The Use of Contact Time and the Reactive Strength Index to Optimize Fast Stretch-Shortening Cycle Training

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SUMMARY

THIS ARTICLE REVIEWS RESEARCH RELATING TO THE STRETCH-SHORTENING CYCLE AND PLYOMETRICS. THE ARTICLE INSTRUCTS STRENGTH AND CONDITIONING PRACTITIONERS IN THE USE OF GROUND CONTACT TIMES AND THE REACTIVE STRENGTH INDEX IN PLYOMETRIC TRAINING. DOCUMENTATION ON HOW THESE MEASUREMENTS CAN BE USED TO OPTIMIZE PLYOMETRICS AND TO IMPROVE ATHLETES' FAST STRETCH SHORTENING CYCLE PERFORMANCE IS PROVIDED. RECOMMENDATIONS ARE MADE REGARDING THE USE OF GROUND CONTACT TIMES TO IMPROVE TRAINING SPECIFICITY AND THE USE OF THE REACTIVE STRENGTH INDEX TO OPTIMIZE PLYOMETRICS, TO MONITOR TRAINING PROGRESS, AND TO SERVE AS A MOTIVATIONAL TOOL. A 4-STEP PROGRESSION OF IMPLEMENTATION IS DETAILED.

THE STRETCH-SHORTENING CYCLE (SSC)

The SSC is a natural type of muscle function in which muscle is stretched immediately before being contracted. This eccentric/concentric coupling of muscular contraction produces a more powerful contraction than that which would result from a purely concentric action alone (14). When the force velocity curve is measured during a complex SSC movement involving a number of joints and muscle groups, such as a vertical jump, the use of a preceding eccentric phase shifts the force–velocity curve to the right. In comparison with purely concentric movements, the SSC allows greater forces to be produced at any given velocity during the concentric phase (13).

The SSC is observed in a wide range of activities. In real-life situations, exercise seldom involves a pure form of isometric, concentric, or eccentric actions (15). The SSC appears to be the natural form of muscle function, and it is evident in everyday activities, such as walking and running, as well as in more challenging actions, including throwing and jumping.

One view has been that the SSC causes an enhancement during the concentric phase attributable to the storage and reutilization of elastic energy (7, 16). During the eccentric phase, the active muscles are prestretched and absorb energy. Part of this energy is temporarily stored and then reused during the concentric contraction phase of the SSC (4). A short transition between the eccentric and concentric phase is necessary for this elastic energy to be used optimally.

Additional mechanisms of action also have been proposed. It has been speculated that the prestretch in the SSC may enhance the concentric contraction through neural potentiation of the muscle contractile machinery during the eccentric phase, allowing for a greater number of motor units to be recruited during the concentric contraction (30). Walshe et al. (32) observed an increase in work output during the concentric phase of squatting exercise when that concentric phase was preceded by a prestretch

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or by an isometric contraction, in comparison with a purely concentric squatting exercise. These authors suggest that the performance enhancement from the preceding stretch or from the isometric contraction may result from an attainment of a greater level of neural excitation before the concentric movement. This potentiation effect increases with the speed of the eccentric action and decreases with the amount of transition time between the eccentric and concentric phases (2).

Bobbert et al. (4) determined that in tasks such as maximal effort vertical jumps, in which eccentric-concentric coupling is used compared with purely concentric squat jumps, the performance enhancement in the SSC is likely caused by the eccentric phase, allowing an increased time to develop force. The slow eccentric phase allows muscles to develop a high level of active state (more attached cross-bridges) before the start of concentric motion. As a result, developed force and joint moments are greater at the beginning of the concentric phase and more work is produced through the first part of the concentric motion compared to concentric only squat jumps. Earlier work from Bobbert et al. (2) supports this theory, showing that in a countermovement jump, peak force is already closely approached or even reached at the transition point between eccentric and concentric motion (before the concentric phase has even begun).

The SSC causes an increased excitability of proprioceptors for an optimal reaction by the neuromuscular system. Two proprioceptors are of most relevance in the SSC. The first is the Golgi-tendon organ (GTO), which is located in the extrafusal fibers and innervated by alpha motor neurons (24). The second is the muscle spindle, which is located in the intrafusal fibers and innervated by γ-motor neurons (19,24).

