a comprehensive guide for practitioners on what to test, how to analyze, and how to interpret vertical jump data. By integrating current literature—especially the foundational work of Samozino and Morin,[8,4] studies on the force–velocity relationship, and recent contributions by Yáñez-García et al.—the paper will outline the most effective testing strategies for identifying individual strengths and weaknesses in jump performance. Ultimately, the goal is to bridge testing with training by offering evidence-based frameworks for diagnosing performance limiting factors and guiding targeted neuromuscular training interventions.

Key performance indicators in vertical jump

A thorough analysis of vertical jump performance requires more than just the measurement of jump height. While jump height remains a primary output variable, it is the result of complex interactions between multiple neuromechanical parameters that can provide deeper insights into an athlete's explosive capabilities. The following are the most essential key performance indicators (KPIs) used to evaluate vertical jump mechanics and inform individualized training strategies.

Jump height (SJ, CMJ, DJ)

Jump height is the most commonly reported measure in vertical jump testing and serves as a general indicator of lower-limb power output. It can be assessed through different jump modalities, each offering distinct diagnostic value:

Squat jump (SJ): The squat jump is executed from a stationary, bent-knee position without any preliminary downward movement. It primarily assesses the athlete's capacity to produce force quickly from a static posture and reflects pure concentric muscle action and explosive strength.[5]

Countermovement jump (CMJ): In this jump, the athlete performs a swift downward movement before exploding upward. This engages the stretch-shortening cycle (SSC), storing elastic energy in muscles and tendons and resulting in higher jumps than the SJ. The CMJ is often considered more representative of sport-specific movements due to its dynamic nature.[1]

Drop jump (DJ): In a drop jump, the athlete steps off an elevated platform and instantly rebounds upon landing. This tests how effectively the athlete can manage high-impact landings and convert them into rapid upward force, providing valuable information about reactive strength and fast SSC function.[9]

Peak power

Peak power represents the maximum rate of mechanical energy output during the jump and is a critical determinant of explosive performance. It is influenced by both the force and velocity components of the movement. Power can be measured using force platforms or estimated via validated equations incorporating body mass and jump height.[2] As power is a product of force and velocity, maximizing peak power depends on optimizing the athlete's position along the force–velocity spectrum.[4]

Rate of force development (RFD)

The rate of force development (RFD) quantifies how fast an athlete can generate force after muscle activation begins. High RFD values are crucial for explosive actions, particularly those demanding swift ground contact, like jumping or sprinting.[10]

RFD is often assessed during isometric testing (e.g., mid-thigh pull) or during the early phase of a jump on force plates.

Contraction time

Contraction time is the duration between movement initiation and take-off. It provides insight into the time-dependent nature of force application and neuromuscular efficiency. A shorter contraction time, especially when paired with high power output, is indicative of a more explosive movement profile. Conversely, excessively long contraction durations may signal inefficiencies or limitations in neural drive or coordination.[11]

Take-off velocity

Take-off velocity is the vertical velocity of the center of mass at the instant of leaving the ground. It is directly related to jump height, as per the ballistic equation $h=v^2/2g$. Monitoring take-off velocity offers a precise measure of the athlete's ability to accelerate their mass upward and is less affected by technique than jump height alone.[2]

Impulse

Impulse is defined as the integral of force overtime and represents the total amount of momentum change generated during the propulsive phase of the jump. A high impulse indicates effective force application sustained over a given period, and is considered a strong predictor of vertical jump performance. It is particularly useful when analyzing different jump types or when comparing athletes with varying body masses.[12]

Together, these key performance indicators allow practitioners to move beyond a simplistic measurement of jump height toward a nuanced understanding of the mechanical factors contributing to performance. This multidimensional approach enables targeted diagnostics and the development of individualized training prescriptions based on specific performance profiles.

Force–velocity profiling in vertical jump analysis

Force–velocity (F–v) profiling represents a key advancement in the biomechanical analysis of vertical jump performance. Rather than relying on jump height alone, F–v profiling provides a comprehensive breakdown of the mechanical components underlying explosive movement. It enables coaches and practitioners to identify whether an athlete's limitations stem from insufficient force production, limited movement velocity, or suboptimal power generation. This framework, pioneered by **Samozino et al.**[2,3] has become an essential tool for performance diagnostics and individualized training design.

Theoretical background and rationale

The force–velocity (F–v) profile is founded on the principle that as movement velocity increases, the force a muscle can produce decreases, and vice versa. By measuring how much force an athlete generates at different jumping speeds and loads, it's possible to chart a personalized F–v curve. Three key theoretical values stem from this curve:

1. **F_0 (Theoretical Maximal Force):** The estimated force output if the athlete were moving at zero velocity, reflecting maximal strength in fast, ballistic actions.
2. **V_0 (Theoretical Maximal Velocity):** The predicted speed at which the athlete's limbs could move if no external load were present, indicating pure velocity potential.
3. **Pmax (Maximal Power):** The highest power an athlete can achieve during a jump, calculated as one-quarter of the product of F_0 and V_0.

