

Optimizing Physical Recovery in Male Field Sport Athletes Following Anterior Cruciate Ligament Reconstruction: Residual Deficits, Performance Targets, and Training Strategies

Short title: **Physical Capacities Following Anterior Cruciate Ligament Reconstruction**

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ABSTRACT

Despite passing a battery of tests and being considered ready to return to sport, residual deficits in physical capacity of the lower limb are commonly present in multi-directional athletes following an anterior cruciate ligament (ACL) reconstruction. These can have a detrimental impact on individual and overall team athletic performance and may increase the risk of re-injury. Targeted strategies to assess and restore lower limb performance within rehabilitation are therefore crucial. The aim of this review is to (1) describe common residual deficits in physical capacities after ACL reconstruction, (2) highlight achievable performance metrics to target during rehabilitation to assist practitioners in collecting useful information, and (3) propose examples of evidence-based strategies to restore full recovery.

Key words: Anterior Cruciate Ligament reconstruction, athleticism, return to play, rehabilitation, knee

33 After anterior cruciate ligament (ACL) reconstruction, residual deficits in maximal strength,
34 explosiveness (i.e., rate of force development), and reactive strength are commonly reported in
35 the literature. This is despite having clear rehabilitation guidelines including criterion-based
36 progressions created to protect healing structures, ensure safe restoration of fundamental
37 physical capacities, and guide appropriate return to sport (RTS) activities (2, 8, 53, 124). It has
38 been highlighted that healthcare professionals have insufficient knowledge in exercise
39 physiology and strength and conditioning (S&C) principles, which impedes their
40 implementation (68, 90, 136). Without this, it can be difficult to develop suitable ACL
41 rehabilitation protocols aimed to fully recover fundamental physical capacities specific to sport
42 such as maximal strength, rate of force development (RFD), and reactive strength that target a
43 return to performance. Most studies have shown that the adopted resistance training protocols
44 could promote muscle endurance and hypertrophy, but were often not progressed to include
45 strength and power training (90). In addition, RTS readiness is currently determined when an
46 athlete displays a limb-symmetry index of $\geq 90\%$ in a battery of strength and functional hop
47 tests (19, 60, 124). However, this approach is limited (19, 60), as it does not consider
48 performance values (i.e., individual limb distances) or the movement strategy used. These tests
49 are also often not sensitive to identify between-limb deficits even in the presence of
50 biomechanical differences (72, 131).

51 The re-development of these fundamental physical capacities after ACL reconstruction is
52 essential to facilitate a good execution of multi-directional athletic skills such as jumping,
53 landing, sprinting or cutting (64, 114), preserve cartilage composition (29, 65, 66, 111), and
54 reduce the risk of osteoarthritis (25) and future injuries (83). The available evidence also
55 indicates associations with greater subjective knee functional scores (IKDC) (20), reductions
56 in inter- and intralimb maladaptive compensation strategies during unilateral and bilateral
57 jumping and landing tasks (69), and lowered risk of subsequent ipsilateral (34, 130) or
58 contralateral anterior cruciate ligament rupture (48). Overseen by qualified rehabilitation
59 specialists, S&C coaches can play a fundamental role in supporting athletes in their return to
60 performance journey and should be considered an essential member of the multidisciplinary
61 team. This is particularly apparent during the later stage of rehabilitation when athletes return
62 to training albeit with specific deficits being overlooked or not fully recovered.

The aim of this article is to create an optimization framework for rehabilitation specialists and S&C coaches to support in: 1) evaluating common residual deficits in physical capacities' after ACL reconstruction; 2) highlighting achievable performance metrics to target during rehabilitation to assist practitioners in collecting useful information; and 3) using evidence-based strategies to restore full recovery. Lower limb strength deficits are the most commonly reported and persistent physical quality deficit post ACL reconstruction (5), therefore specific deficits and achievable goals in force production of key muscular groups after ACL reconstruction will be discussed first. Given muscular strength underpins the ability to produce force at speed and in reduced time frames (RFD and reactive strength) (46, 89), we will then highlight specific deficits and achievable goals of rapid force application during stretch-shortening cycle (SSC) activities.

