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Strength Classification and Diagnosis: Not All Strength Is Created Equal

Lachlan P. James, PhD, CSCS,[1] Scott W. Talpey, PhD, CSCS,[2] Warren B. Young, PhD,[2] Mary C. Geneau, MSc, CSCS,[1] Robert U. Newton, PhD, DSc, CSCS, FNSCA,[3] and Paul B. Gastin, PhD[1]
[1]Sport and Exercise Science; School of Allied Health, Human Services and Sport; La Trobe University, Victoria, Australia; [2]School of Science, Psychology and Sport, Federation University Australia, Victoria, Australia; and [3]School of Medical and Health Sciences, Edith Cowan University, Western Australia, Australia

ABSTRACT

Maximal force can be expressed across a range of conditions influenced by the external load and the time available to express force. As a result, several distinct and specific strength qualities exist. Conversely, some expressions of maximal force are similar and can be categorized as a single quality. Therefore, strength assessment systems must be sophisticated enough to isolate and measure each quality while minimizing redundant information. This article presents a contemporary, evidence-based and practical framework that reduces the many strength and speed-strength metrics into 5 distinct qualities. Alongside this, we present case examples of the application of strength diagnosis.

INTRODUCTION

Performance diagnosis is the process of test selection and administration to quantify relevant physical capacities, analysis of the resulting data to identify strengths and weaknesses, and targeted training prescriptions to address the revealed deficiencies (42,47,64). Application of this process allows coaches and scientists to classify the relative importance of physical qualities to performance in a chosen sport to inform training, to develop an athlete's physiological profile, and to monitor the training process to determine if the desired goals have been met (45,47). Performance diagnosis, therefore, allows resources to be directed to the areas of greatest need with the ultimate goal of improving the physical preparation process for enhanced sport performance and increased athlete well-being.

Address correspondence to Dr. Lachlan P. James, l.james@latrobe.edu.au.

Of particular interest to practitioners is the assessment of maximal strength qualities (i.e., the ability to apply force maximally, in a single action, under particular conditions). Although considerable research has been placed on the reliability of strength assessment and data processing methods (4,10,34,38), it is important first to understand which tests and measures should be included in strength diagnosis models. Specific and independent strength qualities exist (64), and it is therefore vital that diagnosis systems are sophisticated enough to isolate and measure each quality while simultaneously minimizing redundant information.

SPECIFIC STRENGTH QUALITIES

Empirical investigation into distinct strength qualities was undertaken in the early to mid-1970s (29,30) with solutions generally based on upper versus lower body and ballistic versus nonballistic tasks in samples of university students. In-depth systematization of athlete strength assessment was developed through research and professional practice by leaders in the field such as Schmidtbleicher (46), Häkkinen (25), and Bosco (58), who described specific neuromuscular responses elicited by heavy strength training and different forms of jumping. Knowledge at the time was furthered by the doctoral work of Young (64) in the 1990s, who identified the independence of leg extensor strength factors such as high velocity dynamic strength (e.g., quantified by the countermovement jump [CMJ] and squat jump [SJ]), reactive strength (derived from a drop jump where contact time was minimized), and isometric strength (extracted from an isometric squat test). Two decades ago, Newton and Dugan (43) proposed a model containing the following strength qualities: maximal strength, high-load speed-strength, low-load speed-strength, rate of force development, reactive strength, and skilled performance, in an important practical article published

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in this journal to present a pragmatic system to be easily applied in practice.

However, amid the increased volume and availability of information (from practical literature to popular social media), the next generation of practitioners need to be cognizant of strength classification. To this end, we are revisiting this topic on the 20th anniversary of the Newton and Dugan (43) article. In the contemporary training environment, electronic and wireless technology improvements have allowed data streams to become more easily available to the strength and conditioning coach (55), which may cloud parsimonious and valid application of strength diagnosis if not used appropriately. Furthermore, the body of knowledge on the existence of specific strength qualities has increased considerably over the last 20 years, which has provided deeper insight into the area and enables a re-examination of the boundaries between different forms of strength expression.

There is a need for an empirical, evidence-based discussion to separate knowledge from colloquial opinion and anecdotal information. This article provides a contemporary resource for the practitioner to understand the various and distinct forms of strength, how they can be assessed, deficits in certain qualities diagnosed and reported, and intelligent and informed decisions on training program design determined, implemented, and evaluated. A specific focus is placed on multi-joint dynamic and isometric actions of the lower extremity because these are most influential in the widest variety of sports.

