Testing and Profiling Athletes: Recommendations for Test Selection, Implementation, and Maximizing Information

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ABSTRACT

Understanding the physical qualities of athletes can lead to improved training prescription, monitoring, and ranking. Consequently, testing and profiling athletes is an important aspect of strength and conditioning. However, results can often be difficult to interpret because of the wide range of available tests and outcome variables, the diverse forms of technology used, and the varying levels of standardization implemented. Furthermore, physical qualities can easily be misrepresented without careful consideration if fundamental scientific principles are not followed. This review discusses how to develop impactful testing batteries so that practitioners can maximize their understanding of athletic development while helping to monitor changes in performance to better individualize and support training. It also provides recommendations on the selection of tests and their outcome measures; considerations for the proper interpretation, setup, and standardization of testing protocols; methods to maximize testing information; and techniques to enhance visualization and interpretation.

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INTRODUCTION

The testing and profiling of athletes are essential for strength and conditioning coaches. Data from carefully constructed testing batteries can ensure a competitive edge over the opposition by providing information to better guide training prescription and monitor changes in performance (58). Furthermore, information gleaned from testing can be used to identify talent and help justify the selection of athletes (16,36,72,81). However, testing can also be misused, resulting in physical qualities being misunderstood or misrepresented (34,51). Therefore, if information is being gathered to help guide the decisions of coaches, it is important to ensure that the most accurate and impactful information is being collected

KEY WORDS:
physical qualities; monitoring; S&C; technology; coaching; strength and conditioning

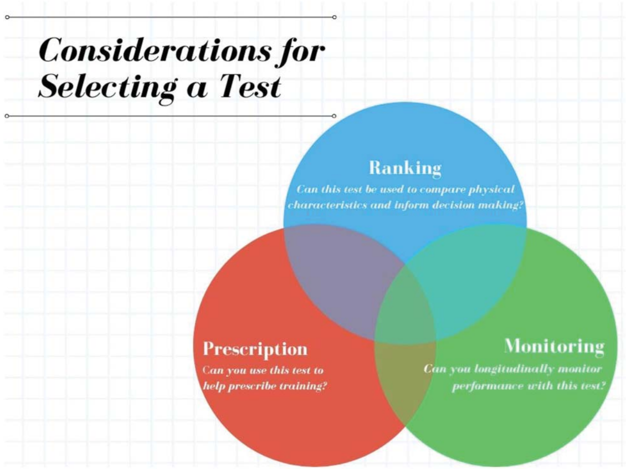


Figure 1. When deciding on a test, it is important to consider whether you can rank, monitor, and prescribe training for athletes with the collected data. Although 2 of these outcomes may suffice, ideally, a test would have all 3. An example of a commonly used test with all 3 considerations is the 1 repetition maximum (1RM) back squat. Coaches can prescribe with these data (particularly if these are combined with a load-velocity profile), use this information to help rank athletes as strength is an important physical quality across most sports, and monitor changes in strength over time as it has acceptable levels of reliability. 1RM = 1 repetition maximum.

and presented. This is particularly important for teams or sporting organizations investing significant time and resources into an athlete.

Considering the importance of testing for coaches and athletes, it is essential to consider why and how the testing is being implemented. While the growing acceptance of sports science and technology has helped to continue the development and innovation within strength and conditioning (85,99), it has also led to extremely large amounts of data often being available (56). This can cause practitioners to be overwhelmed with information (i.e., "paralysis through analysis"), select inappropriate testing methods or outcomes (i.e., the lack of understanding of the test and its underpinning physiological/biomechanical constructs), or cause "testing for testing's sake." Thus, understanding the "why" can support decisions around what information is retained and help determine the purpose, which in turn can help guide the tests that are selected. Furthermore, once the tests have been decided on, "how" testing occurs is essential to establish as this ensures the integrity of the retrieved information. How testing is conducted can make a substantial difference to the outcomes of nearly all tests and encompasses how tests are standardized and implemented, the equipment and variables used, and how the data are handled.

With physical testing being an integral part of strength and conditioning, it is important to acknowledge and detail the key considerations that can ensure effective, efficient, and impactful implementation. This narrative review builds on previous work (45,46) by providing an overview of essential reasoning and justification that can help improve test selection, provide practical and scientific recommendations to ensure accurate and reproducible testing that can maximize the interpretation of physical qualities, and offer suggestions to promote optimal uptake of information. It will also provide examples and real-world evidence to support the interpretation of recommendations.

SELECTING TESTS

Testing within strength and conditioning should be simple. Fundamentally, important physiological qualities should be assessed (e.g., speed or strength) and testing protocols should be completed consistently across time. Although it may be tempting to try and

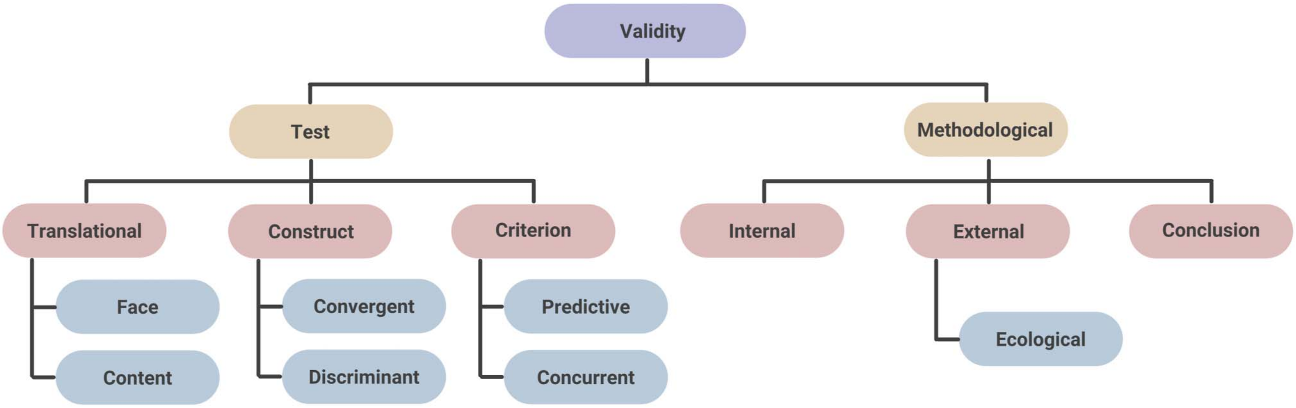


Figure 2. Types of validity and how they interact with each other.

Table 1
Overview and explanations of the different types of validity

Types of validity	Explanation and example
Test validity	
Translational	The extent to which a test outcome is a good reflection of what it intends to represent. *A test can be considered to have good translational validity if it possesses adequate face and/or content validity.*
Face	A subtype of translational validity and sometimes referred to as logical validity. What a test superficially seems to measure, regardless of what it actually measures. *A vertical CMJ might have limited face validity for inferring an athletes upper-body power. Note, this does not mean it is not a useful test for an intended purpose, or that it may be correlated to upper-body power.*
Content	A subtype of translational validity. The extent that the content of a test matches and measures all elements of a given construct. *A questionnaire intending to assess perceived recovery may need to contain several items that cover different domains of recovery (e.g., physical or mental). These items should be determined by consensus from subject matter experts* (48).
Construct	The test's ability to accurately represent the underlying construct. *Tests such as the 30–15 IFT and the YYIRT* (1 and 2) *share strong associations and are believed to represent high-intensity intermittent running capacity—a performance construct underpinned by several physiological qualities (e.g., aerobic, anaerobic, and neuromuscular)* (70).
Convergent	A subtype of construct validity. The extent to which 2 tests that should seem reflective of a similar construct are indeed related. *A large correlation has been evidenced between a standardized running test* that is *purported to measure "leg stiffness" and a repeated hopping test* that is *claimed to assess "leg stiffness"* (41).
Discriminant	A subtype of construct validity. The extent to which test outcomes or groups tested on an outcome that should not be related are indeed unrelated. *Isometric midthigh pull peak force is able to distinguish between amateur and professional rugby players. Discriminant validity is evident because these 2 groups can be expected to differ in their maximal strength due to training status and playing standard (known group difference)* (13).
Criterion	The strength of an association between the scores from an alternative test and the scores from a criterion measure. *There is a strong, positive association between velocity calculated from 3D motion capture systems and linear position transducers during resistance training exercises* (90).
Predictive	A subtype of criterion validity. How accurate an alternative test can predict future behavior of a criterion measure or performance indicator. *A test of maximal dynamic strength (e.g., a maximal back squat) may accurately predict performance in weightlifting (e.g., competition snatch 1RM)* (73).
Concurrent	A subtype of criterion validity. The strength of association and agreement between 2 different assessments measured at the same time. *The concurrent validity of 10-m sprint time (timing gates vs motion capture) would be substantially reduced if the athlete was to start 50 cm behind the starting gates rather than directly behind (e.g., 1 cm) the starting gates* (89).
	(continued)