STRENGTH DEFICITS

Maximal strength can be defined as the upper limit of the neuromuscular system to produce force (110), with increases in this capacity correlated with RFD and power (1, 36, 105, 115). In rehabilitation, it is common practice to use a combination of single-joint exercises (i.e. accessories) to assess and restore specific deficits, and multi-joint exercises (i.e. compound movements) to evaluate and improve the overall limb(s) maximal strength capacity. With the increased use and practical utility of force plates, hand-held dynamometry and isometric strength testing devices, this has allowed S&C coaches to work alongside physical therapists to play an effective role in administering these assessments. Supporting this further, in this section we examine the key musculature involved in dynamic knee joint stabilization including expected deficits and assessment strategies with clear performance targets.

Quadriceps strength deficits

Deficits in peak knee extension torque are commonly displayed in the ACL reconstructed limb throughout their rehabilitation and at the time of RTS (44, 71) in male multidirectional team sport athletes (71). Reductions in quadriceps strength are further pronounced when patellar tendon grafts are used (71, 109), likely due to donor site morbidity and increased likelihood of anterior knee pain. The gold standard assessment mode includes the use of isokinetic peak torque at $60^{\circ}\cdot s^{-1}$ (123), although inline dynamometry can provide alternative reliable and valid measurements in these cohorts (92). Professional and amateur soccer players who completed a

progressive strength training intervention during rehabilitation attenuated quadriceps strength deficits following ACL rehabilitation and reached strength values superior to healthy players (72, 129), indicating this should be the first achievable rehabilitation target. However, pre-injury values may add important information regarding strength recovery following ACL reconstruction. In a professional soccer cohort, normalized quadriceps strength on the involved limb was reduced compared to baseline values and substantially lower than the contralateral limb at the end of rehabilitation (72). These data indicate that both individual limb torque scores need to be considered in RTS decision making, and when pre-injury data are available, assessment of symmetry may be secondary compared to attainment of the athletes own benchmark scores on each limb. In addition, peak torque values alone can mask angle specific moment generation capacity, and further angle-specific analysis to more accurately identify residual deficits should be recommended (38, 102). In particular, deficits in knee extension strength appear more pronounced in angles between 50 and 80 degrees of knee flexion (102), owing to reduced quadriceps voluntary activation, spinal-reflexive and corticospinal excitability, and smaller muscle volumes (62). Longer rehabilitation periods (≥ 9 months) may also be needed to recover knee extensor torque deficits (14) and interventions to target specific ranges of motion to ensure full restoration of knee function should be addressed.

Quadriceps strength assessment and achievable performance targets

Practical recommendations suggest to restore knee extension torque $> 3.0 \text{ N}\cdot\text{m}\cdot\text{kg}^{-1}$ as a minimum requirement of a comprehensive return to sport rehabilitation program (see Fig. 1) (124, 125). Different strength targets considering post-operative stage, graft type, and meniscal involvement are also available (108). It must be noted that isokinetic dynamometry is not commonly available to clinicians, and inline dynamometry has only recently been suggested as a valid alternative (92). Research indicates the validity of assessing quadriceps maximal voluntary isometric contractions (41, 91) with a stabilized dynamometer to detect deficits following ACL reconstruction is equivocal (4, 10), and thus may lack sensitivity (42). Instead, it appears that differences in quadriceps strength are more apparent and consistent in studies using isokinetic dynamometry (3, 84, 85, 93, 129), allowing the detection of strength deficits throughout the entire range of motion analyzed. However, in the absence of an isokinetic dynamometer, we recommend the assessment of quadriceps maximal voluntary isometric contractions using a stabilized dynamometer in positions of 90°, 60° and 30° of flexion, from

full knee extension (10). In addition, isotonic leg extension values can be estimated from isokinetic peak torque scores (35, 63), but it should be considered that normative values in male multidirectional field sport athletes following ACL reconstruction are currently unknown. It is important to reiterate that there is no evidence suggesting a deleterious effect in anterior tibial laxity and healing graft properties using open-chain exercises following ACL reconstruction (96). However, caution can be used in the early and mid-stages of rehabilitation by using pain-free limited range of motion and progressive load stimuli (133). Single leg sit to stand scores greater than 22 repetitions have been suggested and are linked to improved long term knee joint health, but accurate test standardization and attention to trunk and shin angle positions are needed (24, 118). In addition to this, our clinical suggestion is to assess and monitor quadriceps strength capacity using a variety of knee dominant exercises that recruit all quadriceps muscle (namely vastus lateralis, vastus medialis, vastus intermedius, and the rectus femoris). For example, variations of step ups and single leg squat exercises (with progressive overload across sessions) with a particular attention to maintain a vertical trunk and shin angle position to maximize stimuli to the quadriceps muscles (23).