Here, we present a practical framework informed empirically by the scientific literature and applied practice that reduces the many strength and speed-strength metrics into 5 distinct qualities (Figure 1) that share limited commonality ($r^2 < 0.50$, indicating more uniqueness than sameness) (3,18,66) and external load-time characteristics (Figure 2). These are as follows: (a) maximal isometric strength; (b) explosive strength; (c) heavy maximal dynamic strength; (d) fast maximal dynamic strength; and (e) reactive strength.

However, it is important to note that isolating aspects of strength expression is a complex process that is confounded by factors such as the sport, training history of the athlete, resistance training age, adaptability to training, and the training status within a competitive season (50), and boundaries may therefore overlap in some cases. Nonetheless, it is hoped that this article provides a contemporary model to aid practitioners and inspire future research into the topic.

ASSESSING STRENGTH QUALITIES

MAXIMAL ISOMETRIC STRENGTH

The greatest amount of force applied to an unyielding object, regardless of the rate or ability to sustain the effort, represents maximal isometric strength (24,61,70). Because it is considered an expression of strength in its purest form (not affected by changes in skeletal geometry and muscle mechanical characteristics), maximal isometric strength is of notable interest to practitioners. In the context of strength and conditioning, this attribute is assessed in a mid-range or key body position replicating a primary dynamic lift or movement, such as a squat or midthigh pull (36). The athlete applies maximal force to an immovable bar for 2–5 seconds while a force platform, load cell, strain gauge, or tensiometer system is used to quantify force production (22). It is important to consider that even when the isometric position is replicated dynamically under maximal loads (i.e., heavy maximal dynamic strength [MDS]), such as an isometric squat and one repetition maximum (1RM) back squat or isometric midthigh pull (IMTP) and 1RM power clean, it generally demonstrates a commonality of approximately 14–50% in athletes who are not competitive weightlifters (36). The shared variance between isometric and heavy MDS performance tends to be higher when comparing heavy training lifts in competitive weightlifters to their IMTP peak force output (69–86%) (23,24). In these exceptional cases, maximal isometric and heavy dynamic strength can be considered a very similar quality. Although capable of detecting training induced changes in performance, maximal isometric strength may not respond to training in the same way as heavy MDS

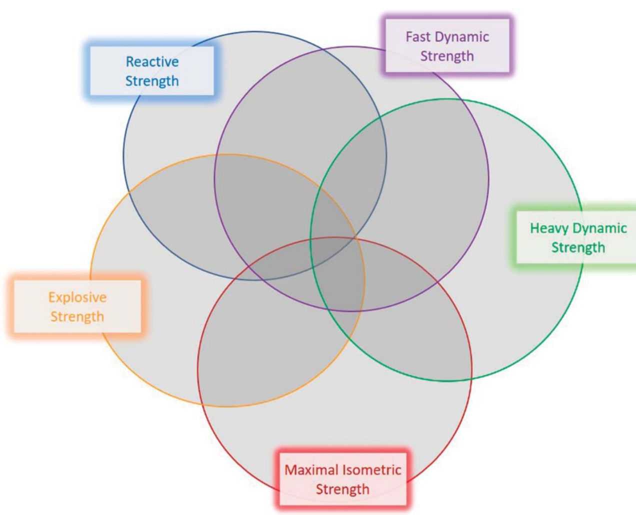

Figure 1. Schematic Venn diagram representing the independent strength qualities. Although each has a degree of overlap with the others, they are empirically distinct enough to be considered unique. Regions of overlap are illustrative only and not to scale.