GTOs respond to changes in tension (24) rather than of those in length. They inhibit agonist muscles and facilitate antagonist muscles (5). These inhibitory effects function as a protective mechanism (19). When muscle contractile forces reach a point at which damage to the muscle–tendon complex may occur, GTOs increase afferent activity, resulting in inhibition of the motor neurons innervating the stretched muscles while simultaneously exciting the motor neurons of the antagonistic muscles (5,19,24). However, the inhibitory action of GTOs can be minimized. Their inhibitory action can be counteracted by the contributions of muscle spindles.

Reflex contributions of the muscle spindle also can contribute to the enhanced work output observed in the SSC. The muscle spindle is a facilitatory mechanoreceptor, which reacts to the rapid changes in a muscle's length to protect the muscle–tendon complex. As eccentric stretching approaches a rate that could potentially damage the muscle–tendon complex, the muscle spindle activates and reflexively stimulates an opposite contraction of the agonist. Contributions from the muscle spindle are one mechanism that accounts for the performance enhancement observed in SSC activities such as depth jumps, which involve very rapid eccentric phases (3).

The precise mechanisms that underpin any given SSC activity may be determined by the demands of the SSC criterion task (10). Schmidtbleicher (28) has suggested that the SSC can be classified as either slow or fast. The fast SSC is characterized by short contraction times ($<$0.25 seconds) and small angular displacements of the hips, knees, and ankles. A typical example would be depth jumps. The slow SSC involves longer contraction times, larger angular displacements and is observed in maximal effort vertical jumps.

For example, the muscle spindle reflex is dependent on a fast rate of eccentric stretching (2) and elastic energy contribution may rely on a short transition period between eccentric and concentric phases (2). Decay in the magnitude of potentiation has been observed as the transition time between eccentric and concentric contraction increases (33). These mechanisms then are more likely to contribute to the fast SSC which has a faster eccentric velocity and a shorter transition period than the slow SSC (2).

Performance enhancement in slow SSC activities may be primarily due to the slow eccentric phase allowing an increased time to develop force (4, 32). The slower, longer eccentric phases and the greater transition times between eccentric–concentric coupling observed in slow SSC activities cast doubt as to whether mechanisms such as the muscle spindle reflex, elastic energy contributions, and potentiation could be as active in slow SSC tasks compared with fast SSC activities (10). As a result, it has been hypothesized that the slow and fast SSC may represent different muscle action patterns that rely on differing biomechanical mechanisms, which can affect performance in different ways (10).

This hypothesis may have implications for strength and conditioning practitioners. Different exercises or the manner in which exercises are performed may elicit different mechanisms of SSC action. Training slow SSC activity may not by as beneficial for athletes who primarily rely on the fast SSC in their chosen sports and vice versa. To adhere to the principle of specificity, careful consideration must be made to select modes of training which incorporate the appropriate SSC action for the athlete's specific needs.

PLYOMETRICS, GROUND CONTACT TIMES, AND THE REACTIVE STRENGTH INDEX

A common modality to enhance athlete's SSC capabilities is plyometric training. "Plyometric training" is a colloquial term used to describe quick, powerful movements using a prestretch, or countermovement, that involves the SSC (23). Plyometrics have been commonly used in power and speed training. Specific plyometrics exercises can be used to train the slow or fast SSC. Examples of slow

SSC plyometrics include vertical jumps and box jumps. Bounding, repeated hurdle hops, and depth jumps typically are regarded as fast SSC movements. The primary focus of this article is the optimization of fast SSC plyometrics, particularly depth jumping. Appropriate plyometric training programs have been demonstrated in the literature to increase power output (20), agility (22), running velocity (17), and even running economy (26,29).

Recently, the reactive strength index (RSI) has been used in the practical strength and conditioning setting as well as in the exercise science literature as a means to quantify plyometric or SSC performance (11,21). The RSI was developed as one component of the Strength Qualities Assessment Test, which originated at the Australian Institute of Sport (33). Reactive strength index is derived from the height jumped in a depth jump, and the time spent on the ground developing the forces required for that jump (21). Using a contact mat during a depth jump exercise, one calculates the RSI by dividing the height jumped by the time in contact with the ground before take-off (Figure 1) (21).

Young (34) has described the RSI as an individual's ability to change quickly from an eccentric to concentric contraction and can be considered as a measure of "explosiveness." Explosiveness is a coaching term that describes an athlete's ability to develop maximal forces in minimal time (35).