Posterior thigh muscle strength deficits

Maximal strength deficits have been shown to be magnified depending on graft selection (40, 71). Lower peak knee flexion torque, albeit to a lesser extent, have been displayed in male athletes at the time to RTS in comparison to healthy matched controls (71). This appears to be more evident when a semitendinosus-gracilis graft is used (40, 71), and is accentuated toward deeper knee flexion angles (i.e. $> 75^\circ$ knee flexion). Research has shown that the ACL reconstructed knee flexor peak torque angle is shifted towards extension when using a hamstring graft (57), with these changes in force-length relationship due to atrophy and shortening of the semitendinosus (after its tendon has been harvested), as well as lack of compensation from the semimembranosus and biceps femoris (76). However, it should be noted that these deficits are trainable. In a cohort of professional soccer players (with predominantly patellar tendon graft) hamstring strength of both limbs increased compared to pre-injury values, but angle-specific analysis was not performed (72).

Posterior thigh muscles strength assessment and achievable performance targets

Overall, research (72, 93) suggests to restore knee flexion torque $> 1.7 \text{ N}\cdot\text{m}\cdot\text{kg}^{-1}$ during rehabilitation (see Fig. 1). Different strength targets considering post-operative stage, graft type, and meniscal involvement are also available (108). Conflicting results are found in knee flexion maximal voluntary isometric contractions using a stabilized dynamometer (41, 119). Our pragmatic approach consists of measuring hamstring strength at different angles (i.e. inner [i.e. deep knee flexion], mid [at approximately 30° knee flexion] and outer range, [i.e. at maximal hamstring extensibility]) using hand-held dynamometer and available normative values (132), while at the same time ensuring that athletes demonstrate sufficient strength levels using different hamstring exercises (hip and knee dominant movements) across the entire range of motion (15). Examples of these include, for instance, Romanian deadlift $> 1.0 \times \text{BW}$ using 3RM, single leg hamstring slide > 6 repetitions and inner range hamstring curls (in which active contractions cover the available passive ROM).

Gluteal muscles strength deficits

In the ACL reconstructed limb, lower internal knee valgus moment, knee internal rotation angle, and ankle external rotation moment are common findings across various single leg hop tests (49), corresponding with positions of peak ACL strain (28, 127) in change of direction activities. These features are influenced by whole body biomechanics. Gluteal muscles strength can be considered relevant when examining frontal plane activities; however, to our knowledge, no research is available to examine hip abduction, external rotation and extension strength at the time of RTS in male multidirectional athletes. Conflicting evidence is present in mixed populations (31, 97), albeit hip muscle strengthening is commonly suggested during rehabilitation (17, 18). This can be due to different contraction types and testing positions used, thus influencing length-tension relationships and potentially masking specific deficits (31). For example, it appears that hip external rotation strength deficits are more evident when using hand-held dynamometry in prone position (11, 32), whereas no significant deficits are observed in hip abduction and extension strength irrespective of the contraction type and testing position used (31).

Gluteal strength assessment and achievable performance target

Due to insufficient evidence regarding gluteal muscles strength deficits in male multidirectional athletes, gluteal strength assessment should be individualized. Isolating monoarticular hip extensors is challenging using hand-held and isokinetic dynamometry, with strength values susceptible to the selected testing position and methods of fixation (55, 56,

104). Likewise, isometric hip thrust strength assessment using force plates should account for the bilateral nature of the task and the selected hip flexion angle (33). Hence, whether hip extensors strength deficits are suspected, clinician should consider different testing positions and assessment modes. We recommend to assess and monitor hip abduction strength (considering both the contralateral limb and normative values) using hand-held dynamometry as suggested in soccer research (116, 117), while at the same time ensuring proficiency in exercises targeting intersegmental control (i.e. hip hitch progressions) and high force production in exercises such as abduction/external rotation in banded mini squat at wall (47). In professional soccer players, side-lying long lever eccentric abduction strength is considered normal between 2.2 and 3.0 Nm/kg (88), whereas, if using the supine long level isometric abduction strength test, values of approximately 2.3 Nm/kg should be expected (117).