This profiling model does not require sophisticated laboratory equipment. Using jump height, body mass, and displacement of the center of mass, these values can be estimated reliably in the field through a series of **loaded and unloaded squat jumps**, measured via contact mats, linear encoders, or apps like MyJump2.[2,7]

Force–velocity imbalance and optimal profiling

An essential innovation of the F–v approach is the concept of **force–velocity imbalance (FVimb)**—the deviation between an athlete's actual F–v profile and their theoretically optimal profile for achieving maximal jump height. Athletes with similar jump heights may have very different F–v profiles; one may rely more on force, another on speed. By identifying this imbalance, practitioners can classify an athlete as:

Force-deficient: Low F_0 relative to optimal profile – needs maximal strength or heavy-load training.

Velocity-deficient: Low V_0 relative to optimal – needs speed-strength or high-velocity training.

Well-balanced: Near-optimal profile – focus on maintaining neuromuscular qualities or maximizing Pmax.

Correcting this imbalance through individualized training leads to more efficient performance gains than generalized programs.[3,4]

Applications and reliability

The F–v profiling approach has demonstrated high validity and reliability in both elite and recreational populations, and across sports including track and field, football, rugby, and volleyball.[13,14] Its portability and practicality make it suitable for routine assessments,

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providing coaches with actionable data to adapt resistance training methods based on mechanical needs.

Importantly, unlike traditional 1-RM or jump height assessments, F–v profiling links movement outcomes directly to force application mechanics, offering a biomechanically specific diagnostic tool.

Complementary neuromuscular tests for vertical jump analysis

While force–velocity (F–v) profiling provides a detailed picture of an athlete's mechanical characteristics in vertical jump performance, complementary neuromuscular tests are essential to further interpret movement strategy, muscle function, and SSC utilization. These tests refine the diagnosis of performance-limiting factors and support more precise training decisions, particularly when combined with kinetic and kinematic data.

CMJ–SJ Comparison and Eccentric Utilization Ratio (EUR)

A fundamental comparison in jump diagnostics is between the countermovement jump (CMJ) and the squat jump (SJ). The eccentric utilization ratio (EUR), typically calculated as CMJ height divided by SJ height, reflects the athlete's ability to exploit the stretch-shortening cycle (SSC) for enhanced performance.[15]

- A higher EUR (>1.1) suggests effective storage and reuse of elastic energy, as well as efficient neuromuscular coordination.
- A low EUR may point to stiffness, poor motor control, or an underdeveloped SSC.

EUR is especially useful for distinguishing between explosive strength (concentric-only ability) and reactive strength (elastic contribution), which is important when tailoring plyometric or SSC-specific training.

Drop jump (DJ) and reactive strength index (RSI)

The drop jump (DJ) is performed by stepping off a box and minimizing ground contact time while maximizing rebound height. It targets fast SSC function and is commonly used to calculate the reactive strength index (RSI):

RSI= Ground Contact Time (s)/Jump Height (m)

The reactive strength index (RSI) measures how effectively an athlete can produce explosive force in a very short time frame, making it especially valuable for sports where quick direction changes and rapid movements are critical. (Flanagan & Comyns, 2008).

A high RSI denotes efficient neural drive and muscle-tendon unit stiffness. Athletes with low RSI may benefit from reactive plyometrics, fast eccentric work, or coordination drills.

Rate of force development (RFD)

As previously introduced, RFD is especially informative when measured during explosive isometric tasks, such as the isometric mid-thigh pull (IMTP) or during the initial 200 ms of a jump. It reflects the neuromuscular system's capacity to rapidly **recruit motor units**, a vital quality for performance in time-limited tasks.[16]

- A **high RFD** corresponds with better take-off performance and shorter contraction times.
- A **low RFD**, despite high peak force, may indicate neuromuscular sluggishness or inefficiency in intermuscular coordination.

RFD is best assessed using force plates, but approximations are possible using high-frequency linear encoders.

Time–force–velocity curves

Using a force plate or high-speed motion capture allows practitioners to generate detailed time-force, time-velocity, and power-time curves. These profiles reveal not only when force is produced, but how it is distributed over the contraction. Parameters such as:

- Time to peak force
- Force at take-off
- Power curve shape

offer valuable diagnostic insights. For example, some athletes may reach peak power early but with low RFD, while others may need longer to develop force—an important distinction for training design.

Isometric and dynamic strength tests

Tests such as the isometric squat, IMTP, or 3–5RM squat provide baseline assessments of lower-limb strength capacities. These are particularly relevant when jump tests suggest force-deficiency (e.g., low F_0 in the F–v profile or long contraction time despite low jump height).