Table 1 (continued)

Methodological validity	
Internal	The degree of control taken to account for potential confounding variables that can influence a test outcome. *A field-based test of maximal aerobic speed may be internally valid if all assessments are performed on the same surface, at the same time of day, and in comparable weather conditions (e.g., wind, heat).*
External	The extent to which test results can be generalized to other athletes, places, or time points. *The influence of growth and maturation on physical test performance is generalizable across both sexes and sports. Athletes who mature early typically have a physical advantage over their less-mature counterparts* (80).
Ecological	A subtype of external validity. How well a test relates to actual sporting performance and matches the athletes real sporting context. *Using a running-based assessment of aerobic capacity for sports that involve running would help strengthen the ecological validity of the test.*
Conclusion	Sometimes referred to as statistical conclusion validity. The extent to which conclusions about relationships or effects are accurate, credible, or believable, as far as statistical issues are concerned. *Concluding that athletes with a higher weekly internal training load had greater improvements in preseason fitness (based on a positive correlation between the 2) may be inaccurate if baseline fitness (confounding variable) was not accounted for.*

make a test seem more "specific" to a sport (e.g., adding a basketball free throw after a change of direction test), by altering a test, the assessment of the underlying physiological quality is often lost, and what is being quantified is no longer clear. Ironically, attempts to make a test more sport specific often undermine the development of an athlete because the test loses construct and ecological validity. Therefore, when testing athletes, the physiological quality must be identified (e.g., maximum strength or aerobic capacity) and practitioners should be comfortable knowing that a single test cannot assess all physiological capacities simultaneously.

The tests that coaches select and implement with their athletes should serve a purpose. Both athletes and coaches have limited time and the collection of data that is unusable or not maximized can be a waste of time and resources. Therefore, it is important to consider the test's purpose and what can be gleaned from its completion. To help guide practitioners in their selection of tests, it is proposed that when assessing physical qualities, at least 2 (and ideally 3) of the following concepts can be achieved:

- Ranking
- Monitoring
- Prescription

These concepts, which are not listed in the rank order of importance, help ensure that there is a purpose behind each assessment and that the test can be used to guide practice. Figure 1 and the explanations below discuss ranking, monitoring, and prescription.

The ability to rank athletes is an important concept that helps guide athlete selection. Ranking refers to the concept that if 2 athletes from the same playing pool are compared, and all other physical qualities and technical/tactical skillsets are equal, the athlete with the greater ability in the tested quality should be ranked higher. It should be noted that the physical quality should be important for sporting performance or has established indirect relationships with performance. For example, a wide receiver in American football needs to have high levels of acceleration and maximum speed (63). Therefore, if 2 players were to be compared and all other physical qualities and technical/

Figure 3. Visual representation of validity and reliability.

Table 2
Recommendations and considerations for improving test reliability in sports science

Recommendations for the improvement of testing reliability and outcomes
All equipment and recording forms are available and prepared.
All equipment is calibrated and operating correctly.
Testing conditions are similar. This includes environmental conditions and surfaces (e.g., running track).
Time of day is consistent.
All pretest protocols (e.g., warm-ups) have been specified and implemented consistently.
Testing order is consistent.
Testers are familiar and competent with all testing protocols.
Athletes are in good health, have had sufficient rest before testing, and are injury free.
Athletes are dressed appropriately (e.g., light and nonrestrictive clothing) and consistently (e.g., running spikes are not used on only 1 sprint occasion).
Athletes are familiar with testing protocols.
Similar levels of encouragement are provided on each occasion.
Ensure that biological and technological error are established and appropriately attributed to the correct source.
Normal dietary intake is consumed with alcohol and caffeine consumption limited before testing.

Based on Woolford et al. (102).

tactical skillsets were equal, the player with the greatest acceleration and maximum speed should be preferentially ranked as this would promote greater performance outcomes. Alternatively, if 2 rugby league players were to be compared, one who had high levels of lower-body strength and another who had low levels of strength, it could be argued that the stronger athlete should be ranked higher than the weaker athlete. Although rugby league is a complex sport and the relationship between improvements in lower-body strength and on-field performance is difficult to directly ascertain, greater strength is likely essential for helping mitigate the effects of collisions, support fundamental skills (e.g., wrestling within rucks), and support recovery postmatch (18,35,82). Consequently, selecting tests that accurately measure fundamental and important qualities can be used to guide the ranking of athletes.

Grounded in the concept of reliability and sensitivity, selecting tests that allow practitioners to accurately monitor whether improvement has occurred is essential for longitudinal tracking. Ideally, the test should be reliable so that there are small amounts of noise (i.e., variability in performance) and sensitive enough to measure when an improvement in the physical quality has occurred. In tests that have a range of outcome measures (e.g., the countermovement jump), the use of highly variable metrics, such as rate of force development (26), is not recommended as these make monitoring changes extremely difficult. It is acknowledged that theoretically an outcome variable can be interesting, but due to the variability associated with the measure, it is difficult to monitor.

Monitoring performance of a test should also be placed within the context of an athlete's entire physical development. Tests can be confounded by a range of variables that, if not accounted for, may shroud the true change in an athlete's performance. For example, athlete sprint times may not seem to improve over a collegiate career. However, when body mass is accounted for, it is clear that substantial improvements in momentum could have occurred (42). For collision sports, this is naturally a great advantage. Similarly, increases in body mass may mask improvements in aerobic capacity as athletes develop. However, increased body mass and maintenance in aerobic field tests can indicate greater running economy and improved high-intensity running ability (11). Similar statements can be made for commonly implemented tests, such as the countermovement jump and corresponding kinetic variables (e.g., force), which can be strongly influenced by changes in body mass. Consequently, practitioners must carefully scrutinize their data beyond absolute values and understand the interaction of other physical qualities on performance. This can not only provide an improved understanding of physical changes for practitioners but also reassure and educate athletes who have not seen the results they desire from a test.

Using testing information to guide training prescription should be a primary consideration for the strength and conditioning practitioner. The ability to test athletes, identify their strengths and weaknesses, and also improve their training is essential and tests have varying levels of application. For example, the 30–15 intermittent fitness test (30–15 IFT) has greater application than a Yo-Yo intermittent recovery test because several programming tools have been developed and validated to guide prescription from this test (4). Alternatively, tests of maximal dynamic strength (e.g., 1-3RM back squat) have greater prescriptive utility than an isometric assessment (e.g., isometric midthigh pull [IMTP]) because strength coaches can prescribe loads as a percentage of maximum

Table 3
Approximate between-day coefficient of variation (%) for commonly used measures of physical capacity

Test	Approximate coefficient of variation (%)	Reference
Strength measures		
Back squat	2.0	(2)
Front squat	2.5	(96)
Bench press	2.0	(96)
Chin up	3.5	(96)
Prone bench pull	2.5	(19)
Isometric midthigh pull peak force	3.5	(53,78)
Jump and jump-related variables		
CMJ height	3.5	(8,65,68)
CMJ concentric peak power	3	(8,65)
CMJ concentric mean power	4	(8,65)
CMJ concentric peak force	3	(8,65)
CMJ concentric mean force	2	(8,65)
CMJ concentric impulse	2	(52)
Squat jump height	5	(43,61)
Dynamic strength index (SJ:IMTP PF)	5	(78)
Reactive strength index (FT:GCT)	4	(6)
Sprint times		
10-m sprint	3	(12,68)
20-m sprint	2	(12,68)
30-m sprint	2	(12,68)
40-m sprint	2	(12,68)
Field endurance assessments		
YoYo IR1	10	(1,15,38,76)
YoYo IR2	10	(1,39,76)
30–15 IFT (V_{IFT})	2	(15,77)
2-km time trial	2	(23)

All values are approximate values due to differences between populations and technology used during data collection.

SJ = squat jump; IMTP = isometric midthigh pull; PF = peak force; FT = flight time; GCT = ground contact time; IR = intermittent recovery; IFT = intermittent fitness test; V_{IFT} = final running velocity at the completion of the 30–15 intermittent fitness test.

capacity using this information. Considering this, if faced with the need to assess a capacity, coaches should strategically select tests that allow for improved training prescription to help individualize and maximize the subsequent training block.