Ankle plantarflexors strength deficits

In addition to previously mentioned muscles, the ankle plantarflexors have a crucial role in modulating mechanical load around the knee and thus, reducing the risk of ACL injury (78). A growing body of literature has highlighted that foot-ankle muscles and especially the soleus possess the greatest potential to generate ACL-protective posterior shear forces during unanticipated sidestep cutting and single leg drop landing (78, 79, 86). Along with mechanical loading protection, deficits in ankle plantarflexion (in particular gastrocnemius and soleus) could also impact jumping propulsion, as recent research in athletes showed the soleus muscle contribution was significantly lower in both limbs after ACL reconstruction compared with a control group during horizontal and vertical jumps (51, 52). Additionally, a study reported a 34% decrease in maximal ankle power (less angular velocity) between limbs in patients after ACL reconstruction during a single-leg squat jump (27). Despite this biomechanical importance, a recent meta-analysis has found no difference of ankle plantarflexion torque in mixed ACL reconstruction populations in comparison to healthy controls, but isokinetic evaluations were assessed in knee extended position thus reducing soleus isolation testing (31).

Ankle plantarflexors strength assessment and achievable performance target

The ankle plantarflexors (especially the soleus) are a key ACL agonist protector with the hamstrings muscle group by limiting anterior tibial translation; thus, strategies to enhance their maximal strength should be encouraged (78, 79, 86). This becomes even more crucial with athletes who have undergone ACL reconstruction using an hamstrings graft (i.e. gracilis/semitendinosus), with knee flexion strength deficits being exacerbated by graft

selection (135). Based on a mixture of clinical experience and research based data (61, 80, 94, 103), we propose that athletes should aim to achieve a seated ankle plantarflexion isometric net force $>1.8 \times \text{BW}$ in neutral position using force platforms as a standard target (see Fig. 1) (61, 80, 82). In clinical settings in which force platforms are unavailable, we recommend to consider alternative objective assessment methods by performing sitting calf-raises using a Smith or calf-raise machine with the aim to achieve $> 140\%$ of their BW with 5RM.

Compound exercises

Although single-joint strength assessment and accessory exercises provide an indication of specific deficits in muscle function following ACL reconstruction, research has shown that multi-joint strength capacities (i.e. squat, trap-bar deadlift, etc.) display a heightened transfer to athletic performance (113). Specifically, moderate to high correlations between multi-joint strength characteristics and jumping ($r = 0.78$), sprinting ($r = 0.71$) and change of direction performance ($r = 0.69$) are reported in healthy athletes (22, 45, 134). It is currently unknown if these global strength measures differ in athletes following ACL surgery in comparison to healthy controls. Our unpublished data in a mixed population of amateur athletes following ACL reconstruction (on average at 5 years post surgery) show values of approximately $1.15 \times \text{BW}$ using 5RM box squat and $0.6 \times \text{BW}$ using 5RM rear-foot elevated split squat (with no difference between limbs). These do not differ from physically active cohorts not participating regularly in resistance training (58), but comparison with closely matched healthy multidirectional field sport athletes needs to be further investigated.

DEVELOPING EXPLOSIVENESS

LONG STRETCH SHORTENING CYCLE

The ability of the neuromuscular system to produce a high rate of rise in muscle force following contraction onset is reduced following ACL reconstruction (122), as well as the ability to rapidly transition from eccentric to concentric muscle actions (73). This is commonly divided into long ($> 250\text{ms}$) and short ($< 250\text{ms}$) SSC activities (30). In long SSC actions, countermovement jumps (CMJ), jump height, and reactive strength index modified (RSImod) (calculated by dividing jump height by contraction time) (112) are the performance metrics

which have most commonly been examined. Measurements of CMJ height and RSImod are obtainable using a variety of measurement tools (e.g. force plate, phone applications, contact mats). These performance variables can help practitioners to quantify neuromuscular qualities that underpin movements inherent to field sport activities such as sprinting, jumping, and change of direction (37). Research has shown that CMJ height, RSImod, and relative peak power are reduced in amateur and professional soccer players following ACL reconstruction in comparison to healthy controls (54, 72, 99), as well as to pre-injury performance values (72).