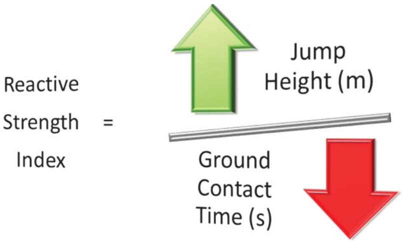

Figure 1. Formula for calculating the RSI. Reactive strength index can be increased by increasing jump height, decreasing ground contact time, or both.

The RSI also has been described as a simple tool to monitor stress on the muscle–tendon complex (21). Thus far, RSI has been used primarily during plyometric activities such as depth jumps, which have a distinct, observable ground contact phase. Depth jumps are one of the most commonly used and most commonly researched plyometric exercises (31). In the depth jump, the athlete drops from a fixed height and immediately upon landing performs an explosive vertical jump (31). Because the RSI is a ratio between ground contact time and height jumped, both these variables need to be considered in conjunction with the overall RSI score.

The ground contact times in plyometric exercises are an important variable for strength and conditioning coaches to consider. By examining the ground contact times during the performance of a plyometric exercise, the attending coach can assess precisely what type of SSC (fast or slow) is being used. The principle of specificity dictates that the demands of an athlete's sport, or the demands of a task in which an athlete wishes to improve his or her performance will directly determine the manner in which the plyometric exercises should be performed (31). Athletes whose training goal is simply to increase maximum jump height, such as line-out jumpers in rugby union, can benefit from longer ground contact times, allowing them to generate maximum force and maximum jump height (31). Athletes wishing to improve their maximum velocity sprinting speed, which is primarily dependent on fast SSC utilization, would require plyometric training with shorter contact times. Examining the ground contact times of his or her athletes during plyometric training will give the strength and conditioning coach an excellent indication of whether the exercise is being performed in a beneficial manner to their athletes' specific sport. Contact time can be measured in the practical setting using contact mats or can be analyzed in the laboratory setting by the use of force plates.

Schmidtbleicher (28) has set a ground contact threshold of 0.25 seconds and shorter as the determinant of the fast SSC. From working with elite rugby players, we have observed this threshold to be reflective of the fast SSC. Indeed, contact times as low as 0.102 seconds have been recorded for jumps over a series of hurdles. In training, we use a long contact mat to measure time on the ground for a depth jump followed by 3 hurdle jumps where the hurdle height is 60 cm. Commonly, we have observed contact times shorter than 0.150 seconds for such an exercise.

If long ground contact phases are observed, the attending coach must emphasize to the athlete to be more explosive and to get off the ground quicker. If, after such instruction, too great a ground contact time (>0.25 seconds) in a specific exercise is still observed, then this suggests that the intensity of that particular exercise is too difficult for the athlete and needs to be adapted or replaced. For example, if an athlete is unable to exhibit ground contact times representative of the fast SSC in a depth jump from 40 cm, the depth jump height will need to be reduced. If an athlete cannot produce short ground contact times when executing repeated hurdle hops over 60 cm barriers, shorter barriers should be used.

For coaches who may not have access to such equipment as ground contact mats, research has highlighted that longer ground contact phases are typified by the athlete being unable to stay on the balls of the feet and having their heels hit the ground during the jumping action (3). If fast SSC enhancement is the training goal, coaches should observe that athletes are minimizing ground contact times, remaining on the balls of their feet through their jumps, and using a stiff lower-limb action with little flexion at the hips and knees.

In addition to ground contact times, the height to which athletes jump to during plyometric exercises is also important. The height achieved in a vertical jumping action is representative of the power production capabilities of that athlete (6). Power output capacity in vertical jumping tasks has been correlated with performance in a number of sports (6,9,27). Monitoring the height jumped during plyometric training will help the strength coach ensure athletes are performing with high effort and maximal power production. In the training environment, jump heights can be simply derived from contact mat data indicating how long the athlete has spent airborne in the jump (flight time). However, many modern ground contact mats automatically calculate jump height for each jump performed. The formula for calculating jump height from flight time is as follows:

$$Height\ (m) = (gravity * (Flight\ time)^2)/8,$$

$$where\ gravity = 9.81\ m/s$$
$$and\ flight\ time\ is\ in\ seconds$$

Alternatively, "jump-and-reach" equipment could be used. In the research setting, jump heights have been commonly calculated using flight times derived from force plate data (6,8,10).

