

# Objective Measurement in Performance and Rehabilitation: Bridging Science, Technology, and Clinical Outcomes

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## ABSTRACT

Objective measurement is increasingly essential in sports medicine, physical therapy, and performance science. However, clinical practice still heavily relies on subjective assessments, resulting in variability in diagnosis, rehabilitation, and return-to-play decisions. This review proposes a comprehensive model that integrates strength diagnostics, force-time analysis, movement profiling, and longitudinal patient monitoring to improve decision-making reliability and precision. Drawing on current scientific literature, it outlines how force plates, dynamometry, load monitoring tools, and physiological metrics can be harmonized into a “Clinical-Performance Pipeline.” Practical applications are detailed across baseline assessment, injury surveillance, rehabilitation progression, and return-to-sport thresholds. A particular emphasis is placed on the “longevity” aspect of muscular strength and power outputs — not only as performance markers, but as prognostic indicators of long-term health, functional independence, and survival. The review concludes by exploring future directions, including predictive analytics and digital twin technologies.

**Keywords:** Objective Measurement, Force Plates, Dynamometry, Grip Strength, Muscle Power, Rehabilitation, Longevity, Digital Health, Clinical Outcomes, Physiotherapy, Physical Therapy

## Introduction

Musculoskeletal injuries continue to challenge sports medicine, orthopedic practice, and physical therapy. Despite technological advances, subjective assessments — such as manual muscle testing, visual gait inspection, or patient-reported pain and function scales — still dominate clinical workflows. While these tools are useful, they suffer from inter-rater variability and lack sensitivity to subtle deficits, asymmetries, or performance capacity.

Objective measurement tools offer quantifiable, reproducible data on neuromuscular performance, asymmetry, and physiological readiness. Technologies like force plates,

dynamometers, velocity-based training (VBT) devices, and wearable sensors are increasingly common in elite sport — but remain underutilized in broader clinical or rehabilitative settings due to barriers including cost, workflow disruption, and limited clinician familiarity.

This review aims to:

- Summarize the rationale for objective measurement in rehabilitation and performance;
- Present an integrated clinical model combining diagnostics, monitoring, and decision thresholds;
- Offer a practical framework for clinicians;
- Discuss the “longevity” dimension of strength/power metrics (e.g., grip strength, muscle power) as prognosticators for long-term health outcomes;
- Outline future directions, including predictive analytics, digital twins, and population-level normative data collection.

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## The Objective Measurement Ecosystem

### Force Diagnostics

Force plates represent one of the most widely validated technologies for capturing neuromuscular output during dynamic tasks — e.g., countermovement jumps (CMJ), squat jumps, drop jumps, and isometric mid-thigh pulls (IMTP). These platforms record ground reaction forces and allow derivation of metrics such as peak force, rate of force development (RFD), impulse, and inter-limb asymmetry. Such variables offer insight into mechanical efficiency, neuromuscular fatigue, and recovery status. In athletic populations, they have demonstrated relevance in identifying performance deficits and correlating with injury risk or readiness to return.

However, despite strong validation in controlled conditions, translation into everyday clinical practice remains limited. Equipment cost, need for space, calibration, data interpretation challenges, and limited clinician training remain significant barriers. Integration into a unified clinical model requires protocol standardization, clinician education, and streamlined workflows to make force diagnostics practical outside of research or high-performance settings.

### Strength Diagnostics

#### Dynamometry and Beyond

Isokinetic and handheld dynamometers provide objective quantification of muscle strength in a clinical context. These tools enable measurement of peak torque (e.g., knee extension/flexion), angle-specific force, bilateral strength ratios, and fatigue indexes. They are particularly valuable in rehabilitation when monitoring recovery post-surgery or injury — for example, persistent hamstring weakness following anterior cruciate ligament (ACL) reconstruction.

Dynamometry offers high reliability and sensitivity compared to manual muscle testing. In clinical settings, repeated measurements over time can detect strength deficits that may otherwise go unnoticed, enabling data-driven decisions on rehabilitation progression, limb symmetry restoration, and return-to-function readiness.

### Movement Velocity, Load Monitoring & Field-Based Wearables

Velocity-based training (VBT) devices — e.g., linear position transducers, accelerometers embedded in bars or wearables — provide insights into movement quality and neuromuscular readiness by tracking bar speed, load-velocity profiles, and power output. When combined with external load measures (accelerations, decelerations, step counts) and internal load indicators (heart-rate variability, sleep, recovery), they offer a comprehensive picture of an individual's training and recovery status.

Recent advances in inertial measurement units (IMUs) — integrating accelerometers, gyroscopes, and magnetometers — allow field or clinic-based assessments of jumps, hops, squats, and drop jumps. These systems make standardized neuromuscular testing more accessible outside of laboratories or high-performance centers. When merged with GPS modules and physiological sensors, clinicians and coaches can monitor both mechanical and physiological stress — valuable in injury

prevention, rehabilitation, and return-to-sport/work decision-making.