Achievable performance targets

The available benchmarks indicate that during a bilateral CMJ, professional soccer players should achieve > 36 cm and an RSImod > 0.47 (72, 74, 99) at the time of RTS. However, residual deficits and reductions at the end of rehabilitation in comparison to healthy controls and pre-injury performance scores are more evident during the single leg (SL) CMJ (72, 93). This is due to a higher relative force requirement of the ACL reconstructed limb compared to a bilateral jump (estimated ~ 1.62 times of those in a CMJ) to displace body mass vertically (21). Therefore, it could be suggested that SLCMJ height offers a better reflection of limb capacity compared to the measurement of the same variable in a bilateral jump, and may be a useful indicator to determine the recovery of limb capacity around the time of RTS. SLCMJ height > 18cm and RSImod > 0.25 are achievable targets for soccer players at the end of rehabilitation (see Fig. 1) (72, 74, 126). Further research is needed to examine jump momentum (take off velocity x body mass) to account for variability in body mass among athletes (81).

DEVELOPING REACTIVE STRENGTH

SHORT STRETCH SHORTENING CYCLE

Persistent deficits in short SSC performance have been demonstrated in athletes following ACL reconstruction (49, 51, 67, 73, 98, 101). These are commonly assessed with multi rebound and drop jump testing (DJ). To elicit an appropriate stretch reflex contribution, ground contact times < 250ms are recommended. However, it should be noted this is often not controlled for when examining this physical quality in ACL reconstructed cohorts, representing a limitation in the available research and thus reporting of normative data is currently not possible. Quantification of SSC performance during high eccentric stretch loads is needed to determine an athlete's ability to efficiently store and reutilize elastic energy (16). This is commonly

expressed as the reactive strength index (RSI) (calculated by dividing jump height by ground contact time) (30).

Achievable performance target

Research (54) investigating double leg DJ (from a 30cm box) in male athletes found significant differences in contact time and RSI, but not jump height between professional athletes following ACL reconstruction and healthy controls (recommended values: jump height > 36 cm, RSI > 1.4 and contact time, albeit ground contact times should be < 250 ms). However, it should be noted that in this study, ground contact times were ~ 340 ms which may preclude these recommendations for the purpose of normative data. Other research (48) has reported RSI values of 0.9 (95% confidence intervals: 0.8-1.0) with ground contact times of 270ms (95% confidence intervals: 0.25-0.29) in ACL reconstructed athletes 9 months post surgery. Of note, lower values were reported in athletes who sustained a contralateral injury on their RTS, indicating the potential for RSI in a bilateral drop jump to be used as a measure of injury risk and readiness to re-perform.

The SLDJ seems to better highlight deficits in knee function compared to SLCMJ in male athletes at the time of RTS (49-51, 73). Research shows that RSI is reduced in the ACL reconstructed limb in comparison to the uninvolved limb and healthy controls (49, 51, 54, 67, 73, 98). Benchmark scores in soccer players indicative of greater performance status include RSI scores > 0.40 and jump height > 14cm (73, 98) (with SLDJ from a 15cm box) (see Fig. 1). However, it should be noted that in the available research, ground contact times for single leg rebound jumps have been shown to far exceed 250ms. Currently, an established ground contact time threshold for RSI in single leg rebound tasks does not exist and this warrants further research. In addition, if coaches have access to a force platform, RSI should not be the sole metric examined. Residual deficits in single leg drop jump mechanics (lower spring like correlation, greater ratio of landing peak to take-off peak force, and the presence of an impact peak in the first 20% of the ground contact phase) have been observed following ACL reconstruction (100). Of note, RSI was the only measure to change across a ~ 10 week rehabilitation phase, but the mechanical variables did not, thus suggesting deficits in SSC function can be masked by RSI alone. Thus, caution should be applied when interpreting ratio data, and their constituent parts should also be considered (12).

An overview of recommended multijoint and single-joint strength, long and short SSC targets to be achieved prior to RTS is displayed in Figure 1. These have previously been described in each section above. In addition, Figure 1 also illustrates any inter-relationships.