If the strength and conditioning coach only examines contact times during plyometric training, athletes may alter their jumping strategies to reduce ground contact times but at the expense of power output. Similarly, if jump height is the only examined variable athletes may produce great power outputs but accrue ground contact times of long duration and violate the specificity of training principle. From our experience of working with elite level rugby players, we have found this to be the case. Consequently, it can be of great benefit to the athlete and the plyometric training process for the coach to monitor the training with a combination of these two variables. The combination of these two variables is the reactive strength index.

OPTIMIZING AND MONITORING PLYOMETRIC TRAINING

Although the monitoring of ground contact times can provide a quick reference to indicate plyometric exercise specificity, the primary benefit of measuring the RSI is its ability to optimize the height from which plyometric depth jumps can be performed from both a performance perspective and an injury risk perspective.

Anecdotally, in strength and conditioning, the process of players performing 3 depth jumps from increasing dropping heights (e.g., 15,30,45 cm) with the RSI calculated for each jump at each height has been described. When the RSI is maintained or improves with an increase in depth-jump dropping height, and the ground contact time is indicative of fast SSC performance, it is assumed that an individual's reactive strength capabilities are sufficient at that height of depth jump. The dropping height at which the RSI decreases, or ground contact time goes above the fast SSC threshold, indicates a height, which may represent a heightened injury risk for that individual or provide a sub-optimal training stimulus.

Figure 2 illustrates 2 example datasets for both a well-trained and an untrained individual. In the case of the well-trained individual, as the depth jump height increases from 10 to 40 cm, performance as measured through RSI also increases. The likely reasons for this increase in performance as depth jump height increases are 2-fold. A higher depth jump height will allow for a greater level of preactivation to occur. Preactivation involves the preparatory excitation of motor units prior to an activity. A degree of well-timed preactivation is necessary for optimal utilization of the SSC and appears to be a requirement for the enhancement of muscular activity during the eccentric phase and for the timing of muscular action during ground contacts (18). Preactivation has been observed to increase as the dropping height used in depth jumps increases (12). The greater the dropping height, the higher level of neural excitation, which may be achieved before the eccentric-concentric coupling, begins which in turn improves muscular action through the ground contact phase.

Second, a greater depth jump height will result in a higher level of velocity in the eccentric phase. The greater the level of eccentric velocity the greater potentiation effect can be elicited from

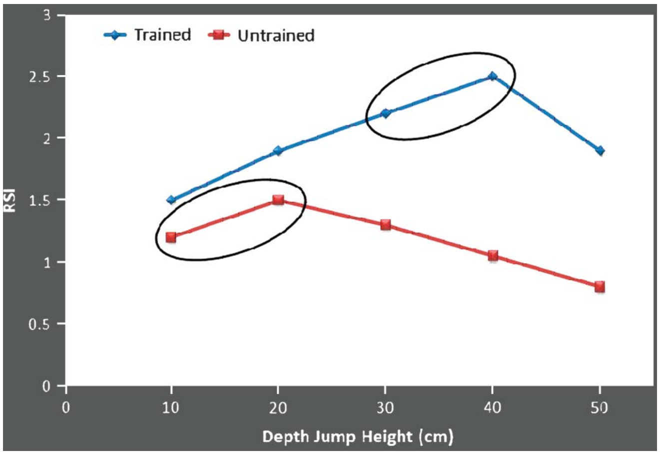

Figure 2. A dataset of reactive strength index during an incremental jump test in a trained and untrained athlete. The untrained individual generally scores lower at all heights and reaches the critical threshold at which RSI decreases at a lower dropping height. The drop-height training zone in which each athlete would be recommended to perform the exercise is circled.

mechanisms such as neural potentiation of the muscle contractile machinery and contributions from the muscle spindle reflex provided the individual possesses the requisite reactive strength to transition quickly from the eccentric to concentric phase. The peak velocity of the eccentric contraction during depth jumps depends on the maximum downward velocity of individual's centre of mass. In depth jumps, this is wholly dependent on the height used in the depth jump (3).