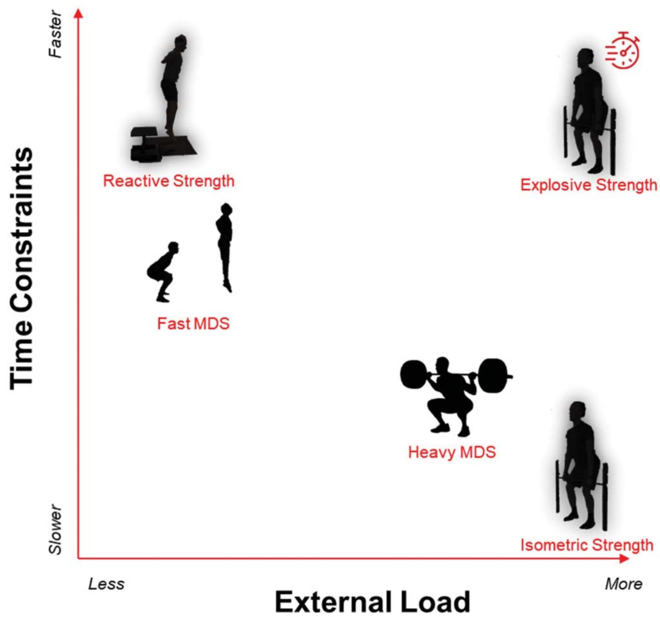

Figure 2. Each strength quality contains a different combination of external load and time constraint characteristics. MDS = maximal dynamic strength.

(7,13,15,32,54). Taken together, maximal isometric strength can therefore be considered an independent form of strength expression in almost all cases.

The cue to produce maximal force in such isometric tests is typically "hard and fast" (22). However, a gradual rise to peak force over several seconds has also been used (48,63). This slow build-up to peak force is often used during the isometric squat to reduce injury potential from a sudden and maximal axial loading from a bar placed across the shoulders (62). It is unclear how the maximal force output differs between a fast and slow cue in these tests, so it is recommended that cues are consistent when comparing within and between athletes. Tests of maximal isometric strength are also appealing because they have low injury risk, are nonfatiguing, and take minimal time when assessing individuals or small groups. However, because specialized equipment and instrumentation are required, it can be challenging to test large squads in the available time. Because maximal strength measured by the IMTP and isometric squat represent somewhat similar strength qualities (44), the decision on which to use can be made by the judgment of the practitioner and might consider factors such as athlete preference and training experience, size, and transportability of the platform and rig, standardization of position, setup, and familiarization time.

EXPLOSIVE STRENGTH

Explosive strength is another strength quality that can be quantified from the previous isometric tests. In technical terms, this refers to a measure of early-stage (0.030–0.150 seconds) force production during an isometric test and is often referred to as rapid or fast force production in research settings. Explosive strength includes quantities such as rate of force development (RFD) (change in force/change in time), time-specific impulse (the area under a specified portion of the force-time curve), or the instantaneous force at a given time point (57). Although RFD was recognized by Newton and Dugan (43) as a unique strength quality derived from either isometric or fast dynamic tests (e.g., CMJ), our definition restricts the description to high external load conditions. This is because measures extracted from the CMJ share very little commonality (<1–30%) to isometric RFD.

Based on a typical force-time curve, maximal strength is not achieved in isometric conditions until 0.60–2.50 (27) seconds after onset. Most athletic tasks (e.g., high speed running, jumping from a run-up) require force application as short as 0.100–0.200 seconds (1,53); thus, practitioners need to measure the force produced in the early stages of the force-time curve.

The instructions should maximize "fast" force production and are conventionally combined with a "hard" cue (e.g., pull or push as hard and as fast as possible). To properly assess explosive strength, the time frame must be brief enough to sufficiently distinguish it from the peak force measure (i.e., maximal isometric strength) (Figure 3). For example, 76% of the variance in force at 0.250 s can be explained by maximal isometric strength (8), indicating that they are testing a similar muscular performance quality. The threshold where explosive strength becomes isolated from maximal isometric strength seems to be 0.150 seconds, with an explained variance of 52% (11) and 48% (8) reported. Therefore, it is recommended to use a measure that occurs no later than 0.150 seconds from the onset of effort.