*****INSERT FIGURE 1 NEAR HERE*****

TRAINING PHYSICAL QUALITIES – CONCLUSION AND PRACTICAL APPLICATIONS

While the growing innovation in technology can help data acquisition, there is also a large amount of data available that can be overwhelming and thus dilute the translation into practice due to misunderstanding of performance outcomes and their underpinning physiological constructs (128). In this scenario, to understand the “why” of a specific test score, a practitioner may work backward to determine the underpinning attributes of a determined physical capacity, and then finally distribute the development of those capacities over the allocated timeframe (121). In addition, clinicians and coaches should consider both absolute scores on each limb to determine performance recovery, and not just symmetry values, ensuring minimum standards are met. Once the required components of performance are identified, targeted reconditioning strategies to improve maximal strength and/or ballistic performance are needed at the appropriate stages during rehabilitation (57, 70, 129). The components underpinning physical preparedness are not independent variables. Therefore, each phase of rehabilitation should have a clear emphasis that provides a valuable foundation for more complex sporting skills. A training emphasis infers that a larger proportion of the mesocycle is utilised to improve a specific biomotor component, while the others are maintained as best as possible (120). For example, a relatively weaker individual would benefit most from an emphasis on strength training, whereas a stronger individual would benefit most from an emphasis on ballistic training, even though both qualities may be included during specific rehabilitation phases. In this last scenario, strength is still trained and maintained as best as possible, although with much less volume, but with the same frequency and intensity. This approach allows coaches to use test data effectively to optimize performance outcomes and not rely on generic program design strategies, promoting test-training integration.

Early rehabilitation should focus on alleviating swelling, restoring range of motion, muscle activation (due to atrogenic muscle inhibition of key musculature [quadriceps / hamstrings]) and movement quality in fundamental patterns (gait, squatting, hinging, single leg stance). During mid and late stages of rehabilitation, provided the athlete has achieved adequate skeletal muscle trophism through a period of familiarization and anatomical adaptation, higher load, lower repetition schemes are introduced to maximize strength gains (26, 59, 87, 106). To increase the overall limb capacity, bilateral exercises, such as the back squat can be used alone, substituted, or adopted in combination with unilateral exercises (i.e. split squat variations) due to similar effectiveness in lower-body strength development (7). At the same time single joint (e.g., quadriceps, hamstrings, calf, abductors) strengthening should continue to be part of the rehabilitation program until minimum requirements are met and inter-limb asymmetries in force production are normalized. External load of strength exercises should be regularly progressed to optimize strength levels according to normative values (95, 129). Progressive overload stimuli appear essential to promote further strength adaptations in more experienced individuals (6, 107). For these, current evidence indicates that prescription of maximal strength training should involve a load (or intensity) of 80-100% of the participant's one RM, utilizing approximately 1-6 repetitions, across 3-5 sets, with rest periods of 3-5 minutes, and a frequency of 2-3 times per week (70).

Heavy strength training, a progressive series of plyometric exercises (in the beginning focusing on higher volume and low intensity (extensive) and in the later phases including higher intensity actions with a greater focus on reactive strength), Olympic weightlifting and their derivatives, and targeted exercises that focus on overloading the eccentric portion of the exercise with the intention of fast force production, are considered effective strategies to improve RFD (13, 43, 75) and braking characteristics that often remain deficient unless targeted (98-100). Therefore a combination of long SSC exercises (e.g. bilateral/unilateral vertical jumps, trap bar jumps with different loads, broad jumps) and short SSC exercises (i.e. plyometric training) are included within the session. These can be completed at the start of the session or during rest periods between sets to maximize each single session. These are commonly defined as potentiation complexes and can facilitate an athlete's rapid force production capacity (113). Progressive plyometric training is performed both bilaterally and unilaterally in vertical, horizontal, and lateral directions to match the braking, propulsive and medio-lateral forces typical of change of direction tasks and sprinting actions (9, 16, 39, 77). Examples of progressive SSC drills that can be used according to rehabilitation stage, load

tolerance and physical competencies can also be found in our recent article (121). Figure 2 provides a schematic example of a rehabilitation session which can be adapted according to specific needs and targets. In Figure 2, the schematic example of a rehabilitation session begins with a multi-joint strength exercise to target larger muscle groups and greater force production. Long or short SSC drills (illustrated from lower to higher intensities in our scheme) can be used during the rest periods to improve reactive strength qualities. Following this, more targeted exercises for specific muscle groups are used, together with the necessary SSC drills. The total number of accessory exercises as well as the selection of the SSC drills depend on each individual specific needs. Practical examples for mid-stage and late-stage rehabilitation using this structure are depicted in Figure 3 and 4.