### Physiological Metrics

Beyond mechanical output, physiological readiness and tissue health remain central to injury resilience and long-term functional capacity. Tools such as DXA scans enable assessment of body composition, bone mineral density, and segmental asymmetries. Cardiovascular fitness (via  $\text{VO}_2$  testing), metabolic rate (resting metabolic rate assessments), and recovery markers (heart rate variability, sleep quality, nutrition status) add an important dimension to neuromuscular profiling.

Poor recovery — indicated by disrupted sleep or persistent autonomic imbalance — has been associated with increased injury risk, suboptimal adaptation, and prolonged recovery times. Therefore, integrating physiological metrics with mechanical assessments enhances the interpretability of performance and rehabilitation data.

### Integrating Measurement into a Unified Clinical Framework

#### Baseline Diagnostic Profile

A comprehensive baseline evaluation is foundational. For patients or athletes, this should include objective strength testing (dynamometry), force plate assessments or jump/power tests (where feasible), movement screens for mobility and biomechanics, and physiological evaluations, including body composition and recovery indicators. In settings without lab-grade infrastructure, wearable sensor technologies and field-based assessments provide alternative but valid baseline data.

#### Longitudinal Monitoring

Objective measures yield maximal value when repeated over time. Clinicians should monitor trends in force output, limb symmetry, jump/power metrics, training load, and recovery indicators. Wearable sensors, when integrated with GPS-enabled devices and physiological monitoring, facilitate ongoing surveillance during training, rehabilitation, and daily living. This enables detection of neuromuscular fatigue, load accumulation, maladaptation, or recovery deficits — all of which may predispose to reinjury or suboptimal long-term outcomes.

#### Early Warning Indicators

One of the greatest advantages of objective monitoring is the ability to detect early signs of dysfunction or risk before they manifest clinically. Indicators may include increasing inter-limb asymmetry (e.g.,  $>10\%$ ), declining RFD or power output, reduced jump impulse, prolonged suppression of HRV, or consistently poor sleep/recovery metrics. Frequent, ecologically valid assessments using wearables and field based tools improve sensitivity and allow for earlier, data-driven interventions.

#### Targeted Interventions

Based on the diagnostic data, interventions can be individualized. For strength imbalances: eccentric or isometric training; for reduced power or RFD: plyometric progressions; for load mismanagement: adjusted periodization; for recovery deficits: lifestyle or recovery focused interventions (sleep hygiene, nutrition, load reduction, etc.). Objective feedback enables clinicians to fine-tune rehabilitation or training programs, optimizing outcomes and minimizing reinjury risk.

### Return-to-Performance Thresholds

Return-to-sport or work decisions should integrate objective thresholds to promote safety and functional readiness. Potential criteria might include: restoration of  $\geq 90\%$  limb strength symmetry, normalization of jump/power metrics (e.g., CMJ, reactive strength index), and stable recovery indicators (e.g., HRV, sleep). Where applicable, sport- or task-specific performance and movement-quality tests should be added to ensure readiness for the demands of the intended activity.

### The Longevity and Health span Perspective: Why Strength and Power Matter Beyond Performance

Historically, objective measurement in rehabilitation and performance has focused on short-term outcomes: injury recovery, return-to-play, performance optimization. However, accumulating evidence now supports a broader, long-term health relevance — particularly for muscular strength, and increasingly, muscular power — as predictors of healthy aging, functional independence, and survival.

### Grip Strength and Long-Term Outcomes

The measure most extensively studied in this regard is handgrip strength (HGS), typically assessed with a handheld dynamometer. Multiple large-scale epidemiological studies and meta-analyses now show that lower grip strength is strongly associated with higher all-cause mortality, greater risk of cardiovascular mortality, and increased disability.

For example:

- A 2018 meta-analysis including 38 studies and nearly 1.9 million participants found that individuals with higher grip strength had a 31% lower risk of all-cause mortality compared with those with low strength (HR = 0.69; 95% CI, 0.64–0.74).
- A 2024 large cohort study confirmed that absolute grip strength (or grip strength normalized to height squared) was the optimal predictor for all-cause mortality across sexes and ages, with the lowest 20% grip strength group showing hazard ratios of 2.20 (men) and 2.52 (women) compared with higher strength groups.
- Another 2022–2023 meta-analysis demonstrated a dose response relationship between incremental handgrip strength and reduced mortality risk, especially in older adults. In that study, no clear upper threshold of protective effect was identified for individuals over 65 years old, suggesting that “more strength is better” — at least within normative ranges.

Earlier longitudinal work showed that individuals with greater grip strength in midlife were more likely to remain functionally independent in old age and had lower risk of disability, irrespective of chronic comorbidities.

Given its simplicity, low cost, and strong prognostic value, some have proposed adopting handgrip strength as a “vital sign” in clinical practice.

### Beyond Grip

#### The Emerging Role of Muscle Power

While grip strength remains the most studied metric, recent work is beginning to examine muscle power — defined as force  $\times$  velocity — as a potentially superior prognostic marker. A new

longitudinal cohort study (2025) evaluated both muscle power and static strength in middle-aged to older men and women, finding that muscle power outperformed strength as an indicator of all-cause mortality risk.

