Bishop, Chris ORCID logoORCID: https://orcid.org/0000-0002-1505-1287, Turner, Anthony N. ORCID logoORCID: https://orcid.org/0000-0002-5121-432X, Jordan, Matt, Harry, John, Loturco, Irineu ORCID logoORCID: https://orcid.org/0000-0003-1309-2568, Lake, Jason and Comfort, Paul (2022) A framework to guide practitioners when selecting metrics during the countermovement and drop jump tests. Strength & Conditioning Journal, 44 (4) . pp. 95-105. ISSN 1524-1602 [Article] (doi:10.1519/SSC.0000000000000677)

A Framework to Guide Practitioners when Selecting Metrics During the Countermovement and Drop Jump Tests

Abstract

Researchers and practitioners have highlighted the necessity to monitor jump strategy metrics as well as the commonly reported outcome measures during the countermovement (CMJ) and drop jump (DJ) tests. However, there is a risk of confusion for practitioners, given the vast range of metrics that now seem to be on offer via analysis software when collecting data from force platforms. As such, practitioners may benefit from a framework that can help guide metric selection for commonly used jump tests, which is the primary purpose of this article. To contextualise the proposed framework, we have provided two examples for how this could work: one for the CMJ and one for the DJ, noting that these tests are commonly utilized by practitioners during routine testing across a range of sport performance and clinical settings.

Introduction

Jump testing is commonly used to assess lower limb neuromuscular function (5,6,9,50), monitor adaptations to training (4,11), readiness to train (14,19,20,48) and readiness to return to training and competition after injury (24,25,43). Whilst numerous types of jumping exist, two of the most common forms utilized in both research and practice are the vertical countermovement jump (CMJ) and drop jump (DJ) (14,17,18,30,32,33,40,50). These two jump tests provide an indirect, performance-based assessment of neuromuscular capacity and reactive strength (i.e., coupled eccentric-concentric movement capacity), with a plethora of studies highlighting good to excellent reliability of jump outcome measures (14,19,20,33,34). Consequently, this helps to ensure that practitioners can interpret results with confidence from the outset. From a practical perspective, jump assessments are simple to perform, generally non-fatiguing and time-efficient, which are factors that should not be overlooked in sport performance and rehabilitation settings, especially when working with large squads of athletes where time constraints may preclude regular neuromuscular testing.

Historically, many research studies have utilised jump mat systems to measure time-based outcome measures like flight time, jump height (based on flight time) and the reactive strength index (RSI) during these tests (27,37,42). Arguments have been made that force platforms are not always accessible to practitioners due to cost and portability issues (8), hence why jump mat systems have been so popular. However, recent technological developments have seen the creation of smartphone apps (3) and reduced cost of portable force platforms systems; thus, enhancing their availability across a range of sport performance settings, including those with budgetary constraints. This is a positive outcome for strength and conditioning and sport medicine practitioners as it has enabled them to gather more detailed information when profiling their athletes' jump ability and lower limb mechanical muscle capacities. Furthermore, an analysis of vertical jump kinetics (using force platform technology) permits a more extensive neuromuscular assessment, allowing practitioners to move beyond solely outcome measures (e.g., jump height), to include measures that describe jump strategy. The relevance here is that strategy metrics (e.g., duration prior to take-off) have been shown to be more sensitive to change compared to outcome measures, after intense exercise (19,20), when returning from injury (22), during long term athlete development (23) and when assessing neuromuscular function across the lifespan (11). Consequently, this has led to numerous studies acknowledging the limitations of outcome measures alone and the need to concurrently monitor jump strategy as well (6,13,21,37).

Despite the advantages of moving beyond a simple measure of jump height and including jump strategy variables, there is also a risk of confusion for practitioners, given the vast range of potential metrics that force platform systems can offer (12,19,20). Simply put, the appropriate jump performance and jump strategy variables to include as a part of athlete monitoring and neuromuscular testing is often unclear. Thus, it is important for any practitioner who is using such tests and technologies to ensure that the selected metrics help to inform practice. As such, practitioners may benefit from a system or framework that can help guide metric selection for commonly used jump tests and this is the primary purpose of this article. To contextualise the proposed framework, we have provided two examples for how this could work: one for the CMJ and one for the DJ, noting that these tests are commonly utilized by practitioners during routine testing across a range of sport performance and clinical settings. Before discussing in detail however, practitioners must first consider a few broader questions specific to their practice.