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INSERT FIGURE 3 NEAR HERE

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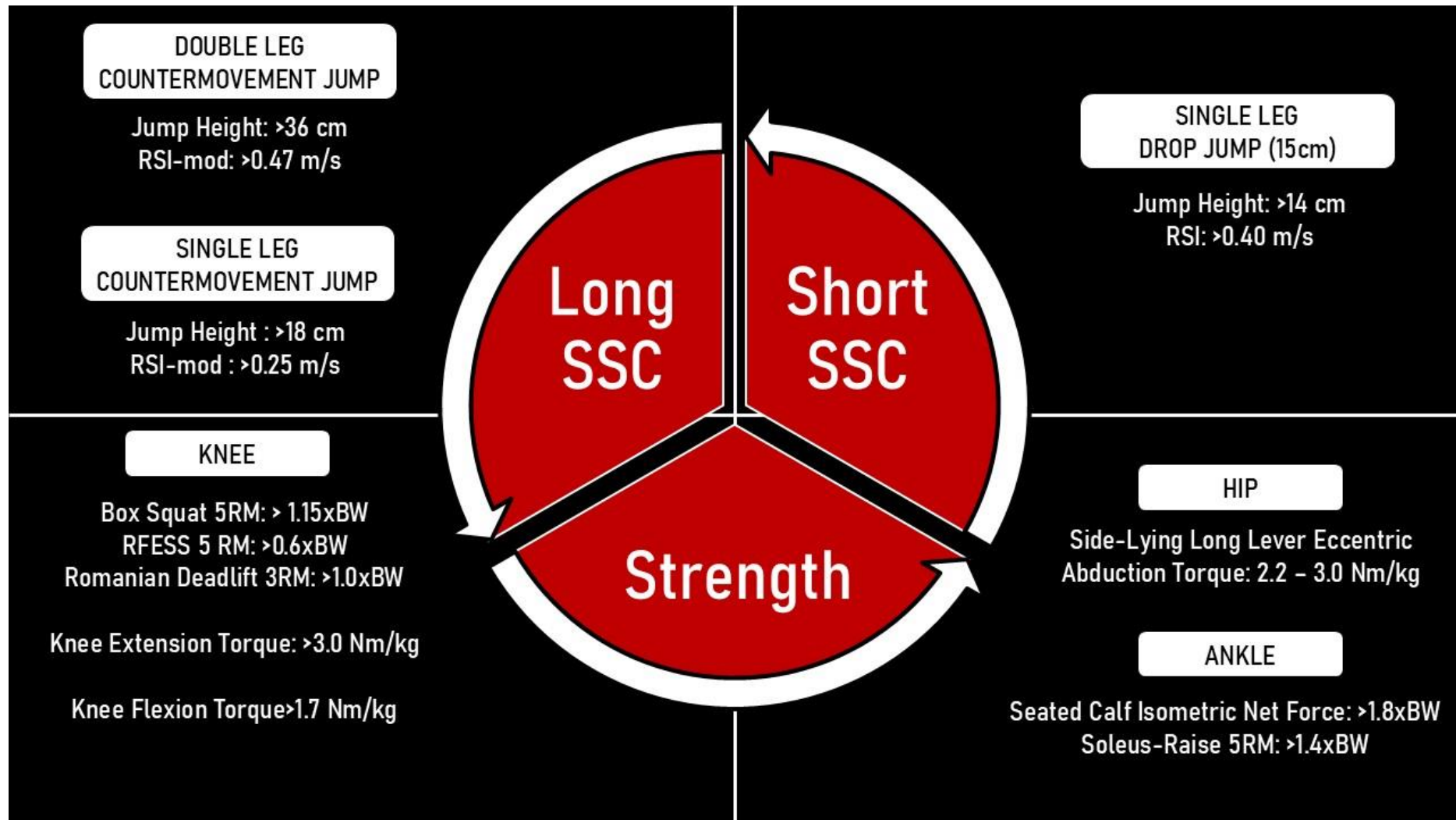
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804 **Figure 1** Graphical representation of physical capacities. (cm) centimeter, (RSI-mod) Reactive Strength Index Modified, (m) meter, (s) second,
805 (RM) repetition maximum, (BW) bodyweight, (RFESS) Rear Foot Elevated Split Squat, (N) Newton, (Kg) kilogram, (RSI) Reactive Strength
806 Index, (SSC) Stretch Shortening Cycle.