HEAVY MAXIMAL DYNAMIC STRENGTH

The most common method for assessing heavy MDS is via a 1RM, 3RM, or 5RM test and is therefore very familiar to practitioners. As previously highlighted, this quality is independent of maximal isometric strength, particularly when tracked longitudinally. A very low explained variance exists between MDS in heavy conditions and explosive strength, particularly at early time points (0.050 seconds = ~2%, 0.100 seconds = 10–40%, 0.150 seconds = 20–45%) (8,19,56). The higher end of the range is generally found when comparing explosive IMTP values to heavy MDS in

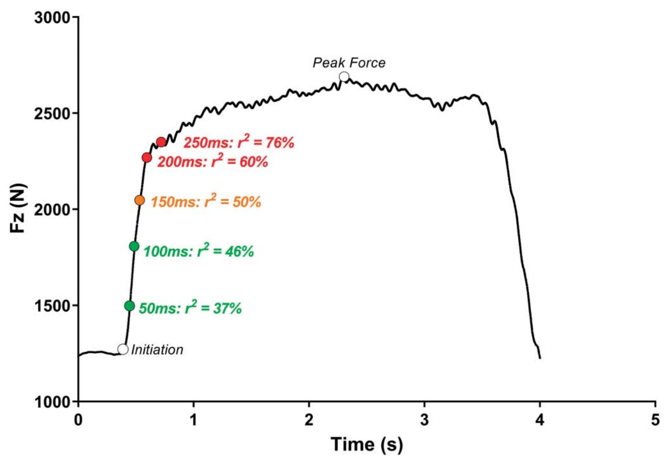

Figure 3. Commonality (represented by the coefficient of determination—r^2) between explosive strength measured at different timepoints and peak force in the isometric squat. A similar pattern exists for the isometric midthigh pull. The lower the r^2, the more new information the variable contains, which is important for valid strength assessment models.

weightlifting actions among competitive weightlifters (8).

Although the equipment needed for an RM test is minimal, the time taken to perform these tests and the requirement to achieve failure can limit the feasibility of these tests and prevent frequent monitoring (e.g., weekly). In the last 20 years, considerable progress in training technology, such as force platforms, accelerometers, and linear position transducers, has made these systems readily available to coaches at nearly all levels. When accompanied by such devices, submaximal loads moved with maximal intent in a nonballistic (e.g., back squat) or ballistic (e.g., jump squat) manner can provide an objective outcome measure (e.g., vertical velocity and peak vertical force) that is representative of dynamic strength under heavy loads. This is because there is a linear and near-perfect relationship between relative external load and barbell mean velocity (4,59). For example, using velocity at a series of incremental loads up to 90% 1RM will explain 86% of the true 1RM, however this is reduced to approximately 60% when the heaviest load is 60% of 1RM (4). Although 30% of 1RM was originally proposed as the cutoff between heavy and fast dynamic strength (43), training with these loads results in very little 1RM improvements (~5%) when compared with training intensities of 75–90% 1RM (~30%) (15). From a practical perspective, the velocity (or peak force) of a single repetition at a load approximately ≥80% 1RM can represent a heavy MDS characteristic (see Weakley et al. (59) for more information). Because the proximity to failure is relatively low compared with an RM test, these assessment methods can be performed more frequently and easily integrated into the training process. An assessment of heavy MDS typically contains both an eccentric and a concentric phase but can also be designed to isolate each phase. However, performance across these conditions is highly interrelated. For example, Spiteri et al. (49) demonstrated an 85% commonality between traditional 1RM back squat strength and 1RM eccentric only back squat strength. In most cases, practitioners will, therefore, only require one of these forms of heavy MDS assessments.

FAST MAXIMAL DYNAMIC STRENGTH

This quality is defined by an expression of force produced maximally against no or little additional load over somewhat quick movement times (>0.30 seconds). The most common test of fast MDS is the CMJ, although the squat jump (no countermovement) can also be used. The commonality to each of the other strength qualities ranges from 20 to 40%, and variation can occur based on population and training status (36,51,52,69).

Depending on the instrumentation used, a multitude of variables can be derived from the CMJ or SJ test (14,21). In its simplest form, the vertical jump or squat jump can give a measure of jump height with only chalk on the wall or a jump-and-reach-device, and this alone can be an acceptable measure of fast MDS. Although this may be suitable for sports where jumping tasks are important, it may not be sufficient to fully understand an individual's fast MDS ability. A more sophisticated analysis is often required because the jump output (e.g., height) generally describes only 45–65% of what occurred during the CMJ (33). To address this, a CMJ or SJ can be performed with a force platform, accelerometer, or linear position transducer (37). Such systems can derive multiple variables from the action and potentially provide greater insight into an individual's high velocity MDS. The large number of metrics available from a CMJ or an SJ test can, however, make it challenging for the practitioner to determine which variables possess diagnostic utility (41). Fortunately, most of the variation in CMJ test performance can be explained with only 2 to 3 variables (33,40). Jump height, vertical velocity at takeoff (which dictates jump height), peak vertical velocity, and relative peak power tend to load onto the same statistical factor (i.e., contain very similar information) (33,40). Timing variables (e.g., time to take off, time to peak force/velocity/power) generally represent the second major component of the CMJ (33). Bishop et al. (9) recommend supplementing these with countermovement depth and the ratio of jump height to movement time to better understand what occurred in the jump. The choice of a variable within each factor can then be determined by what is most reliable, interpretable, and relevant to the end user. Practitioners may also compare changes in fast MDS relative to maximal isometric strength (referred to as the dynamic strength index) to help decide when to switch between heavy strength and high velocity training (31,48).