VALIDITY, RELIABILITY, AND SENSITIVITY–THE HEART OF ATHLETE TESTING

Fundamental to athlete testing and profiling is the concepts of validity, reliability, and sensitivity. If a test has low validity and/or reliability, the data collected are often a poor reflection of the individual's capacity or not a reflection of that capacity at all. Furthermore, when the sensitivity of a test is poor, interpretation of changes in the test between time points can be extremely difficult. Consequently,

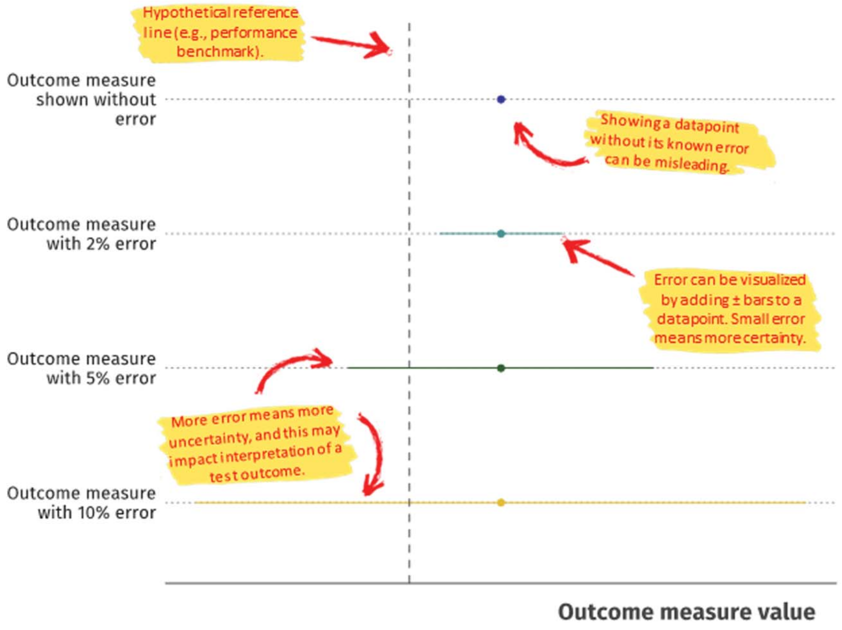


Figure 4. Visual example of how "test error" can influence the interpretation of a performance score. Bars are the CV (the standard error of measurement as a percentage, shown hypothetically as 2%, 5%, and 10%). CV = coefficient of variation.

when considering whether to use a test, it is important to establish whether a test indeed measures that physical quality. In addition, it is important to quantify the normal variation between assessments (i.e., the repeatability of the test and its outcomes).

Validity. Validity refers to whether a test indeed measures what it was designed to measure (32). There are several forms of validity which can be classified based on the accuracy of the outcome measure (i.e., test validity) or how trustworthy the protocols, conclusions, and generalizations are (i.e., methodological validity [often termed experimental validity in a research setting]; Figure 2). In Table 1, we detail the different forms of validity and how they relate to testing physical qualities.

All types of validity are important when assessing an athlete's physical qualities and evidence for validity in several of its subdomains is often necessary. With the growing uptake of sports technology for the monitoring of athletes, it is important to establish whether the equipment being used provides an accurate reflection compared with a standard measure (i.e., criterion validity) (86,87). Recent reviews of global and local positioning systems (10) and commonly used resistance training monitoring devices (e.g., linear transducers or accelerometers) (90) have highlighted several concerns and considerations with these forms of technology. Specifically, these reviews highlight the importance of comparing devices to a "gold-standard" criterion. This is important because if the criterion does not accurately reflect a measure, then the device that it is being compared with can have a misleading amount of error (either increased or decreased). Furthermore, it is essential to establish the accuracy of different outcome measures that are reported from technology. For example, when measuring back squat performance, mean and peak barbell velocity can both be assessed. However, a single device can report very different levels of accuracy dependent on which outcome measure is used (9,87,91).

Threats to validity can occur not only from technology but also from the test instructions and protocols used. For example, when assessing accelerative ability with a 10-m sprint, starting an athlete 50 cm behind a timing gate or triggering timing using a front foot trigger (as is commonly conducted within practice and throughout the scientific literature (12,92,93)) substantially reduces the concurrent (criterion) validity because these methods routinely miss ~20–50% of the athlete's acceleration phase (89). In this instance, the criterion validity of the timing gates is not changed (i.e., the timing system is accurate), but modifications to the starting method have substantially altered the outcome. In a situation such as this, criterion validity becomes the victim but the issue stems from internal validity (i.e., the test design does not allow a true reflection of the observed results).

Conversely, on the opposite end of the methodological validity spectrum, ecological validity refers to how well a test relates to actual athlete performance and whether it can be applied to real-life settings. For instance, asking field hockey athletes to complete a cycling time trial to establish $\dot{V}O_2$max has limited ecological validity. Alternatively, a field-based running assessment (e.g., 30–15 IFT) may be more appropriate. This example additionally highlights the consideration for construct validity. Coaches may use tests such as a laboratory-based $\dot{V}O_2$max assessment or the 30–15 IFT to assess cardiovascular "fitness." The former achieves this through direct measurement of aerobic capacity, whereas the latter is a construct within itself (high-intensity intermittent running ability) that comprised aerobic capacity, as well as other physical qualities such as anaerobic and neuromuscular qualities. Therefore, it is important for practitioners to understand which physical constructs are being assessed and the extent to which the tests used are an accurate representation of the definitions of that construct.

Reliability. Reliability refers to the degree of repeatability, reproducibility, or consistency in a measure (49,102). A

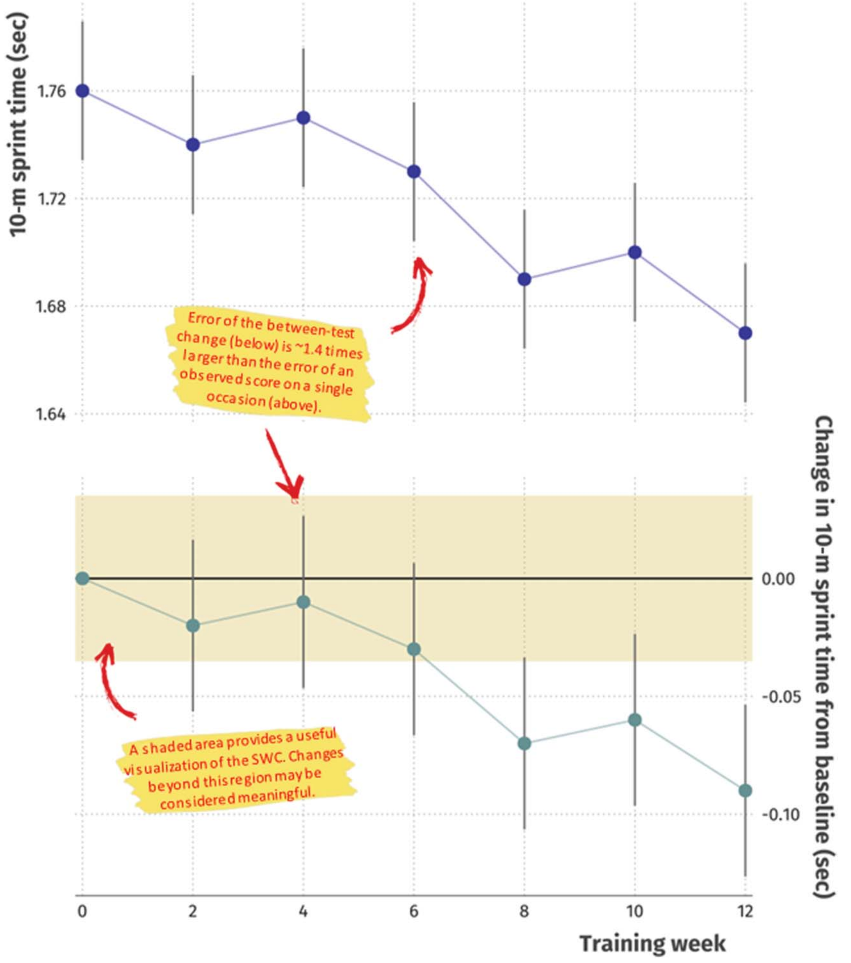


Figure 5. Annotated example of change in 10-m sprint performance in a single athlete (youth soccer player) across 12 weeks. The top figure illustrates the raw times (s) presented with the SEM, which is approximately 1.6% (24). The bottom figure demonstrates the corresponding test change score relative to the first testing occasion, presented with the adjusted SEM. The shaded region depicts the SWC for 10-m sprint time in soccer players, which is said to be around 2% (24). A difference of 2% in 10-m time would allow a player to be ahead of an opponent over this distance in a one-on-one duel to win the ball (25). SEM, standard error of measurement; SWC, smallest worthwhile change.

test outcome can be reliable even if it is not valid (Figure 3), but if it is not reliable, then it cannot be valid. To be able to assess changes in performance, the reliability of the test needs to be established (test-retest reliability). If a test cannot be reliably reproduced, coaches cannot confidently state whether an athlete has truly improved in a test.