This aligns with conceptual and physiological reasoning: power reflects not just maximal force capacity, but the ability to generate force quickly — a quality critical for functional tasks such as rising from a chair, avoiding a fall, reacting to perturbations, or performing activities of daily living. Because power typically declines more rapidly than strength with age, it may provide a more sensitive early warning of functional decline and increased mortality risk.

### Implications for Rehabilitation, Physical Therapy, and Clinical Practice

The epidemiological links and prognostic value of strength/power metrics like grip strength or muscle power argue strongly for their inclusion in routine clinical assessments — not only in sports medicine or rehabilitation, but in general orthopedic and physiotherapy practice, especially for middle-aged and older adults.

- **Functional reserve and independence:** Maintaining or restoring strength and power may delay or prevent age-associated functional decline, frailty, and disability.
- **Prognostic value:** Metrics such as grip strength and muscle power provide prognostic information on mortality, disability, and long-term health, beyond traditional risk factors.
- **Rehabilitation prioritization:** Rehabilitation and strength conditioning protocols should emphasize not only strength restoration, but also power development (e.g., via velocity- or plyometric-based training), particularly in older or deconditioned patients.
- **Public health and prevention:** Early detection of low strength/power via simple tools (e.g., dynamometry) can prompt preventive interventions long before overt disability or disease develops.

### Integrating Longevity Measures into the Clinical-Performance Pipeline

Given the emerging evidence, we propose expanding the Clinical-Performance Pipeline (from Section 3) to include a “Longevity & Health-span Module,” with the following elements:

- **Baseline screening of strength/power:** Include grip strength (via dynamometer) and — where feasible — lower-limb power or global muscle power assessments (e.g., sit-to-stand power test, countermovement jump, leg press velocity) as part of routine clinical assessment, especially for patients over midlife.
- **Regular monitoring over years:** Periodic reassessment (e.g., annually or bi annually) to track trajectories of strength/power decline, allowing early detection of accelerated decline or increased risk.
- **Intervention triggers:** Define thresholds or “red-flag” cutoffs (e.g., below age- and sex-specific normative percentiles) that trigger preventive or rehabilitative interventions (strength training, power training, lifestyle optimization).
- **Integration with broader health data:** Combine strength/power data with other metrics (body composition, bone

density, cardiovascular fitness, lifestyle, recovery) to build a multidimensional profile of health-span, resilience, and biological aging.

- **Patient-centered goal setting:** Use strength and power assessments to set long-term functional and health goals — e.g., maintenance of independence, reduction of fall risk, improved quality of life, enhanced physiologic reserve.

### Challenges and Limitations

Despite these compelling opportunities, several challenges remain:

- **Infrastructure and workflow:** Many clinics may lack access to dynamometers, force plates, or VBT devices. Even when available, integrating them into busy clinical workflows requires time, training, and resources.
- **Normative data and standardization:** While population-level studies exist (particularly for grip strength), normative reference curves stratified by age, sex, body size, and ethnicity remain incomplete — especially for power metrics and lower-limb outputs.
- **Causality vs. association:** Most evidence linking grip strength or muscle power to mortality or functional outcomes is observational. It remains uncertain to what degree improving these metrics (via training or rehabilitation) will causally reduce long-term risk. Interventional trials are needed.
- **Patient heterogeneity:** Comorbidities, chronic diseases, and individual lifestyle factors affect strength, power, and health outcomes — complicating interpretation and risk stratification.
- **Data management and privacy:** Longitudinal monitoring and data integration raise issues of data storage, privacy, interoperability, and clinician burden.

### Future Directions

- **Predictive analytics and digital twins:** By combining longitudinal strength/power data with physiological, biomechanical, and lifestyle metrics, clinicians can build predictive models of health-span, injury risk, and functional decline. Digital twin approaches — patient-specific simulated models — may help forecast trajectories and optimize individualized interventions.
- **Normative database development:** Large-scale, multicenter efforts should collect longitudinal strength and power data across diverse populations to establish normative reference values and risk thresholds.
- **Clinical implementation research:** Investigate how to integrate objective measurement tools into routine orthopedic and physical workflows — including cost-benefit analyses, clinician training, patient adherence, and data management systems.
- **Patient-centered outcomes:** Broaden outcomes beyond performance or return-to-play — focusing on long-term function, independence, quality of life, fall risk, metabolic and cardiovascular health, and mortality.

### Conclusion

Objective measurement of neuromuscular performance — via force diagnostics, dynamometry, velocity-based or wearable-based monitoring — offers powerful advantages over subjective assessments in rehabilitation and performance settings. When

extended beyond short-term injury recovery and performance endpoints, strength and power metrics (particularly grip strength and muscle power) emerge as robust biomarkers for long-term health, functional capacity, and survival.

By incorporating a “Longevity & Health-span Module” into a unified Clinical-Performance Pipeline, clinicians and physical therapists can move toward a proactive, preventative paradigm — using data-driven thresholds to identify risk, personalize interventions, and monitor long-term outcomes. As predictive analytics, normative databases, and clinical implementation mature, objective measurement is poised to shift from the domain of elite sport into mainstream orthopedic and physical therapy practice — ultimately promoting healthier aging, prolonged independence, and improved quality of life [1-20].

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