Theoretical Considerations for Practitioners Regarding Selecting Metrics

There are principally three questions to consider before deciding which metric to use as part of any performance monitoring tool:

1. *Is there some biological basis that theoretically links what we are aiming to measure, with some desirable performance outcome?* For example, if jump height decreases (jump height being the performance outcome we are aiming to measure), does that suggest the presence of high neuromuscular fatigue? Alternatively, if jump height improves, does that imply the potential for better on-field performance such as increased sprint velocity? Assuming a theoretical associative link exists, which has been investigated on numerous occasions previously (26,30,31,54), we move on to question two.
2. *What is the feasibility of implementing this monitoring tool or system*? Without access to an educated staff, dedicated time for testing, finances to obtain quality equipment, and the right team culture or attitude, implementing jump testing to make actionable decisions might not be reasonable. For example, small coaching staffs are often stretched beyond typical coaching duties. Adding in daily or weekly force plate assessments (including data analysis, feedback sheets, and personal communication) may pull some members away from other fundamental practices. At that point,

practitioners may likely lose more than they gain from implementing jump testing on force platforms. Equally, some players may not "buy-in" or have an interest in participating in testing. Perhaps most importantly, would the head coach support and encourage this practice amongst the athletes? Assuming that practitioners have attempted to outline the reasons why testing is needed, how it can benefit all parties involved, and there are no feasibility issues, the final question can be addressed. Despite these potential challenges, the authors would suggest that testing at the end of each mesocycle is still advised. This is so that practitioners can determine that the training programmes have had the desired outcomes and so that continued feedback to the key stakeholders takes place, in an attempt to build a sustainable human-centered high-performance environment (51).

3. *What is the quality of the data being collected, and in particular, are the data more sensitive or less accurate according to the quality of data that is possible to collect?* As a crude example, practitioners may want to measure RSI each morning to determine whether their athletes have recovered from the previous day's training load and if they display sufficient readiness for the day's planned training sessions (52). If having determined their baseline scores across 5 days of normal activity, we establish there is a high degree of variability, the data may not be sensitive enough to inform practice and allow us to make accurate and informed training decisions. This realisation can often be a bitter pill to swallow and challenge some deeply rooted biases we have, especially when a theoretical link to sport performance is strong (26,30,31,54), and we have invested substantial financial and human resources to enhance our testing process. Equally, we may be familiar with other teams that do use it and who do indeed plan training around it. However, it is important to remember that the accuracy of the data is based on numerous contextual factors such as the performance level of the athletes, the skills of the testers, the equipment, and the environment (53). Therefore, what works for one team may not work for another. With this in mind, practitioners are encouraged to compute their own benchmarking and reliability analysis to ensure that they have usable data and can establish thresholds that are sensitive enough to detect meaningful changes in performance. In closing then, there will be some circumstances whereby the error or variability in a test, irrespective of how well it meets questions one and two, is so large, that it will be ineffective to inform decision making and practice. Figure 1 provides a schematic overview of these three primary questions for practitioners to consider before embarking on selecting a given metric.

Selecting Metrics from the Countermovement and Drop Jump Tests

Assuming the above three questions have been considered by practitioners, we can consider an example of how to select our metrics from the CMJ and DJ tests. It is important to note at this point, the forthcoming examples represent suggestions only and additional metrics commonly used in the literature such as power (19,20,32), may still have their place. However, readers should also note that jump strategy can be altered increasing power output, but with a concurrent reduction in jump height as it is propulsive net impulse that determines jump height, not power (36,39,46). Thus, the purpose of this framework is to demonstrate how the example metrics chosen 'fit together' and consequently, may make using the data in practice easier to help inform decision-making.

As previously mentioned, a concurrent focus on the outcome measure and jump strategy may provide a more holistic picture of an athlete's neuromuscular capacities, during jump profiling and ongoing monitoring. Where possible, the key here is for the metrics to be supported by empirical research and a documented history of acceptable validity and reliability for sport performance and clinical applications. Where validity is concerned, this relates to the degree to which the tests measures what it is supposed to measure, supporting practitioners to determine the utility of a given set of outcome measures (15). The use of any test will largely be determined by a needs analysis of the sport or athlete in question, and with team or court-sport athletes often requiring ballistic force production in as short a time as possible, jump testing is often a popular choice for practitioners. Once validity is established, reliability and the associated measurement error should then be determined. In doing so, and assuming the results are deemed acceptable, practitioners can have greater confidence that the data will be usable for continued monitoring purposes (53). In addition, any observed changes from a training intervention should also be interpreted relative to the measurement error, to determine whether such changes are 'real' or within the error of the test (discussed later) (4,53). Although acceptable reliability is open to interpretation (and a bit like drawing a line in the sand), previous suggestions for intraclass correlation coefficients would be a lower bound 95% confidence interval > 0.75 (28) and < 10% for the coefficient of variation (CV) (14). As a final point, the volume of metrics available from force plate assessments is vast (12,19,20). Because of this, it is suggested that only a few key metrics are monitored, otherwise it can be difficult to use this information to inform training when multiple data from the same test are monitored concurrently.