As with internal validity, a range of factors can influence reliability, and these factors are often unique to a test or a specific outcome measure. For example, jump height during the countermovement jump could be influenced by the instructions provided to the athlete (37,62), the method of calculation (e.g., flight time versus impulse-momentum relationship versus take-off velocity) (55), or the technology used (60). Alternatively, for anthropometry and body composition, food or fluid consumption could alter outcomes and should be standardized across days (59). Consequently, to make accurate inferences about changes in performance, coaches should quantify the reliability of each test and outcome measure with their cohort of athletes or have strong grounds to justify the reliability from a similar cohort in the literature (8,65,68). Recommendations for enhancing test reliability and reducing measurement error are supplied in Table 2.

For tests of physical performance or capacity, it is recommended that the reliability of a test is established across the period that data will be routinely collected and interpreted (i.e., between-day reliability). Typically, longer periods between test-retest assessments result in less reliable outcomes. This has implications for tests of a more exhaustive nature, such as those assessing maximal high-intensity intermittent running ability, which are typically performed >6 weeks apart (50). Furthermore, it is important to test in a standardized state (e.g., 48 hours of rest before the test) and when changes in physical performance/capacity would not be believed to have changed (e.g., after strenuous exercise). If human error can be introduced through assessment (e.g., skinfold measurements for estimates of body composition), intrarater and interrater reliability should be quantified and, if possible, minimized. To reduce this variability and improve measurement reliability, all assessors should be adequately trained (e.g., International Society for the Advancement of Kinanthropometry for body composition measurements), and changes in assessor between premeasurements and postmeasurements should be avoided if possible. Finally, environmental conditions (e.g., temperature, wind, and testing surface) should be standardized to enhance the reliability of physical performance testing. Naturally, this can be difficult when testing outdoors. Therefore, practitioners should carefully consider where and when testing occurs.

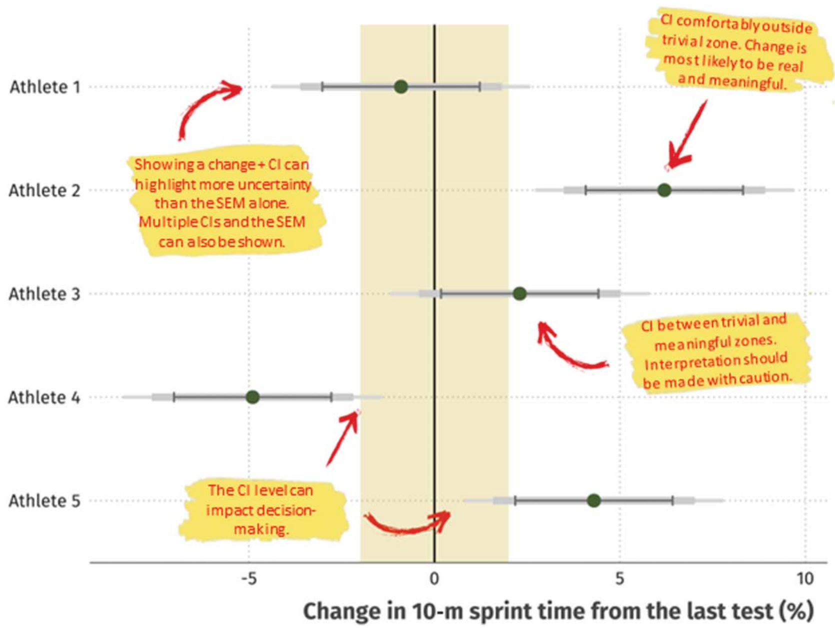


Figure 6. Annotated example of change in 10-m sprint time in a group of athletes (youth soccer players). The variation around the point estimates (error bars with caps) represents the adjusted SEM, and the shaded region is the SWC of 2% (refer to Figure 5 caption for further details). Also shown in this figure are compatibility limits of either 80% (thick gray line) or 90% (thin gray line). Depending on the certainty required for the measure, either option may be appropriate. This demonstrates how certain statistical choices can influence the interpretation of a change in test performance and the importance of showing uncertainty and practical importance. CI = confidence interval; SEM, standard error of measurement; SWC, smallest worthwhile change.

One final consideration of testing that is often reported but poorly disseminated within the literature is the reliability of technology. Considering that technology is commonly used during testing, there is a need to establish the between-device error and between-day error. However, to accurately reflect the error of the technology being assessed, it is essential not to attribute biological error to technological error (86,90). For example, if a practitioner wishes to establish the reliability of a linear position transducer for the measurement of mean concentric barbell velocity during the back squat, it is important to delineate between the variability of exercise performance during the squat and the error of the technology. This minimizes the risk of inappropriate attribution of error to technology when it may just be that humans struggle to replicate a task perfectly (i.e., normal performance variation). Recent reviews (10,90) have emphasized this point and strongly recommended that to measure the reliability of a measurement device appropriately, human error should be eliminated.

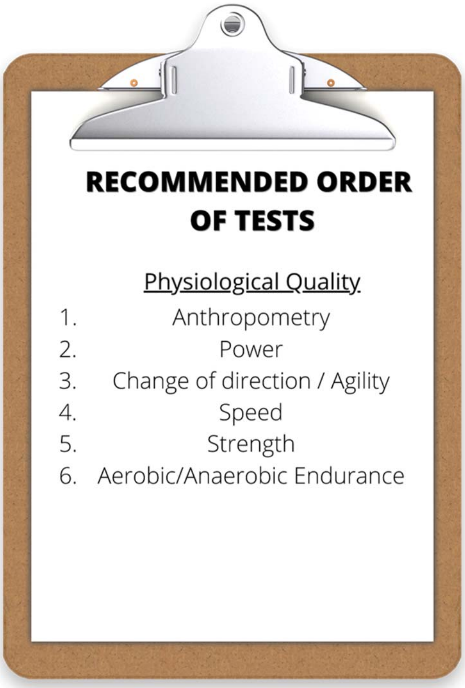
The reliability of a test outcome measure can be quantified with various statistics, such as the standard error of measurement (SEM; sometimes referred to as the typical error) or the intraclass correlation coefficient. Although both these statistics are recommended to paint the full picture of reliability (i.e., absolute versus relative reliability, respectively), the SEM is perhaps more useful in practice as it provides an estimate of the within-athlete variability (i.e., how much athletes typically fluctuate by in their test performance over the retest period). Approximate between-day coefficient of variations (CVs; the SEM expressed as a percentage of the mean) for commonly used physical capacity tests are provided in Table 3. The CV or SEM can be used to assess test sensitivity, such as tracking changes within an individual. Full details on reliability analysis and applications can be found elsewhere (30,49).

Sensitivity. Test sensitivity, or responsiveness, refers to the ability of a test to detect real and important changes in performance. It is implicitly linked to both validity and reliability for several reasons. First, if a test does not possess adequate test or methodological validity, then changes in the outcome measure may occur despite no real changes in an athlete's physiology or performance capacity. Second, when the outcome measure of a test is a construct itself, it may be difficult to identify changes in specific, underlying physiological qualities. For instance, the 30–15 IFT is commonly used as a marker of cardiorespiratory or aerobic fitness in team sports. However, because the test assesses maximal intermittent high-intensity running ability, final running performance (V_{IFT}) is also determined by anaerobic and neuromuscular qualities. Therefore, tests in which the outcome measure is a construct may lack sensitivity to isolated physiological systems. Despite this, such tests may still be considered useful.

The reliability of a test outcome also has implications for responsiveness. Reliability determines the noise of a test, which is needed to help understand whether the changes in performance are "real" or simply the result of test error/biological variation. In addition, the "smallest worthwhile change" (SWC) must be established. Thresholds for a worthwhile change are primarily established through 2 methods. These are as follows:

- Anchor-based
- Distribution-based.

Ideally, an anchor-based method should be implemented because it



RECOMMENDED ORDER OF TESTS

Physiological Quality

1. Anthropometry
2. Power
3. Change of direction / Agility
4. Speed
5. Strength
6. Aerobic/Anaerobic Endurance

Figure 7. Recommendation of the order of tests when completing a testing battery in a single day (45). It should be noted that this order may differ if certain physical qualities are not assessed or if testing takes place across multiple days.

holds high levels of ecological validity while also allowing practitioners to relate changes in training and testing data to real-world outcomes. Anchor-based SWC can be established through prognostic or validity studies in which a measure has been used to predict an outcome and can be found within the literature (79) or through an opinion-based method in which an expert (e.g., an established practitioner) in the field provides an estimate of what would be deemed a meaningful, real-world change (14,40). These thresholds are often also named the minimum practical or clinically important difference.

When an anchor-based approach is not feasible, a distribution-based method could be implemented. This method quantifies the typical deviation in how athletes perform between each other (i.e., the between-athlete SD) and a fraction of this is used to represent the change required to meaningfully alter their position within this distribution. Commonly, 0.2 between-athlete SD is calculated to detect the SWC. Furthermore, 0.6 and 1.2 are often used for moderate and large changes, respectively (28). This method is commonplace in the sports science literature, perhaps due to the lack of studies or quality evidence for anchor-based approaches. However, we warn practitioners and coaches that a "blanket" target change of 0.2 of the between-athlete SD systematically underestimates practically relevant and more informed changes from the methods previously described (14). We therefore advocate anchor-based approaches, which can be informed by literature, empirical research findings (in-house or published), and internal discussions between the entire performance, coaching, and medical team.