However, we hypothesize that a critical threshold may be reached at which the downward velocity becomes too great and the athlete will lack the requisite strength to overcome this eccentric loading and transition effectively to a powerful concentric phase. It could be speculated that this reduction in performance is due to GTOs exerting their protective, inhibitory effects. Therefore, as the muscle tension required to overcome the increased downward velocity approaches a level which could potentially damage the muscle tendon complex, the GTOs may be activated and might inhibit contraction. From the same depth jump height, a well trained individual may have an increased muscular activity during the eccentric-concentric coupling when compared with an untrained individual who has muscular recruitment inhibited during depth jumping.

In this hypothetical well-trained athlete, the critical threshold occurs at a depth jump height of 50 cm. At this threshold, typically, the athlete can no longer remain on the balls of his or her feet through the jumping action, the heels hit the ground as he or she lands, and a much longer ground contact period is used in the transition to concentric movement to absorb the great eccentric loading. Ground contact times will increase over 0.25 seconds, jump height may decrease, and RSI decreases.

From the standpoint of specificity, this is not optimal. The athlete is now performing a slow SSC movement rather than fast SSC and may be activating and training very different biomechanical mechanisms. The notable decrease in RSI indicates that depth jump performance is not optimal at this dropping height. The individual is not expressing an appropriate jump height relative to his or her ground contact time. The jumping action is no longer sufficiently "explosive."

A third point to note here is the effect too great a dropping height can have on the risk of injury. Plyometrics are known to have a potentially increased risk of injury because of the powerful forces generated. Bobbert et al. (3) demonstrated that when too great a height is used in depth jumps, sharp peak forces are generated, which can be potentially dangerous to the athlete. These forces were observed to be caused as a result of the athlete's heels hitting the ground, producing sharp joint reaction forces at the hips, knees, and ankles. Such joint reaction forces can potentially cause damage to passive structures of the musculoskeletal system.

The dataset of the untrained individual is also worth considering. Such an athlete is likely to score lower in RSI at all dropping heights and will reach the critical threshold where RSI decreases sooner than the well trained athlete. Therefore, training becomes suboptimal, and this individual is exposed to a potential dangerous training stimulus at a lower dropping height. The recommended ranges of dropping height to be used for each athlete are shown in Figure 2.

The use of too great a depth jump height in plyometric training can reduce the specificity of the athletes training, decrease performance, and be deleterious to athlete safety. This RSI procedure can assist coaches in optimizing plyometric training from a performance and safety perspective. A team profile of plyometric ability can be developed allowing athletes of similar abilities to be grouped together for training. Such a procedure may also assist coaches in identifying athletes whose reactive strength capabilities are deficient.

THE RSI AS A MOTIVATIONAL TOOL

Research has demonstrated that specific verbal instruction can positively affect jumping performance. Arampatzis et al. (1) found that instructing subjects to "jump high and a little faster than your previous jump" instead of instructing them simply to "jump as high as possible" encouraged subjects to perform depth jumps with significantly shorter ground contact times.

This research demonstrates the role that knowledge of results can play in motivating athletes through plyometric training sessions. Making the athletes aware of their jump heights and ground contact times or their reactive strength index may motivate them to perform their plyometric exercise at a level closer to maximum effort. However, it has been suggested that when constant feedback in the form of knowledge of results is given on every single trial, participants can become overly reliant on the feedback and fail to process the information required to improve performance (25). The attending coach may then be wise to only provide knowledge of results intermittently and might best be used when the athlete's performance is declining and the individual is in need of motivational support.

From our experience working with elite rugby players, we have found that the quality of the plyometric process is enhanced by the use of contact mats for performance feedback. To prevent against a dependence on regular feedback, RSI is not used in every training session. In addition, we question the players after the plyometric exercise on the quality of the jumps asking "which was the quickest jump, and why?" This questioning method is useful for making the players think about what is required for successful jump performance and creates a more active learning process.

It is recommended that strength and conditioning coaches should provide this augmented feedback in an enthusiastic manner indicating a personal interest in the performance of the athlete and with encouragement to make maximum effort (21). Intermittently throughout the plyometric training session the coach should also remind the athlete to "jump high" and "jump fast" when performing depth jumps.