Countermovement Jump

Recent literature has shown a huge rise in popularity for RSI modified (RSI-Mod) (4,17,21,47), which can be calculated by dividing jump height by time to take-off and is likely to be considered an outcome measure. It is important to recognize that this metric is a ratio which is a single value made up of two components which can make it harder to generate meaningful interpretations (1). This is supported in recent research on inter-limb asymmetry, which showed the data to be 'noisier' than the individual components (6,7,9). This is likely to hold true for RSI-Mod which is also born out of two other metrics (i.e., jump height and time to take-off). Thus, practitioners are advised that any changes in RSI-Mod may be hard to comprehend, without concurrently monitoring the individual components that create it. Thus, our second and third suggested metrics are jump height (ideally determined from take-off velocity) and time to take-off. Despite the challenges that often accompany ratio data, readers should note that in this instance, an increase in RSI-Mod cannot occur without an improvement in one of the component parts (i.e., increased jump height or reduced time to take-off), and vice versa. For example, if an athlete jumps 0.4 m and time to take-off is 0.8 s, RSI-Mod will equal 0.5 (0.4 divided by 0.8). However, if an athlete exhibits a 10% improvement in jump height (0.44 m), with no change in time to take-off, RSI-Mod will improve to 0.55. Equally, a 10% reduction in jump height (0.36 m) would result in a new (and worse) RSI-Mod score of 0.45; with the same trend in scores for RSI-Mod evident if changes in time to take-off occur. As such, the importance of monitoring the component parts of any ratio should be clear here, noting that any changes in RSI-Mod can only be explained by changes in either jump height and/or time to take-off. Equally, in some instances, an athlete's body mass may also need to be factored into the monitoring process. For example, if the purpose of a training intervention is to increase muscle mass and an athlete now achieves the same jump height but with an increase of 2-kg in body mass, this can also be seen as a positive adaptation. Although jump height has come under some scrutiny to detect neuromuscular readiness to train or compete (19,20), it will almost always be considered relevant. The importance of effective knowledge translation of routine athlete monitoring data, including vertical jump testing, using athlete-appropriate language must not be overlooked. Although this remains anecdotal, we observe substantially better buy-in from stakeholders (e.g., athletes and head coach) when simplified language is prioritized. While key stakeholders may lack the requisite knowledge of physiology and biomechanics to grasp a detailed breakdown of a vertical jump kinetic analysis, a variable like jump height is likely to be of interest to the athlete (as well as understood), as this value provides some confidence that they can outperform their peers. Furthermore, the use of feedback to the athlete in particular, may be a powerful method for establishing better overall stability in test measures, which subsequently may have a positive impact on test reliability as well.

However, as practitioners and support staff, we may also be interested in what is driving the outcome, which is where an understanding of jump strategy comes in. Time to take-off provides a useful understanding of the duration of time between the initiation of the countermovement and take-off, which may represent a useful strategy metric (4,21). Simply put, if practitioners see reductions in time to take-off, two explanations may be evident: i) the athlete may not be dipping as deep (negative displacement) in the countermovement and as a result will likely generate lower net impulse, resulting in a reduced jump height (46), which would be a negative adaptation from training or, ii) if jump height remains the same, the athlete is now achieving the same outcome but in less time, which infers improved ballistic qualities such as rate of force development, which would be a positive adaptation from training. Despite the usefulness of time to take-off in this instance, it still may not be entirely obvious why any changes in time have occurred. Thus, our final suggested metric in this example is countermovement depth. For example, if time to take-off was 0.8 s in one test session, but 0.7 s in another; practitioners can see the athlete completes the movement prior to take-off in a shorter duration in the second test session, which based on our aforementioned discussion, would be desirable. However, the reason for this change may not be obvious. With the inclusion of countermovement depth, practitioners would be able to contextualise changes in time to take-off, by reporting any discrete differences that may be evident in the depth of movement prior to the jump. Thus, monitoring countermovement depth may help practitioners to determine why any changes in time to take-off may have occurred between test sessions. To the best of the authors' knowledge, no research specifically looking at the association between countermovement depth and time to take off has been published. However, previous research has shown moderate relationships between countermovement depth and jump height (r = 0.60-0.67) (35). With the present article focused on the use of metrics as a collective to inform practice, the magnitude of these relationships is likely strong enough to justify the use of countermovement depth as a stand-alone metric, especially when it can be used to also inform changes in time to take-off. As a final point, practitioners should also note that this metric may potentially benefit from being normalised to standing height, especially when monitoring longitudinally in groups such as youth athletes (29) or in sports where large anthropometric differences may be evident, such as basketball (43).