Once a meaningful change has been calculated/established, consideration of the reliability of the test relative to the observed change can occur. Tests that have high levels of reliability have greater likelihood of being able to infer a "real" change. First, the error of the test can simply be scaled in relation to the SWC to determine its "usefulness." The Australian Institute of Sport has historically rated tests as follows:

- "Good" - When the SEM of the test is less than the smallest meaningful change.
- "Ok" - When the SEM of the test is approximately the same as the smallest meaningful change.
- "Marginal" - When the SEM of the test is much greater than the smallest meaningful change.

There are several other ways in which practitioners can determine the certainty of a change. Perhaps the most informative is visualizing the test change against both its error (noise) and the SWC. In this process, there are a few simple but effective methods that can help inform the interpretation of a test.

- An observed test outcome can be visualized with its SEM derived from a test-retest reliability study or similar. The SEM represents within-athlete variability under "normal" or "standardized" conditions (Figure 4).
- A change in the test outcome between 2 measurement points can be visualized with the adjusted SEM, which is the usual SEM multiplied by the square root of 2. This correction accounts for the fact that the change score must incorporate error from both testing occasions (test 1 and test 2). Naturally, this makes the adjusted SEM larger (~1.4 times) than the observed SEM (Figure 5).
- The adjusted SEM for a change can be converted into compatibility limits (CLs), which provide a range of values compatible with the test error. There are many resources available describing how this process can be achieved (29,49,88). The CL can be specified at a given "level" that defines the coverage probability (i.e., how much of the distribution is covered). For example, a 100% CL would cover all the distribution, whereas the SEM alone is equivalent to only a 68% CL. There is no right or wrong answer as to which CL is

optimum and it depends on how conservative a practitioner wishes to be when interpreting the data. Our recommendation would be values between 80 and 90% (Figure 6).

ORDER OF TESTING

The order of a testing battery can substantially alter the validity of the testing outcomes. For example, if a highly fatiguing test (e.g., a maximal aerobic test) is completed before another test (e.g., a sprint), the second test's performance will likely suffer. Naturally, this can have ramifications for identifying performance changes; consequently, the standardization of testing order is essential for the accurate, reproducible, and fair assessment of physical performance.

The order of tests should be determined by the physiological demands placed on the athlete. Completing 1 test should have minimal impact on the performance of subsequent tests, with tests that require minimal recovery (e.g., anthropometry or short efforts) placed before more physically demanding tests (102). Furthermore, for the sake of feasibility and efficiency, there also needs to be an appropriate "flow" within the testing order, or in other words, athletes should not be required to undergo substantial logistics to undertake testing.

Naturally, the tests that each sport and athlete require differs. Furthermore, the available time can also alter the number of tests completed. Thus, the

Table 4
Examples of additional outcomes that can be obtained from the addition of technology or combination of other testing data in commonly used tests

Test	Commonly used outcome	Additional technology	Additional outcomes
Linear sprint	Time (s)	Laser/radar	• Peak velocity • Theoretical maximal horizontal force production • Theoretical maximal running velocity • Maximal mechanical power output in the horizontal direction • Ratio of horizontal force • Theoretically maximal effectiveness of force application • Rate of decrease in ratio of force
Linear sprint	Time (s)	Global Positioning System	• Peak velocity
Countermovement jump	Jump height (cm)	Force plate	• Force-time kinetic and kinematic analysis • Mean and peak power • Mean and peak force • Flight time:contraction time • Time-specific metrics (e.g., impulse at 100 ms)
Strength testing	Maximal strength (kg)	Linear position transducer/optic sensor	• Load-velocity profile • Load of peak power output
Test	**Commonly used outcome**	**Additional measure**	**Additional outcomes**
Linear sprint	Time (s)	Body mass	• Initial sprint momentum • Peak sprint momentum
Linear sprint	Peak velocity ($m\cdot s^{-1}$)	Maximal aerobic speed (MAS)	• Anaerobic speed reserve
30–15 intermittent fitness test	End velocity (V_{IFT})	Body mass	• V_{IFT} momentum
Isometric midthigh pull	Peak force (N)	Peak force from countermovement jump or squat jump	• Dynamic strength index
Countermovement jump	Jump height (cm)	Jump height from squat jump	• Eccentric utilization ratio

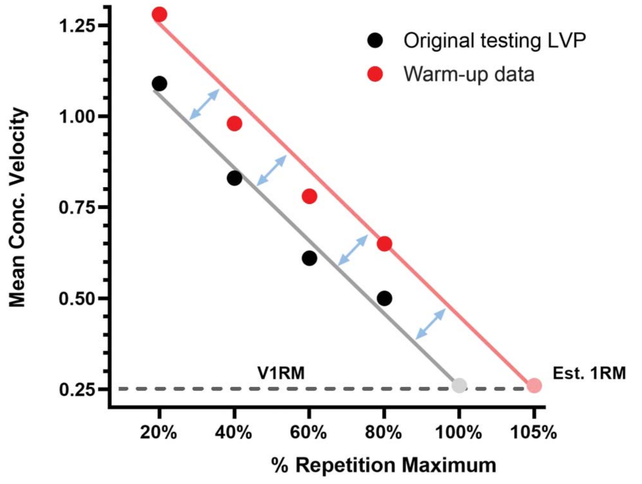


Figure 8. Changes in a back squat load-velocity profile of an athlete from baseline (black dots; gray line) and a load-velocity calculated during the warm-up (red dots; light red line) 3 weeks later (93). Training had not been changed to record this information (i.e., "invisibly monitored"). This information was then used to infer improvements in strength characteristics within a mesocycle. Light blue arrows demonstrate a change in the linear relationship. LVP = load-velocity profile; V1RM = velocity at 1 repetition maximum; Est. 1RM = estimated 1 repetition maximum.

physical qualities that have the largest contribution or influence on athletic performance should be prioritized. However, across nearly all sports, the assessment of fundamental physical qualities (e.g., strength, power, and aerobic and anaerobic capacity) is valuable. Consequently, Figure 7 provides recommendations on the order of tests considering these fundamental qualities (45).

MAXIMIZING THE OUTCOMES FROM TESTING

Practitioners often have limited time to test athletes. Although testing is an important step in physical development, due to the many requirements that athletes face, windows of opportunity are often limited. Therefore, there is a need to maximize the amount of information that can be attained from a small number of tests that can help the ranking of athletes, the monitoring of physical characteristics, and the prescription of training. Maximizing testing data can be achieved through a range of methods, including the strategic selection of tests, the outcome measures recorded, and the equipment used. While technology should not be used just because it is available, if the technology enables greater insight into an athlete's physical qualities when they perform the same test, practitioners should consider its use. Furthermore, by carefully considering how and what tests are being implemented, practitioners can have a substantial improvement in the efficiency of testing while improving the impact for coaches.

The inclusion of certain forms of technology can help improve the information that can be attained from testing, with little to no additional effort from the athletes involved. An obvious example is the inclusion of a force plate over a Vertec to assess jump performance so that additional important kinetic and kinematic information can be quantified. However, other technology includes using laser/radar devices, linear position transducers, mobile applications, and global positioning systems to enhance testing outcomes. For example, if linear sprint testing is already occurring, the addition of laser/radar technology that can measure athlete's instantaneous time-displacement data can provide a wealth of information regarding an athlete's horizontal force-velocity-power profiles (57). Moreover, this information can be used to identify deficiencies in physical capacity and justify whether greater high force (e.g., heavy sled pull/pushing) or high velocity (e.g., unresisted maximal sprints) exercises are required (27). Alternatively, if a laser is not available, but a team uses global positioning systems (GPS), an athlete's peak velocity can be attained to guide decisions around exposure to sprinting during training or paired with an athlete's maximal aerobic speed to provide their anaerobic speed reserve (67). Finally, during resistance training, if athletes are already completing maximal strength testing (e.g., 1 repetition maximum (1 RM) in the bench press or squat), the inclusion of a device that can accurately measure barbell velocities during the submaximal loads (e.g., 25, 50, and 75% of 1 RM) can support the development of a load-velocity profile (2). This information can be used to regulate resistance training loads and volumes better and help mitigate the risk of training to failure. Furthermore, it can support monitoring changes in strength/power characteristics across time.