Isometric tests offer high reliability with reduced injury risk and allow clear interpretation of maximal voluntary force output without movement artifacts (Table 1).[17]

Table 1 Application Summary

Test	Key parameter	Diagnosis	Training implication
SJ vs CMJ	EUR	SSC efficiency	Plyometrics vs strength
DJ	RSI	Fast SSC/ reactivity	Reactive training
IMTP	RFD	Explosiveness	Neural drive focus
Force curve	CT, peak F	Strategy insight	Technique or strength
Isometric squat	Peak force	Max strength baseline	Heavy resistance training

Interpreting the data: identifying strengths and weaknesses

A crucial step following the collection of vertical jump data is interpreting the results in a way that directly informs training. Rather than relying solely on normative comparisons, the integration **of force–velocity profiles, neuromuscular test outcomes,** and **biomechanical indicators** allows practitioners to construct individualized performance models. These models help identify whether an athlete's performance is limited by force production, velocity expression, reactive capabilities, or a combination thereof.

Identifying performance-limiting factors via F–v profiling

Based on the framework established by Samozino and Morin (2012, 2015), athletes can be categorized according to their **actual force–velocity profile** in comparison to their **optimal profile** (i.e., the profile that would theoretically maximize their jump height). This yields three typical profiles:

Force-oriented deficit (F_0-limited): The athlete demonstrates high movement speed but lacks the ability to generate large forces. This profile is often observed in athletes who rely on speed-based actions (e.g., sprinters, jumpers), but lack strength reserve. Training should emphasize maximal strength development using high loads (e.g., squats ≥80% 1RM, isometric training).

Velocity-oriented deficit (V_0-limited): The athlete can produce high force but has limited movement speed or stiffness, possibly due to excessive body mass or low neural efficiency. Training should focus on high-velocity actions, such as jump squats with low loads, resisted sprints, and ballistic movements.

Well-balanced profile: The athlete's F–v profile is close to the optimal curve, with balanced F_0 and V_0 values. In this case, training should aim to increase overall **Pmax** and maintain efficiency through mixed methods (e.g., contrast training, complex training).

The **magnitude of F–v imbalance**—expressed as a percentage difference from optimal—can be used to prioritize which qualities need attention. Research has shown that correcting this imbalance results in superior improvements in jump height and power output compared to generic programs (Jiménez-Reyes et al., 2017).

Interpreting complementary variables

Additional performance indicators help validate and refine this interpretation:

- **Low CMJ but normal SJ** → Indicates poor SSC utilization. Focus: eccentric and plyometric training.
- **Low RSI with long contact time in DJ** → Suggests reactive strength limitation. Focus: reactive jumps, stiffness drills.
- **Long contraction time with high force output** → Reflects explosive coordination limitations. Focus: rapid movement drills, RFD-specific training.
- **Low RFD despite high peak force** → Signals delayed motor unit recruitment. Focus: fast lifts, isometric explosive pulls.
- **Low impulse despite high velocity** → Indicates poor ability to apply force over time. Focus: technique, deceleration strength.

Case-based example

Let's consider two athletes with the same jump height (e.g., 45 cm), but with different profiles:

Athlete A has low F_0, high V_0, low RFD, and low SJ compared to CMJ.

Interpretation : Force deficient, elastic compensator.

Recommendation : Prioritize strength training with slow eccentrics and isometrics.

Athlete B has high F_0, low V_0, low RSI, and similar SJ and CMJ.

Interpretation : Velocity-deficient, underutilizes SSC.

Recommendation: Focus on speed-strength, bounce-type plyometrics, and coordination drills.

Prioritization and training transfer

Each diagnosis must be linked with an appropriate **training focus** that aligns with the physiological adaptation required. Practitioners should also account for sport-specific demands (e.g., volleyball vs. sprinting), the athlete's training age, and injury history.

Progress should be monitored periodically using **simple re-testing** of jump parameters and F–v profiles to assess whether the selected training is effectively shifting the athlete's profile toward the optimal.

Practical application to training

Once vertical jump performance has been accurately assessed and interpreted, the next critical step is designing a training intervention that directly targets the identified mechanical limitations. The force–velocity profiling model, combined with neuromuscular diagnostic tools, allows practitioners to deliver precision-based programming—moving away from one-size-fits-all approaches and toward interventions that correct individual imbalances and enhance performance more effectively.