In summary, the inclusion of jump height and time to take-off will help to simultaneously explain any changes in RSI-Mod, whilst also providing an understanding of both the outcome measure and jump strategy employed. Finally, countermovement depth may also help to explain why any changes in time have occurred, noting that time is one of the constructs of RSI-Mod as well. Collectively, these metrics 'tell a story' and complement each other, which hopefully allows data to be effectively used to inform decision-making. It should be noted of course, that this decision-making process is entirely context-dependent and what may apply for one athlete, may not for another. This framework (Figure 2) which aims to inter-link selected metrics to one another, can also be applied to the DJ test as well.

Drop Jump

The most common metric reported in DJ test protocols appears to be RSI (6,18,29,33,34) and would be considered the outcome measure. This is another ratio metric and in line with our suggestions for the CMJ, any changes in RSI may be hard to comprehend, without concurrently monitoring the individual components that create it. Thus, our second and third suggested metrics are jump height (again, ideally determined from take-off velocity) and ground contact time (GCT). When aiming to understand how the jump is performed, GCT does provide some understanding of strategy in the DJ task, especially when existing literature seems largely in agreement about the distinction between fast (< 0.25 s) and slow (> 0.25 s) stretch shortening cycle (SSC) timeframes (18,41,49). Simply put, monitoring GCT may provide an understanding of whether athletes are utilising fast or slow SSC mechanics during the DJ, which may subsequently inform programming recommendations, when related to the needs of the athlete. In a similar notion to time to take-off in the CMJ, it can be hard to comprehend why changes in GCT have occurred between test sessions, without an additional strategy metric. Thus, our fourth suggested metric in this framework could be leg stiffness. This refers to the resistance of deformation in the lower extremity joints relative to the force placed upon it and can be calculated as peak ground reaction force divided by displacement of the leg spring (10). For example, if GCT data was 0.23 s in one test session, but 0.28 s in another; practitioners can clearly see the athlete is spending less time on the ground in the first test session (which is typically desirable). However, the reason may not be obvious. With the inclusion of leg stiffness, we would likely see a reduction in stiffness in test session two, meaning greater flexion of the lower extremity joints, resulting in the athlete spending longer on the ground. Thus, monitoring leg stiffness may help practitioners to determine why any changes in GCT may have occurred between test sessions, assuming aspects such as drop height have been standardized. This is supported in empirical research by Arampatzis et al. (2), which reported strong relationships between leg stiffness and GCT during the DJ at 20-cm (r = -0.82) and 40-cm (r = -0.89) in female athletes. Although these correlations can be deemed 'strong', they provide r^2 values of -0.67 and -0.79, respectively. This shows that 33% and 21% of the variance for GCT cannot be explained by leg stiffness, which may indicate that both metrics can be used together, without directly inferring the same information.

Some additional information should also be considered for DJ testing and monitoring. Firstly, practitioners should try to standardize the fall height when stepping off the platform each time they conduct the test. Not doing so will affect impact and take-off velocity and ultimately, the outcome measures. This can be accommodated using a single force platform using the new methods proposed by McMahon et al. (38). Secondly, if practitioners do not have access to a force platform, an equation developed by Dalleau et al. (16) has validated leg stiffness against the aforementioned method using flight time, GCT and body mass (r = 0.94), meaning this can also be implemented from the data gathered using a jump mat or smartphone app. However, it is worth noting that the usefulness of leg stiffness as an additional metric may be questioned, if GCT is > 0.25 s, noting that times above this threshold are indicative of poor fast SSC mechanics, which are typically a key requirement in the DJ task (33,34,41). Thus, perhaps the use of leg stiffness is reserved for interpreting changes in GCT, that remain below the suggested 0.25 s threshold for fast SSC mechanics.