A simple method of enhancing the recorded data can be through "pairing" outcomes from tests together so that data can be used to infer additional information. For example, by calculating mean sprint velocity from the times retrieved during linear sprint testing, then multiplying this value with body mass, initial and peak sprint momentum can be calculated. This information is a valid discriminator between professional and subprofessional athletes and may be useful for monitoring long-term changes in physical capacity (36,42). Alternatively, the consideration of body mass during tests of aerobic capacity, such as the 30–15 IFT, may help account for the influence of body mass and demonstrate to an athlete that there has been an improvement in high-intensity running performance despite

Table 5
Recommendations for presenting testing data to coaches and athletes

Tip	Explanation
Know your audience	Who is your audience? What do they know about the data? What level of statistical or data expertise do they have? Knowing who your audience is can help you decide the level of information that you will provide and how it is presented.
Show the data	By showing the individual data points, sport scientists can have greater transparency. By hiding data (e.g., bar graphs), the number of observations, context, distribution/clustering, and individual data are lost.
Integrate graphics and text	Directly label the lines, bars, and circles on your charts instead of using separated legends; use concise, active titles to tell the reader what they should learn from the graph instead of simply describing what is in the graph; and add important annotations and labels to highlight important aspects of the graph.
Provide context where possible	It is very difficult to understand values from tests without adequate context. Context can be provided from a range of sources including normative positional, league-wide, team, and longitudinal individual data. It is important to establish what is a "good" score and place testing data in context so that coaches can adequately interpret performance outcomes.
Use color (appropriately)	Color always means something. Color makes visualizations more memorable; furthermore, in today's digital environment color is cheap. However, do not be overzealous with the use of color and ensure that the color used accurately represents information.
Declutter	Gridlines, excessive use of data labels, 3D effects, and tick marks can all make your visualisations "busier" and harder to understand. Minimize unnecessary information and emphasise the key points.
Include uncertainty	Not only is uncertainty an inherent part of understanding most systems but also failure to include uncertainty (e.g., CIs) in a visual can be misleading. As some forms of uncertainty can be difficult to understand, showing the underlying probability distribution may help.
Use space, size, shape, orientation, and position to emphasise different things	The use of these different visual channels can infer different outcomes. Carefully consider integrating 2–3 visual channels to help highlight and emphasise your key points.
Group and categorize data if useful	Use a range of visual channels to help reduce the cognitive load on the viewer. By grouping or clearly categorizing data, processing time can be substantially reduced.
Simplify comparison data	Multiple comparisons can substantially increase processing time. Statistical methods, such as showing the delta change, can help speed up interpretation.
Get a second opinion	Ask a friend or colleague if they can understand immediately what is being presented. If not, you may need to try showing the data in a clearer way.

Based on (17,54,69,83).

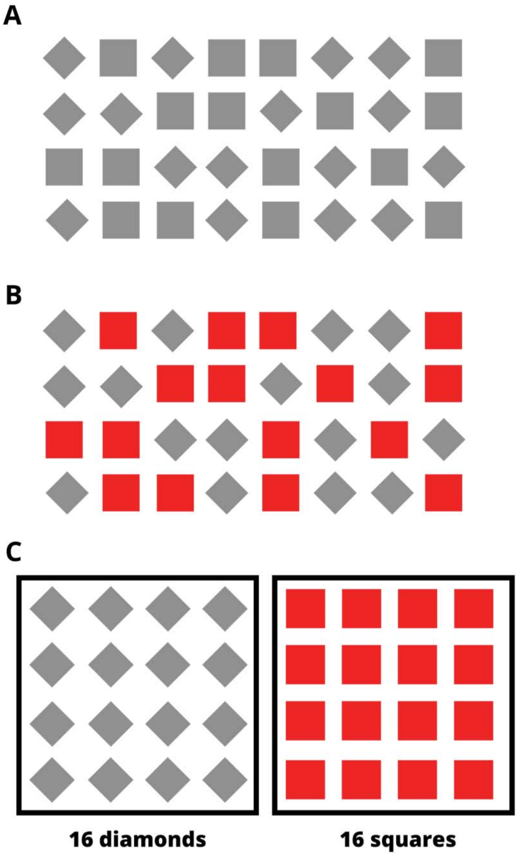


Figure 9. Parts A, B, and C demonstrate the progressive reduction in cognitive load and decrease in processing time, establishing that there are 16 diamonds and 16 squares when color and grouping are strategically implemented.

not necessarily attaining a higher score (11). Outside the addition of body mass, simple strength and power measures can be combined to help quantify performance and guide training. For example, the dynamic strength index can be calculated by comparing peak force from the IMTP and the countermovement jump/squat jump and may be useful in justifying whether additional strength or plyometric work would be beneficial (7). Alternatively, the eccentric utilization ratio, which uses the performance from eccentric-concentric and concentric-only exercises (e.g., countermovement jump and the squat jump) in a ratio, could be useful in guiding practitioners as to whether athletes are effectively using the eccentric portion of a movement (47). However, it should be noted that the dynamic strength index and eccentric utilization ratio should be contextualized, with each subcomponent scrutinized (74,75). Consequently, practitioners and researchers should carefully consider whether the strategic combination of data can enhance testing outcomes. Table 4 provides information regarding technology and measures that can be easily used to attain additional testing outcomes.

"INVISIBLE MONITORING" AND ITS USE IN TESTING

The concept of "invisible monitoring" (i.e., testing athletes as they train and perform without specific intervention) has had substantial interest in recent times (20,41,71,97). Organizing and coordinating testing opportunities with coaches, players, and support staff can be time-consuming and stressful. Therefore, understanding an athlete's physical capacity without intervening is highly valued. The use of wearable microtechnology and monitoring equipment has allowed continual, noninvasive assessment of qualities without having to make extensive alterations to training. By using technology to invisibly monitor performance during exercise, practitioners have more regular information regarding their athletes and can also use this information to detect changes across time. They can also make better-informed decisions if previous testing data are poor/inaccurate (e.g., if an athlete is demotivated or performance during a testing occasion simply does not reflect their true capacity). The ability to test/monitor physical changes can occur during warm-ups or the main training session, depending on what is being monitored (e.g., changes in strength or aerobic adaptations).

Identifying opportunities to monitor changes in important physical qualities is integral to invisible monitoring. For example, peak velocity can be assessed during training through the use of GPS (64). If speed is an important quality for a given sport, practitioners often expose athletes to maximal sprinting efforts during training to develop this quality. Therefore, coaches may wish to include a maximal effort at the end of a warm-up or the start of a training session and monitor changes in peak velocity across time using GPS data (64). By doing this, the coaches gain important information around the development of this quality. Furthermore, if changes occur, these data can guide decisions around relative exercise intensity and subsequent training prescription (e.g., anaerobic speed reserves). On the other hand, the use of submaximal fitness tests has been proposed as a feasible alternative to maximal fitness tests to evaluate an athlete's physiological state. Although the reader is directed toward the review by Shushan et al. (71) for a thorough explanation of their implementation, submaximal fitness tests have the potential to be administered to a group of athletes as part of a warm-up to help detect changes in cardiorespiratory and endurance performance. These tests are far less intensive than traditional methods of assessing endurance performance (e.g., Yo-Yo