Training goals based on profile type

Each athlete will exhibit a unique combination of mechanical strengths and deficiencies. Based on F–v profiling and complementary jump diagnostics, training should be prioritized as follows: (Table 2)

Table 2

Profile type	Deficit	Primary focus	Training strategies
Force-deficient	Low F_0	Maximal and relative strength	Heavy squats, isometric holds, slow eccentrics
Velocity-deficient	Low V_0	Movement velocity, neural drive	Jump squats (30–40% 1RM), ballistic training, sprints
Reactive-deficient	Low RSI or SSC usage	Fast SSC utilization	Drop jumps, depth jumps, rebound hops
Explosiveness-deficient	Low RFD	Rate of recruitment	Olympic lifts, band-resisted movements, explosive pulls
Technique-limited	Long contraction time	Movement efficiency, coordination	Jump drills with verbal cues, contrast and complex sets

Periodization and programming examples

Depending on the profile, practitioners can prioritize one block over others in their programming cycle:

- **Force block (4–6 weeks):** Emphasis on high-load resistance training Back squats, deadlifts, leg press, tempo squats (3-0-1-0), heavy split squats
- **Velocity block (3–5 weeks):** Use of light loads at maximal speed Jump squats (30–40% 1RM), trap bar jumps, sprint bounding, resisted jumps
- **Power block (mixed):** Combination of moderate loads, ballistic actions Loaded CMJ, kettlebell swings, push press, velocity-based training
- **Plyometric block (2–4 weeks):** Neuromuscular reactivity and SSC efficiency Drop jumps, hurdle hops, single-leg rebounds, contrast training

Each phase should be supported by mobility, core stability, and movement pattern refinement to ensure efficient force transfer.

Training prescription based on diagnostic variables

A simple decision matrix can be used based on key variables:

- **LowF₀:** Emphasizemaximalstrength(≥85%1RM)2–3x/week Include isometric squats and tempo-controlled lifts
- **LowV₀:** Emphasize unloaded jump performance and sprint drills Use elastic resistance or band-assisted jumps for overspeed effect
- **Low RSI or long ground contact:** Train with short-contact plyometrics(dropjumps ,pogohops) Include ankle stiffness and footwork drills
- **Low RFD:** Olympic lift derivatives (e.g., hang clean, mid-thigh pulls) Complex training (heavy lift followed by explosive jump)

Monitoring and reassessment

Training interventions should be monitored using:

- Bi-weekly or monthly re-assessments of CMJ, SJ, DJ
- F–v profiling every 4–6 weeks
- Trend analysis of contraction time, RSI, and take-off velocity

Athletes who shift toward a more optimal profile with improved Pmax typically show better transfer to sports performance tasks like sprinting, cutting, and rebounding.[13]

Integration with sport-specific demands

Finally, training interventions must be contextualized within the sport-specific calendar and biomechanical demands:

- **Volleyball players** may need greater focus on reactive strength and multi-jump efficiency.
- **Track and field jumpers** require maximal power and take-off stiffness.
- **Team sport athletes** benefit from general Pmax enhancement and injury-prevention-oriented eccentric work.

Careful manipulation of load, velocity, contact time, and fatigue allows coaches to balance performance enhancement with injury prevention, especially in congested competition periods.

Vertical jump performance is a cornerstone of athletic explosiveness and a reliable indicator of lower-limb neuromuscular capabilities. However, assessing jump height alone is insufficient for understanding the individual mechanics that drive performance or for prescribing effective, targeted training. This review has outlined a comprehensive framework that integrates **force–velocity profiling, neuromuscular diagnostics**, and **biomechanical indicators** to enable practitioners to identify specific performance-limiting factors in each athlete.

The force–velocity profile, as developed by Samozino and colleagues, provides a powerful, field-friendly method for quantifying the balance between an athlete's force and velocity capabilities, allowing coaches to detect whether an individual is force-deficient, velocity-deficient, or well-balanced. Complementary tests such as the squat jump, countermovement jump, drop jump, and rate of force development assessments add further resolution to this diagnosis, revealing limitations in SSC utilization, reactive strength, or coordination.

Once performance strengths and weaknesses are identified, training can be precisely tailored to address them—whether through maximal strength development, velocity-based training, reactive plyometrics, or power-focused mixed methods. Periodic reassessment ensures that adaptations are occurring in the intended direction, and that training remains aligned with the athlete's evolving needs and sport-specific demands.

In summary, combining biomechanical assessments with neuromuscular evaluations and tailored data interpretation empowers coaches to design training strategies that are specific to each athlete's profile. This shift from generic methods to personalized interventions has the potential to boost jump performance, reduce injury risk, and enhance overall athletic efficiency and development.

Final takeaways

Vertical jump testing should include multiple mechanical and neuromuscular variables—not just jump height.

Force–velocity profiling offers a valid, field-based method for individualized performance analysis.

Athletes can be categorized as force-deficient, velocity-deficient, or balanced, guiding specific training priorities.

Neuromuscular tests (RFD, RSI, contraction time) refine diagnosis and support training specificity.

Individualized, imbalance-corrective training is more effective than traditional, uniform programs.

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Conflicts of interest

Authors declare that there is no conflict of interest.

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