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809 **Figure 2** Schematic example of a rehabilitation session. Each box contains examples of exercises for each specific target. (SSC) Stretch Shortening
 810 Cycle, (CMJ) Countermovement Jump

Box Squat 8-10RM x 4 Sets

Snap Down x 5

Rear Foot Elevated Split
Squat 8-10RM x 4 Sets

Ankling x 5 Meters

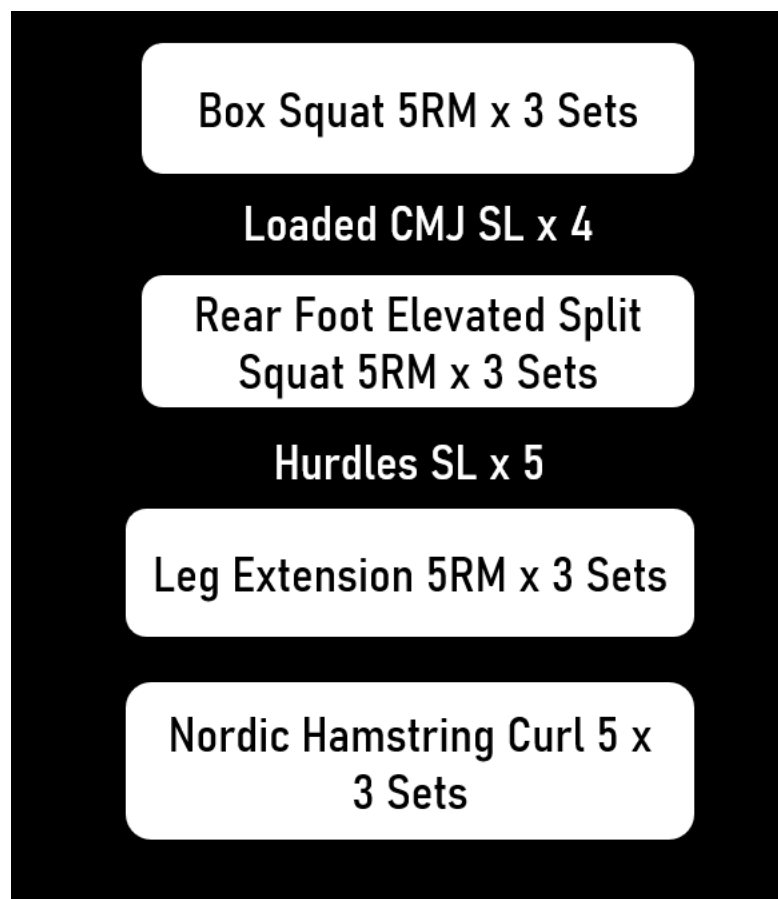
Leg Extension 8-10RM x 4
Sets

Romanian Deadlift 8RM x
3 Sets

Single Leg Bridge 8RM x 3
Sets

811

812 **Figure 3** Example of a mid-stage rehabilitation session for a multidirectional field sport athlete at 4 months following Anterior Cruciate Ligament
813 reconstruction (Bone-Patellar Tendon-Bone graft) presenting with reduced quadriceps muscle volume and strength. (RM) repetition maximum



814

815 **Figure 4** Example of a late-stage rehabilitation session for a multidirectional field sport athlete at 7 months following Anterior Cruciate Ligament
816 reconstruction (Bone-Patellar Tendon-Bone graft) whose main need is to maximize quadriceps strength and reactive strength. (RM) repetition
817 maximum, (CMJ) Countermovement Jump, (SL) Single Leg.

818