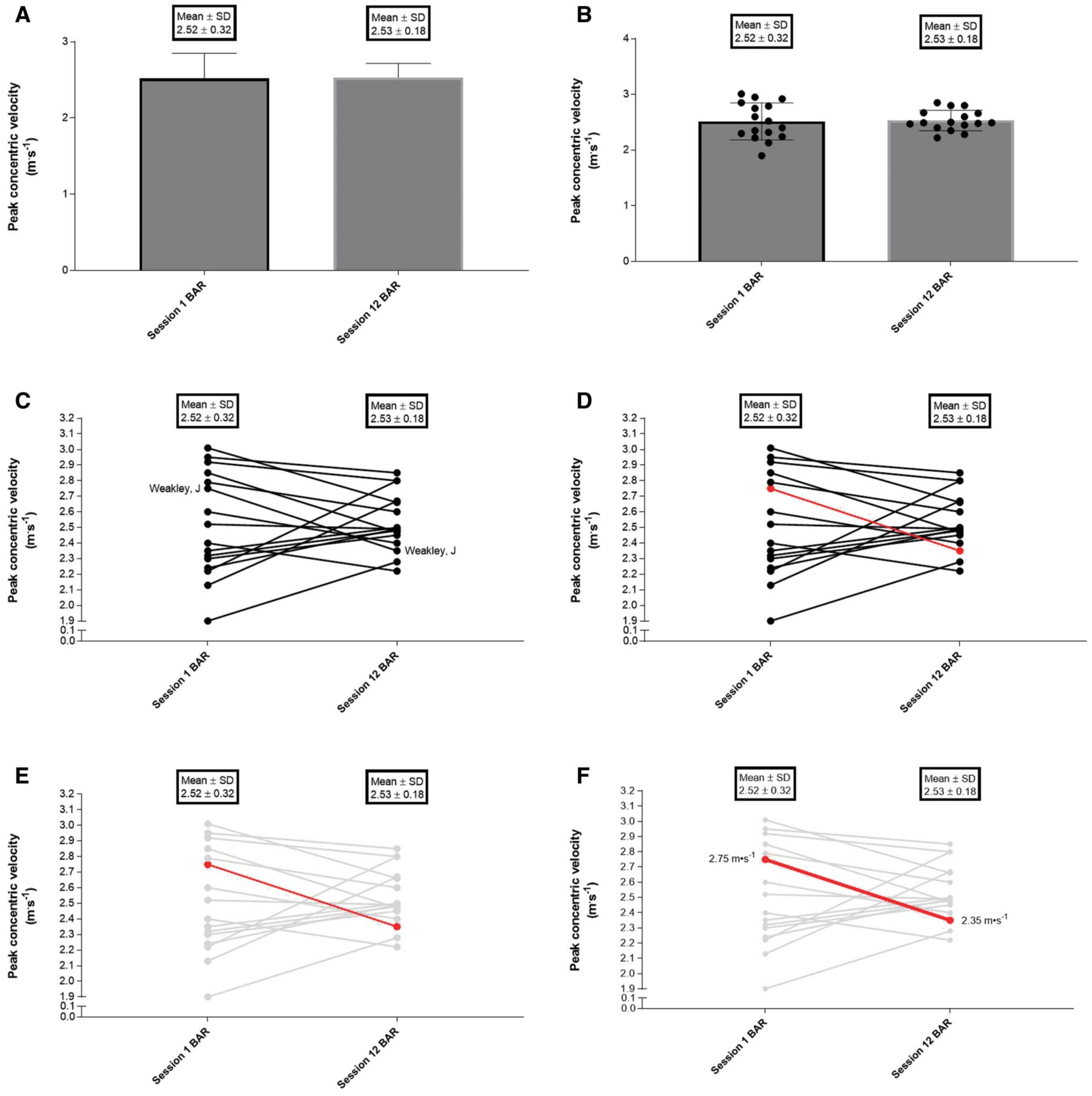


Figure 10. Same data are presented in 6 different ways (sub-figure A–F), emphasizing and providing greater information through progressive layering of visual channels.

intermittent recovery test) and can be completed in as little as 3–4 minutes with standardized distances and velocities used to help reduce setup time (71).

During resistance training, changes in strength and power can regularly be assessed through monitoring the kinetic and kinematic outputs produced with submaximal loads at the end of a warm-up or throughout a training session. Because of the linear and relatively stable load-velocity relationship and the knowledge that velocity at 1RM shows minimal variation within-athletes and between-athletes (2,19,33,66), changes in the velocities with submaximal loads can infer improvements in maximal strength/power qualities. Examples include monitoring the changes in barbell velocity with a set load (e.g., 100 kg) at the end of a warm-up, measuring changes in set loads based on a previously constructed load-velocity

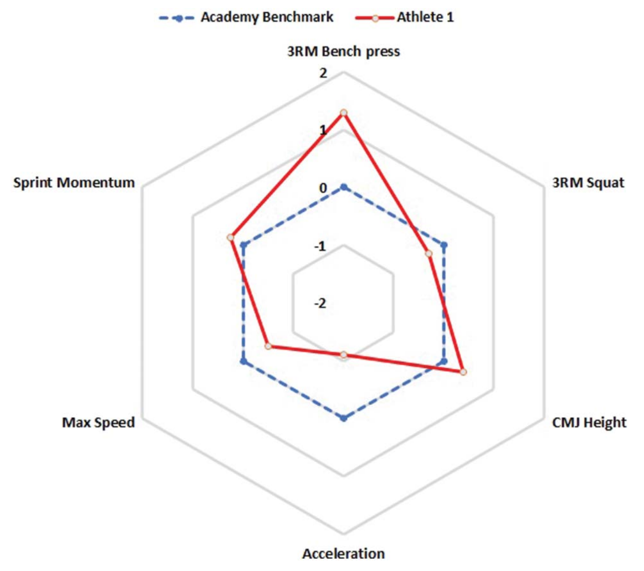


Figure 11. Z-score radar plot demonstrating the strengths and weaknesses of "athlete 1" in comparison to the "academy benchmark." In this example, it can be observed that the athlete's upper-body strength is well above the benchmark, but further work in acceleration and maximal speed is required (46).

profile, or using multiple loads and velocities from a warm-up to estimate changes in maximal strength (e.g., implementation of the "2-point method") (3,21,88,98). These methods can all be conducted outside of usual testing and can be implemented with little to no alteration to training. Furthermore, they offer viable and pragmatic solutions beyond setting aside specific testing occasions to help practitioners gain regular updates on their athlete's physical qualities. An example of testing data from an athlete's warm-up is compared with data recorded from an original testing occasion in Figure 8, with these data suggesting that changes in their strength have occurred.

PRESENTATION OF DATA

The presentation of testing data is both a science and an art. There is science behind how humans process, analyze, and subsequently interpret data (69,83). However, the presentation and actual visualization of data is an art in which you can present information, communicate an idea, and persuade the viewer if needed. This is particularly pertinent within sports science because effectively designed data visualizations allow the viewer (often a coach or athlete) to quickly understand key points and patterns across large swathes of data (5). However, ineffectively designed visualizations can cause misunderstanding and, potentially, distrust. Therefore, the presentation of testing information can be just as important as the testing itself. Although a range of methods can be used to enhance testing data, this section provides recommendations to help improve data presentation so that athletes and practitioners can understand testing outcomes.

When presenting information, the most important considerations are who is the audience and what is the purpose of presenting these data. "Understanding your audience" includes (a) knowing their preference of data presentation (e.g., do they want a quick visual or do they want to know every single number?) and (b) establishing what level of understanding they have of this type of information (e.g., does a head coach know what the test is trying to measure and why it matters to performance?). Furthermore, establishing *why* the data are being presented can ensure the information is clear and differences, or the lack of them, can be emphasized. Consequently, considering who the audience is and the purpose of presenting the information, you can best guide the viewer to reach the right conclusion and help influence decision-making.

The presentation of data should be as simple, effective, and efficient as possible. Time is often the biggest constraint in sports; therefore, keeping testing data simple and informative so that maximal information is quickly conveyed is advantageous. Considering this, a range of methods (refer to Table 5) can be used to emphasize certain points and help convey a message. Furthermore, visual processing of data can be substantially enhanced when several of these methods are combined strategically (83). For example, information can be portrayed more efficiently, and the cognitive load can be reduced when the information is colored, grouped, and enclosed to show discrete differences (refer to Figure 9). Alternatively, data (e.g., player performance) could be more easily interpreted when color, size, and grouping of the data are combined (refer to Figure 10). Moreover, to reduce the cognitive load on the viewer, visual presentations should emphasize the key points, while surplus information that is not integral should be minimized or removed. Classic examples of "figure clutter" that can impede the processing of information includes gridlines, tick marks, unnecessary data labels, and three dimensional (3D) effects (69), whereas simple edits, such as the rotation of axis titles and the provision of specific information relating to performance that would not be easily ascertained (e.g., the use of the specific velocities attained in Figure 10F), help to remove any uncertainty in performance.

To help accentuate the value of the data being presented, providing as much context as pragmatically possible can help coaches to understand the meaning of the data. Even experienced practitioners and researchers will have a poor understanding of a single value (or set of values) when performance is not placed into context. This may include information that compares the performance of

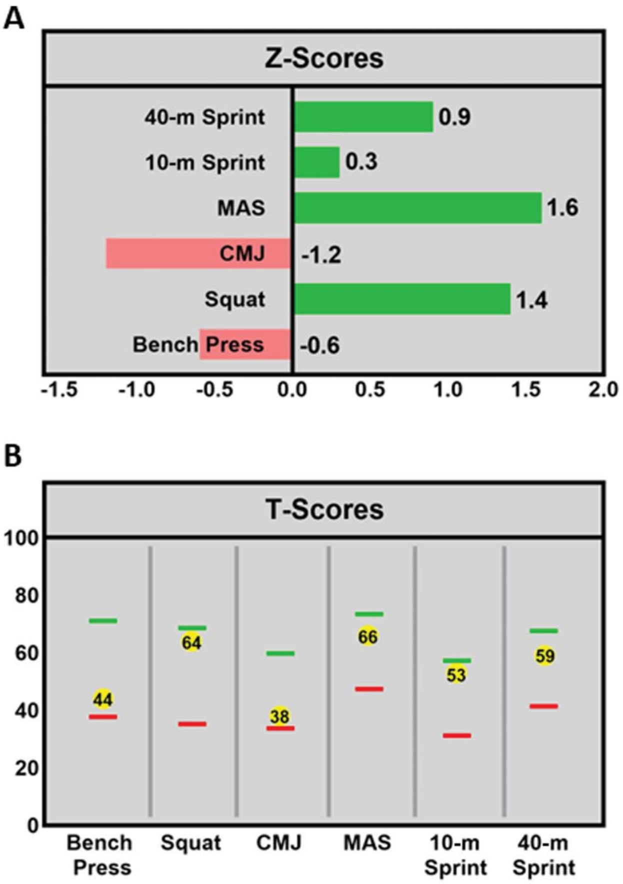


Figure 12. (A and B) Present athlete testing data through Z-scores and T-scores. In (B) (T-scores), the yellow circle and number represent the athlete's score out of 100, while the green and red values represent the highest and lowest scores from the cohort (84).

players of a similar position, playing level, or the wider population. In addition, graphical illustrations that emphasize the magnitude of differences in certain physical qualities between athletes can be valuable. For example, a difference of 0.2 seconds could sound trivial to many coaches. However, others will know that 0.2 seconds in a 20-m sprint is a large improvement/difference. Alternatively, a 0.2 m· second^{-1} mean concentric barbell velocity difference in the back squat may sound small, but in reality, it suggests a difference of ~15–20% 1 RM (22). A range of statistical methods are available to help illustrate these differences (e.g., Z-scores and T-scores (46,84); refer to Figures 11 and 12) and demonstrating the magnitude of difference, irrespective of the units of measurement that can effectively illustrate the practical significance of the data being presented.