In summary, with the DJ being a measure of reactive strength, RSI is likely to be a metric of interest. However, given it is a ratio, the component parts of jump height and GCT should also be monitored. Finally, leg stiffness would complement GCT, by enabling practitioners to understand why changes have occurred over time, during the amortization phase. Similar to the CMJ, this framework (Figure 3) aims to link the selected metrics together so that a concurrent focus of outcome measures and jump strategy can be utilised to inform decision-making, during the ongoing monitoring process.

Practical Applications: Testing Their use in Practice

Once metrics have been selected for the CMJ and DJ tests, the key is to test the hypothesis that they are both reliable between test-sessions and sensitive to change. Tables 1 and 2 provide hypothetical data for our previously identified CMJ and DJ metrics, pre and post an 8-week training intervention – although a previous publication was used to ensure that the suggested values are realistic, but not the same (4). Both tables show mean data, pre-intervention absolute reliability (using the CV), percentage change and magnitude of difference (effect sizes [*d*]) between test sessions. At this point, readers should note two key points: i) when interpreting percentage change relative to the CV, the baseline or pre-intervention CV is used (not pooled values) because "change" is always interpreted relative to where it originated (i.e., baseline) (4) and, ii) given this is a hypothetical scenario, any discussion around the specifics of the training intervention would be out of place in this article. However, practitioners should consider the efficacy of their training programs within the context of the overall aim of the training phase and the metrics being monitored.

In Table 1, RSI-Mod and jump height show only trivial changes ($d \leq 0.18$). Although these metrics appear reliable (CV < 10%), the percentage change values (which has been included to differentiate between change that is real and that inside the error of the test) are also < the CV. Thus, our conclusion in this instance is that these metrics are reliable, but not overly sensitive to change post training intervention. However, our strategy metrics (time to take-off and countermovement depth) show much larger changes (d = -0.83 to -1.08). Specifically, these athletes have reduced their time to take-off, essentially resulting in a faster movement. As discussed earlier, jump height has largely remained the same, but now the movement is quicker prior to take-off. As such, practitioners are able to infer greater improvements in rate of force development qualities, which will represent largely the same impulse being applied over a shorter timeframe. This is supported by the large reduction in countermovement depth (d = -1.08), which may help to explain the changes seen in time to take-off. Finally, with our strategy metrics also showing acceptable reliability, practitioners can also see that the percentage changes are this time, greater than the associated variance in the test; thus, exhibiting real change at the group level. At this point, it is important to note that this scenario relates to group mean data. However, given every athlete gets their own scores, percentage change relative to the baseline CV can also be computed on an individual basis, which has been reported in a recent study using Premier league academy soccer players (4).

In Table 2, all of our metrics show CV values < 10%, which means practitioners can be confident in acceptable reliability of the chosen metrics. Similar to the CMJ, the magnitude of difference varies between metrics though. Jump height shows only a small improvement (d = 0.35), whilst GCT has exhibited a moderate (d = -0.75) and statistically significant improvement. Unsurprisingly, the effect size for RSI is somewhere in the middle (d = 0.57), noting that RSI is a ratio that is constructed by dividing jump height by GCT (49). Finally, although these greater improvements in GCT (relative to jump height and RSI) are desirable, this is reinforced by large improvements in leg stiffness (d = 0.81). Thus, the inclusion of leg stiffness as a metric reinforces our understanding of the improvements seen for GCT.

Although hypothetical, hopefully readers can comprehend how the selection of these metrics for the CMJ and DJ tests, help to inform each other. In addition, this section in particular highlights that: i) not all metrics will be sensitive to change after training interventions; thus, some will inform decision-making better than others, ii) not all metrics will elicit the same level of reliability and thus, practitioners may wish to implement standardized familiarization sessions prior to any formal data collection to improve reliability and determine a threshold for meaningful change and, iii) if metrics are chosen that do not relate to others that are being monitored, it may not always be obvious why some have been selected and why some changes are evident between test sessions.

Conclusion

This article aims to encourage practitioners to consider the metrics they select from CMJ and DJ tests, so that the information obtained helps to explain the findings of other chosen metrics and guide decision-making in practice. Although examples have been provided for both the CMJ and DJ tests, readers should note that we are not solely suggesting that these are the only metrics to be monitored in these tests. Merely, our aim here was to demonstrate in these examples, that the chosen metrics can help complement each other by helping to explain why any changes in scores may be evident. Whilst a plethora of metrics from jump testing exists in the literature to date, it is the final step in the puzzle – testing their use in practice, which should drive whether they have any continued use for monitoring. This should help to aid whether their inclusion is warranted or not, alongside more commonly used outcome measures, such as jump height.