REACTIVE STRENGTH

Reactive strength is the ability to produce force in a short/fast stretch shortening cycle characterized by ground contact times <0.25 seconds (46). Because reactive strength is a measure of an athlete's ability to tolerate and use high stretch loads, it has a strong relationship with activities associated with high eccentric demands, such as sprint running (65), vertical jumps after a run-up (66), change of direction speed (67), and attacking agility (68). Reactive strength seems to be uniquely independent of the other strength qualities, sharing approximately 10, 20, 30, and 35% commonality with maximal isometric (36), explosive (35), heavy (5,20), and fast strength (52,66), respectively.

Historically, a drop jump performed onto a contact mat, force platform, or optical measurement system (e.g., Optojump) from progressively more intense heights (30, 45, and 60 cm) with an instruction to "jump for maximal height with minimal contact time" has been used to assess reactive strength. From this assessment, characteristics of the jump such as height, contact time, and determination of reactive strength index (RSI) as calculated by the jump height or flight time divided by the ground contact time can be used to assess reactive strength capabilities. Additionally, this test has prescriptive utility because the individual's theoretically optimal drop height (that produces the greatest RSI) is superior or equal to other drop heights used in plyometric training at eliciting improvements in reactive strength. A noted limitation of the drop jump test is that extensive familiarization with the movement is needed. It is necessary to provide feedback after each jump to find the balance between contact time and subsequent jump performance (69).

More recently, other tests of reactive strength have been developed to overcome the limitations associated with the drop jump. For example, rebound jump tests have been established where the athlete performs an initial maximal CMJ and, upon landing quickly, rebounds for maximal height with minimal contact time (12). It is hypothesized that rebound jump tests require less familiarization and may better indicate an athlete's ability to repeatedly express reactive strength, such as when sprinting, compared with one-off efforts in a drop jump (26). However, further research is needed to better understand the differences between the 2 tests. Practitioners should note that the more recently proposed metric "reactive strength index modified" is derived from a CMJ and is therefore not a measure of reactive strength but rather strength

Table 1
Example tests and associated metrics for each independent strength quality

Strength quality	Test	Primary metric	Supplementary metric(s)
Maximal isometric strength	Isometric squat or IMTP	Peak force	
Explosive strength	Isometric squat or IMTP	Force or impulse @ ≤0.150 s	
Heavy maximal dynamic strength	1RM or 3RM, or mean velocity at incremental loads to >80% 1RM in a relevant primary lift	The load lifted for RM tests, or the mean velocity of a single repetition at >80% 1RM	
Fast maximal dynamic strength	CMJ or SJ with no, or minimal, additional load	Any one of: jump height, vertical velocity at takeoff, peak vertical velocity, or relative peak power	Any one of: time to takeoff, time to peak force/velocity/power Ratio of jump height or flight time to time to takeoff Countermovement depth
Reactive strength	Drop jump or rebound jump for minimal contact time and maximal height	RSI	Constituent RSI variables (jump height and contact time)

CMJ = countermovement jump; RM = repetition maximum; RSI = reactive strength index; IMTP = isometric midthigh pull; SJ = squat jump.