Finally, perhaps of greatest importance to the maximization of the collected data is the speed with which the information can be returned to those who require it. It is well established that immediate augmented feedback during exercise can support the execution and improvement of physical performance (94,95,100,101), and the provision of testing data to coaches is no different. Time delays in the provision of feedback mitigate its usefulness, with the usefulness of information inversely related to the turnaround time between the performance and when it is available to the user (Figure 13) (31). Consequently, it is prudent for sport scientists and strength and conditioning coaches to clearly establish when data will be returned, with information from testing ideally being made available as soon as feasibly possible so that coaches can make informed decisions around training programs and prescription. The longer the delay in returning testing information, the less useful that testing occasion is.

"IT IS IMPORTANT, BUT IT IS NOT EVERYTHING" – UNDERSTANDING THE IMPORTANCE AND ROLE OF TESTING

Undeniably, well-developed physical qualities are important and often essential for high-level performance. However, it is also crucial to acknowledge that they are only one aspect of sporting success (44). Although athletic development and performance

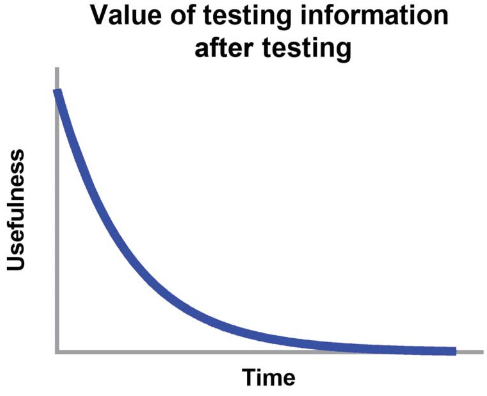


Figure 13. Image that emphasizes the inverse relationship between the time taken to present testing information and its usefulness to coaches.

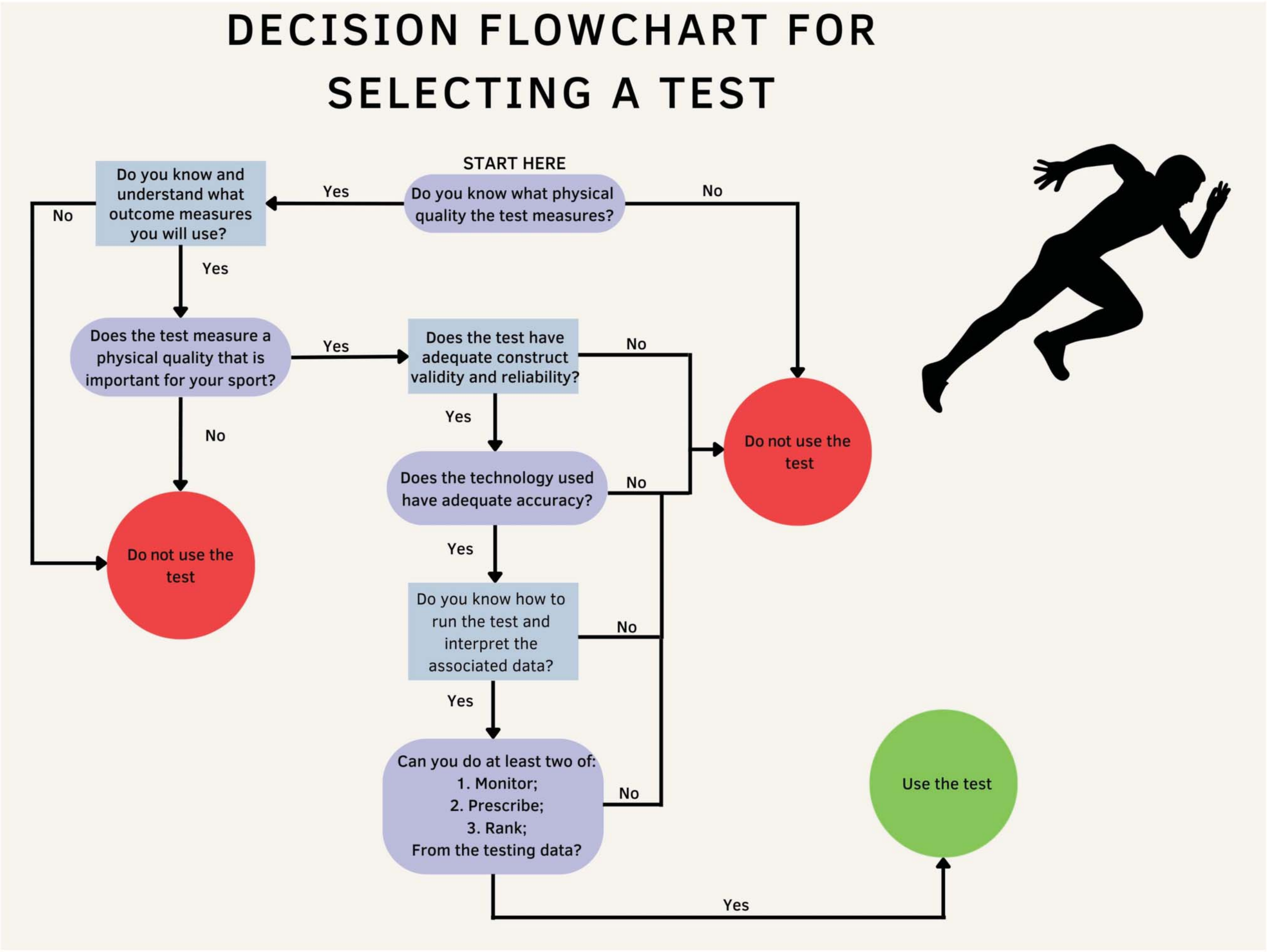


Figure 14. Flowchart to help practitioners decide whether to use a certain test when assessing athletes.

in tests of physical qualities can be incredibly alluring, they do not always transfer to improved outcomes. Indeed, it should be acknowledged that performance on physical testing batteries often only makes up a portion of the selection picture, with sport-specific skills extremely important. Consequently, strength and conditioning coaches should understand the perceptions of fitness testing and physical qualities and how they fit within the holistic development of the athlete. Therefore, while appropriately selected testing batteries should be used to guide selection decisions, monitor changes in physical qualities, and support training prescription, chasing numbers for the sake of improvement on a test or setting arbitrary thresholds/standards for players to attain may be counterproductive. Instead, it is recommended that strength and conditioning coaches work alongside a multidisciplinary team and use testing results to guide decisions and drive conversations within context rather than letting the results dictate them.

CONCLUSIONS

The testing of physical qualities is fundamental to strength and conditioning and can help improve the chances of success for an athlete or team. Information from testing can support coaches in their selection of athletes, the prescription of training, and the assessment of whether training interventions are working. However, it is essential the tests that are being implemented are selected for the right reasons. Fundamental concepts such as validity, reliability, and sensitivity need to be well understood so that decisions are made from accurate and reproducible testing information. Furthermore, understanding why testing is being completed, how the testing is being executed, and what outcomes will occur from this information can substantially improve the odds of implementing a successful testing battery.

When well-designed testing batteries are used, a host of previously unavailable information becomes accessible. Strategic selection of outcome measures, use of technology, and awareness from coaching staff can help maximize information about athletes and help to provide regular updates about physical qualities. In addition, through good data-handling practices and clever presentation, testing information can be efficiently portrayed to athletes and colleagues to convey important points and help influence decisions around physical development. While it is acknowledged that testing of athletes can be stressful, the decisions around the tests used and actual outcome measures retrieved should be simple. To help guide these decisions, Figure 14 provides a simple flowchart to help coaches decide whether the test should be implemented.

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