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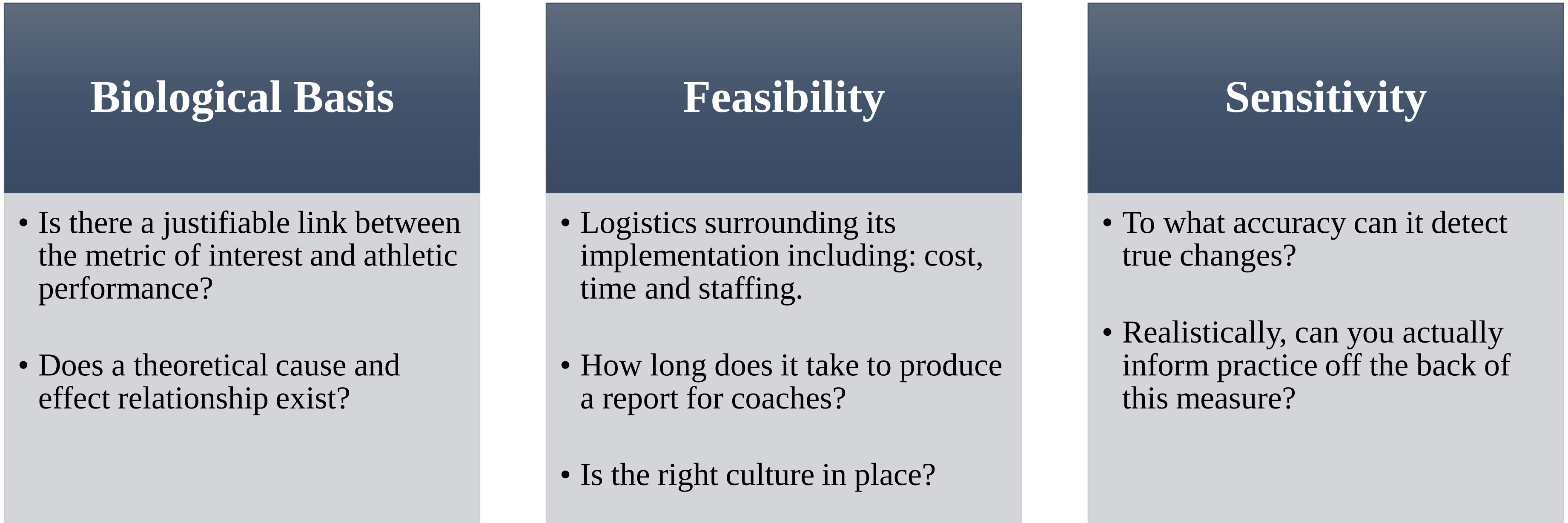

Figure 1. A 3-step process to determine the efficacy of selected metrics and the ability to use them in practice.