PRACTICAL APPLICATIONS: A PROGRESSIVE PROGRAM FOR USING THE RSI

The use of RSI during fast plyometric exercises, such as repeated tuck jumps, hurdle jumps, and depth jumps, is an effective practical application of this performance measure and can enhance the quality of plyometric training. From our experience with elite rugby players, a 4-stage progression toward the use of fast SSC exercises and the RSI has been most effective (Figure 3). A progressive plyometric program is especially needed with athletes who have limited plyometric training experience. This is done to ensure that athletes perform fast plyometric exercises with correct technique from a performance and safety perspective. Correct fast plyometric exercise technique involves the following coaching points being adhered to (a) minimize ground contact time, (b) maximize jump height, (c) imagine the ground is a hot surface, (d) imagine your leg is a stiff spring that rebounds off the ground on landing, and (e) pretense your leg muscles before landing.

The first step of our 4-stage progression involves an eccentric jump phase. Here, the focus is on landing mechanics and the athlete concentrates on holding the landing of a low intensity jump, such as an ankle hop, with the center of gravity over the base of support. The player is instructed to focus on making a "quiet" landing and is encouraged to exhibit minimal flexion at the ankle, knee, and hip joints during landing (imagining freezing on ground contact). These exercises are included to improve the player's ability to tolerate the downward velocity of plyometric exercises and the eccentric load associated with the fast SSC.

After this step, the next stage focuses on teaching the athlete to minimize ground contact times. During any fast plyometric exercises, the leg should act like a stiff spring and rebound with minimum delay off the ground on contact. This is accomplished with the institution of low-intensity, fast plyometric exercises, such as ankle jumps and skipping, where the focus is on short ground contact times ("imagine that the ground is a hot surface"). The athlete can be instructed to keep on the balls of his or her feet at all times and pretense the lower leg muscles before landing to assist with this action.

Progression is continued by having the player now jump over a series of low hurdles where the focus is on minimizing ground contact time and clearing the hurdle. Contact time is given here as the feedback score. Once the player can clear the low hurdle with a low ground contact time, then the height of the hurdle may be increased to provide an overload effect. In these examples, the height is controlled by the hurdle so that the focus is on teaching the player to perform the plyometric exercise with minimum ground contact time.

Once the players have then learned to perform these fast plyometric exercises with short ground contact times, depth jumps can be introduced where the focus is on both minimizing short ground contact times and maximizing height jumped. In this case, the RSI can be used as the feedback variable to the athlete or as a coaching tool to optimize plyometric exercises or to monitor athletes' plyometric performance.

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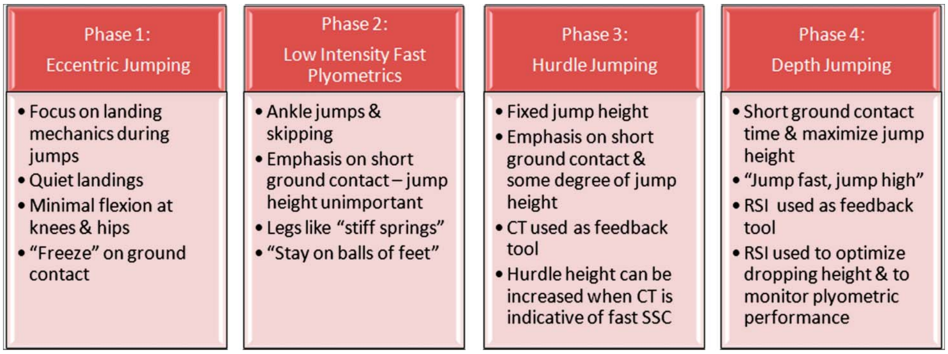

Phase 1: Eccentric Jumping	Phase 2: Low Intensity Fast Plyometrics	Phase 3: Hurdle Jumping	Phase 4: Depth Jumping
• Focus on landing mechanics during jumps • Quiet landings • Minimal flexion at knees & hips • "Freeze" on ground contact	• Ankle jumps & skipping • Emphasis on short ground contact – jump height unimportant • Legs like "stiff springs" • "Stay on balls of feet"	• Fixed jump height • Emphasis on short ground contact & some degree of jump height • CT used as feedback tool • Hurdle height can be increased when CT is indicative of fast SSC	• Short ground contact time & maximize jump height • "Jump fast, jump high" • RSI used as feedback tool • RSI used to optimize dropping height & to monitor plyometric performance

Figure 3. A 4-step progression for developing fast stretch-shortening cycle (SSC) performance and introducing contact time (CT) and reactive strength index (RSI) as feedback tools.

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