Table 2
Prioritization of resistance training modalities for each strength quality

Strength quality	Primary training	Secondary training
Maximal isometric strength	Heavy strength training emphasizing a concentric start and end portion RoM	Maximal isometric tasks[a]
Explosive strength	Weightlifting derivatives	Ballistic/plyometrics with minimal countermovement
Heavy maximal dynamic strength	Heavy strength training	Weightlifting derivatives
Fast maximal dynamic strength	Plyometrics (slow SSC)	Heavy strength training and weightlifting derivatives
Reactive strength	Plyometrics (fast SSC)	Plyometrics (slow SSC) and heavy strength training

Practitioners should also consider the impact of existing strength level, opportunities for concentrated loading, and sequencing of training over time.

[a]Although this modality holds the greatest transfer to the maximal isometric strength, it may possess relatively limited transfer to other strength qualities. As such, it has been de-emphasized.

RoM = range of motion; SSC = stretch shortening cycle.

at fast velocities. This is reflected in the limited commonality it shares with DJ-derived RSI (22%) (39). Table 1 summarizes the associated test and metrics for each strength quality.

DIAGNOSING STRENGTH QUALITIES IN SPORT

With an understanding of the distinct strength qualities that exist in athletes, the practitioner must then determine the degree of relevance each holds to outcome and performance in the sport of interest. Perhaps the most critical step in this process is defining what "outcome" and "performance" actually mean, so empirical links to each strength quality can be explored and prioritized. Competition outcome can be defined by factors such as wins or losses, higher versus lower-level players, and ladder rank (17). In sports defined by distance, mass, or time, the results in the respective units directly represent outcome (2). "Performance" is characterized by action variables that occur during competition that are linked (positively or negatively) to competition outcome (28). These indicators are generally derived from notational analysis and can include metrics such as kicks, goals, strikes landed, tackles, and many others, depending on the sport (6). Once the outcome and performance indicators are established, associations to each strength quality can be explored and prioritized. An assessment of the athlete's current capabilities relative to the key strength qualities will enable the strength and conditioning professional to develop a strength profile to inform training interventions.

INTERPRETATION AND TRAINING RESPONSE

Once the most relevant strength qualities for the sport are identified and the athlete's strengths and weaknesses are diagnosed (relative to benchmarks or

Table 3
A comparison of two athletes with similar isometric and explosive strength, but different heavy dynamic strength capabilities

	IsoSq PF/BM, N/kg	F@100 ms/BM, N/kg	1RM/BM, kg/kg	Diagnosis	Training emphasis
Athlete A	37.0	26.3	2.14	Good strength at slow velocities; lacking pure and explosive strength	Heavy rack pulls; weightlifting derivatives from the hang across a range of loads
Athlete B	37.1	25.8	1.82	Good pure and explosive strength; lacking strength at slow velocities	Heavy strength training through full ranges of motion that use the SSC

BM = body mass; F@100 m = force at 100 milliseconds from onset in the isometric squat; PF = peak force; IsoSq = isometric squat; RM = repetition maximum.

Table 4
A comparison of two athletes with contrasting performances in a fast dynamic strength assessment and a reactive strength assessment

	CMJ height, m	CMJ TTT, s	DJ RSI, m/s	DJ contact time, s	Diagnosis	Training emphasis
Player A	0.42	0.84	2.37	0.190	Good reactive strength; poor slow SSC strength at fast velocities	Combined heavy strength, loaded and unloaded ballistic tasks
Player B	0.41	0.75	1.72	0.240	Good slow SSC strength at fast velocities; poor reactive strength	Plyometrics with instructions to maximize jump heights or distance with minimal contact times

CMJ = countermovement jump; DJ = Drop Jump; TTT = time to takeoff.

previous results), training can be targeted towards the aspects of strength that require the most attention. Based on the principle of specificity, the training modalities that are most similar to the strength quality of interest will likely have the greatest transfer (Table 2). Although further experimental evidence is needed to compare the impact of different training structures on certain strength qualities, some additional general recommendations can be made:

- Training history and existing maximal heavy dynamic strength level. Those who are stronger (i.e., 1RM back squat of 2.0 × BM) will display superior adaptations to high velocity (e.g., ballistic) and explosive training (e.g., weightlifting derivatives) (16,32).
- Those who are weaker or with low-level training experience will show improvements across a broad range of strength qualities when exposed to heavy strength training. Accordingly, as one becomes stronger, more specific and targeted training is required (16,32,60).
- Training should be periodized. Consider the timeline of events, opportunities for concentrated loading, logical sequencing, and progression (i.e., how does the development of one quality now impact the development of another in the future?) (50).