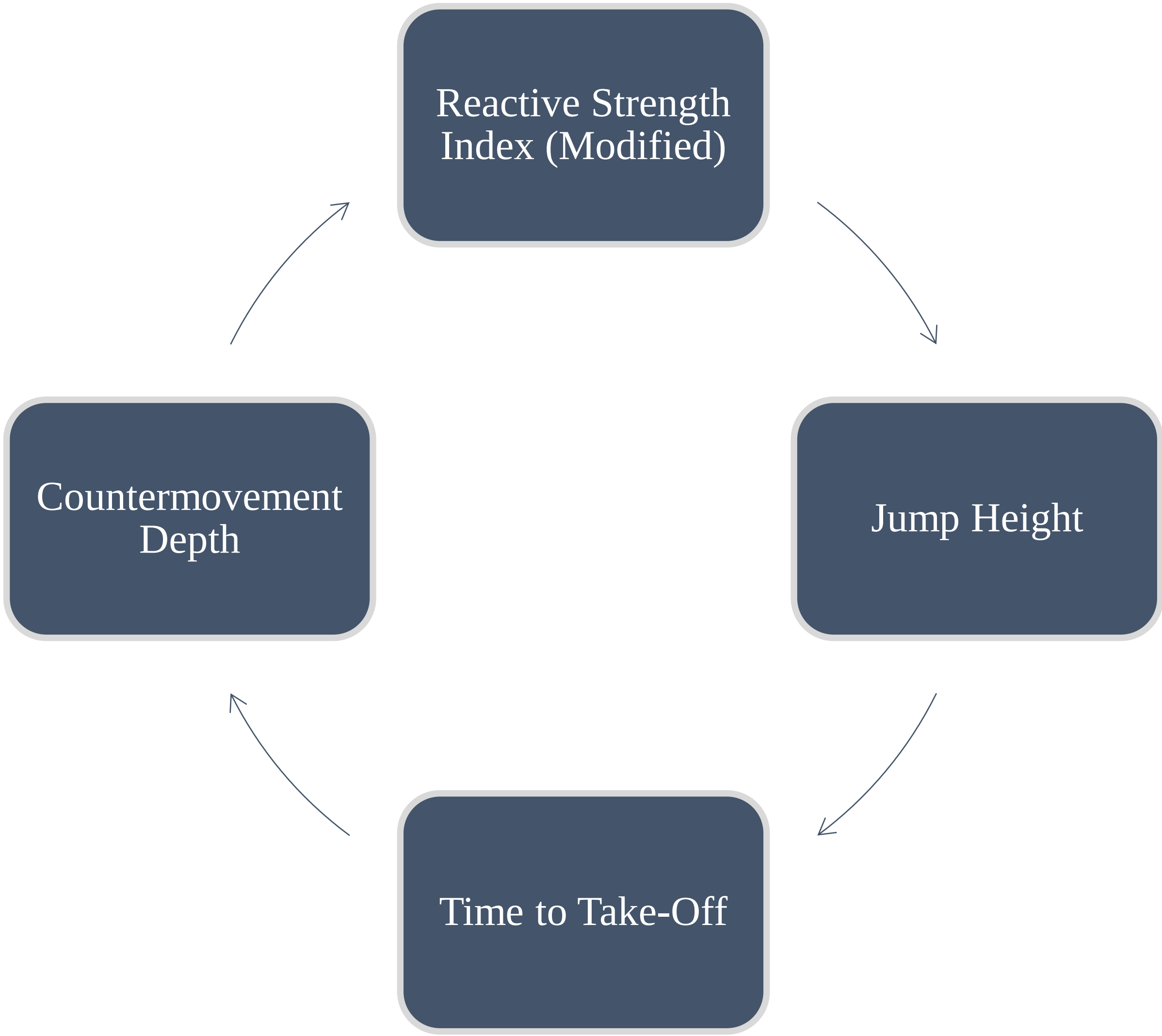

Figure 2. Schematic outlining metrics chosen in the countermovement jump test.