Strengths or weaknesses can be determined by comparing test results to squad averages or norms from the same cohort. Here we provide several case examples of how strength diagnosis can inform training.

In Table 3, the isometric squat assessment of maximal and explosive strength was unable to distinguish the 2 athletes. However, Athlete A has a markedly greater MDS in heavy conditions. As a result, the 2 athletes can be distinguished and different training interventions can be prescribed.

The jump profiles presented in Table 4 demonstrate that both players produce a similar CMJ height, but Player B achieves this with a faster movement. However, this does not necessarily mean that Player B also performs well in a fast SSC task, so a test of reactive strength (DJ-RSI) was needed to differentiate the 2 individuals. An important point is that a fast movement time in a slow SSC action (e.g., a CMJ) does not imply a fast contact time in a reactive strength assessment because the constraints and objective of the tasks are different.

Table 5
A comparison of two athletes with contrasting performances in a fast dynamic strength assessment, a sport specific jumping test, and a reactive strength assessment

	Standing VJ, m	Running VJ, m	% Gain	DJ RSI, m/s	Diagnosis	Training prescription
Player A	0.83	0.95 (double)	14	2.08	Good fast strength, poor reactive strength and single-leg takeoff ability	Single-leg plyometric training where contact time is minimized
Player B	0.73	0.91 (single)	25	2.26	Good reactive strength and single-leg takeoff ability; relative weaker fast strength capacity	Bilateral slow (longer contact/movement time) SSC plyometric training, heavy strength training

DJ = drop jump; RSI = reactive strength index; SSC = stretch shortening cycle; VJ = vertical jump.

The inclusion of a test that replicates the execution of a sport-specific task can be used as a diagnostic performance measure. In jumping sports such as basketball and volleyball, an example would be a standing vertical jump or a vertical jump that incorporates a run-up with a single- or double-leg takeoff. This information can be combined with the direct assessments of muscle function like a countermovement jump or drop jump to diagnose strengths and weaknesses to inform training.

Presented in Table 5 is a running vertical jump, standing vertical jump, and RSI from 2 basketball players. From this information, we can decipher the percentage improvement in jump height with respect to their RSI to inform training. Player "A" has a greater vertical jump from a standing position but is not as effective at using their run-up as Player "B" (as measured by the % gain in height in the running jump compared with the standing jump). For this athlete, prescribing single-leg plyometric exercises such as bounding would be advantageous to improve a deficiency in their basketball-specific jumping performance.

SUMMARY AND CONCLUSIONS

Empirically distinct strength qualities exist, so practitioners must have sophisticated assessment systems to isolate the forms of strength most relevant to their sport. To aid in interpretation strength diagnosis must also seek to minimize redundant data by ensuring that each metric contains novel information. This article presents a current evidence-based strength assessment framework that addresses these factors. Practitioners can use the proposed methods to direct testing processes, prioritize training, and inform athlete needs analyses. However, further research is required to clarify the divisions between strength domains across a range of contexts. A greater understanding of how these relationships change over time and in response to specific training interventions is also needed.

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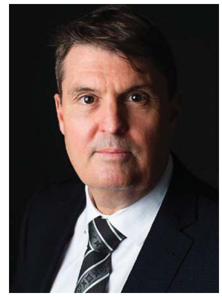
Lachlan P. James *is a lecturer and course coordinator of the Master of Strength and Conditioning at La Trobe University, Melbourne, Australia.*

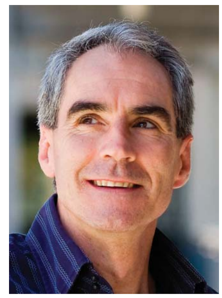
Scott W. Talpey *is a senior lecturer and program coordinator for the Master of Strength and Conditioning at Federation University, Ballarat, Australia.*

Warren B. Young *is an adjunct associate professor at Federation University Australia, Ballarat, Australia.*

Mary C. Geneau *is a PhD student at La Trobe University, Melbourne, Australia and co-funded by Vald Performance.*



Robert U. Newton *is a professor of Exercise Medicine in the Exercise Medicine Research Institute at Edith Cowan University, Perth, Western Australia.*



Paul B. Gastin *is a professor and head of Sport and Exercise Science at La Trobe University, Melbourne, Australia.*

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