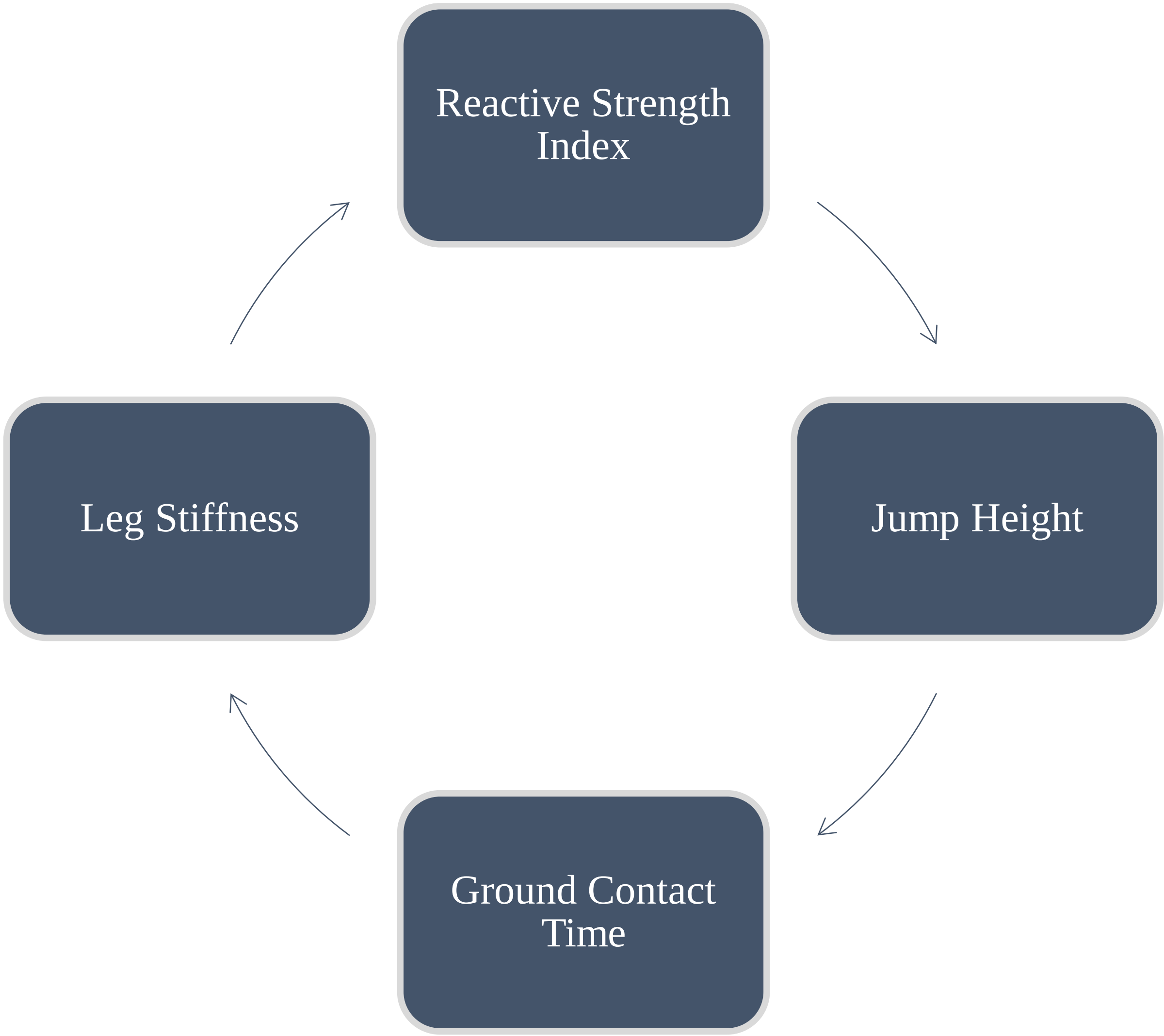

Figure 3. Schematic outlining metrics chosen in the drop jump test.

Table 1. Mean ± standard deviation data for the countermovement jump test in 20 adult male professional soccer players pre and post training intervention, with absolute reliability (coefficient of variation – CV), percentage change and effect size differences (*d*) with 95% confidence intervals (CI). Note: Effect size values in bold represent statistically significant ($p < 0.05$) changes.

Metric	Pre-Intervention	Post-Intervention	Pre-Intervention CV (%)	% Change	Effect size *d* (95% CI)
RSI-Modified	0.47 ± 0.12	0.49 ± 0.13	6.7	4.3	0.16 (-0.36, 0.68)
Jump height (m)	0.41 ± 0.06	0.42 ± 0.05	3.3	2.4	0.18 (-0.34, 0.70)
Time to take-off (s)	0.88 ± 0.06	0.83 ± 0.06	5.0	6.0	**-0.83 (-1.36, -0.28)**
CM depth (m)	0.44 ± 0.05	0.39 ± 0.04	8.9	12.8	**-1.08 (-1.64, -0.53)**

RSI = reactive strength index; CM = countermovement; m = metres; N = Newtons; Ns = Newton seconds; s = seconds.

Effect size scale: < 0.25 = trivial; 0.25-0.50 = small; 0.51-1.0 = moderate; > 1.0 = large (39).

Table 2. Mean ± standard deviation data for the drop jump test in 20 adult male professional soccer players pre and post training intervention, with absolute reliability (coefficient of variation – CV), percentage change and effect size differences (*d*) with 95% confidence intervals (CI). Note: Effect size values in bold represent statistically significant ($p < 0.05$) changes.

Metric	**Pre-Intervention**	**Post-Intervention**	**Pre-Intervention CV (%)**	**% Change**	**Effect size *d* (95% CI)**
Reactive strength index	2.85 ± 0.32	3.06 ± 0.41	7.6	7.4	0.57 (0.03, 1.09)
Jump height (m)	0.35 ± 0.11	0.39 ± 0.12	3.9	11.4	0.35 (-0.18, 0.86)
GCT (s)	0.24 ± 0.04	0.21 ± 0.04	6.2	12.5	**-0.75 (-1.27, -0.20)**
Leg stiffness ($kN \cdot m^{-1}$)	58.81 ± 8.90	66.41 ± 9.90	9.6	12.9	**0.81 (0.25, 1.33)**

m = metres; GCT = ground contact time; s = seconds; $kN \cdot m^{-1}$ *= leg stiffness in Newtons multiplied by metres per second.*

Effect size scale: < 0.25 = trivial; 0.25-0.50 = small; 0.51-1.0 = moderate; > 1.0 = large (39).