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The Back Squat: Targeted Training Techniques to Correct Functional Deficits and Technical Factors That Limit Performance

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ABSTRACT

THE BACK SQUAT IS A WELL-RESEARCHED AND WIDELY USED EXERCISE TO ENHANCE FUNDAMENTAL MOVEMENT COMPETENCY THAT CREATES A FOUNDATION FOR OPTIMAL MECHANICAL STRATEGIES DURING A BROAD RANGE OF ACTIVITIES. THE PRIMARY COMMENTARY INTRODUCED THE BACK SQUAT ASSESSMENT (BSA): A CRITERION-BASED ASSESSMENT OF THE BACK SQUAT THAT DELINEATES 30 POTENTIALLY OBSERVABLE FUNCTIONAL DEFICITS. THIS FOLLOW-UP COMMENTARY PROVIDES A TARGETED SYSTEM OF TRAINING CUES AND EXERCISES TO SUPPLEMENT THE BSA TO GUIDE CORRECTIVE INTERVENTION. WE PROPOSE A CRITERION-DRIVEN APPROACH TO CORRECTIVE EXERCISE THAT CAN SUPPORT PRACTITIONERS IN THEIR GOAL TO HELP INDIVIDUALS ACHIEVE MOVEMENT COMPETENCY IN THE BACK SQUAT.

INTRODUCTION

The back squat is a well-researched and widely used exercise that can enhance an individual's ability to develop a fundamental movement competency for optimal mechanical strategies during a broad range of activities (2,10,13,21,25). Technical proficiency during squatting is beneficial for youth to help them correct and master optimal movement strategies during growth and development (12,13). Likewise, the squat exercise can help youth and young adults to improve physical performance and health (18,21). Adult and elderly populations can use the squat exercise to promote daily living independence during activities, such as sitting and lifting (26). Based on the lifelong benefit of the back squat, the ideal

KEY WORDS:
back squat; squat; corrective exercise; training intervention; fundamental movement

opportunity to master the movement is likely during youth when the neuromuscular system is highly plastic (23).

Training interventions that incorporate squatting exercises have been shown to improve physical performance and to decrease modifiable risk factors associated with sports-related injuries (8,9,16,17,21). Correct and consistent squat performance is a prerequisite to safe progression to more intense training activities involving more dynamic or high-load squat-related exercises (18). The back squat can function as both a fundamental training exercise and a screening tool to identify and correct functional deficits (22). Specifically, we have previously outlined ideal back squat technique with 10 position and movement criteria and pinpointed 30 functional deficits that can be identified with the back squat assessment (BSA) (22). The purpose of this follow-up commentary is to provide corrective strategies for each biomechanical deficit criteria (22). The following proposed exercises to supplement the BSA, inclusive of corrective cues, are designed to be effective training tools to enhance the delivery of back squat exercise instruction by practitioners. It is hopeful that these proposed tools will result in improved physical health and ability for individuals of all training levels through deficit correction and optimal technique acquisition of the back squat.

CORRECTING FUNCTIONAL DEFICITS

The underlying deficits for incorrect back squat performance may be due to a myriad of limitations, including miscomprehension of exercise instruction, poor neuromuscular coordination and recruitment, insufficient muscular strength or joint stability, and/or joint immobility (22). The use of systematic analyses may help guide practitioners as they identify the underlying biomechanical or neuromuscular deficits responsible for poor back squat performance (22). Once deficits have been identified, or are reasonably suspected, targeted corrective interventions can be implemented to begin to ameliorate functional deficiencies.

Practitioners should initiate corrective interventions by first assessing for miscomprehension of task instructions as the potential underlying cause for insufficient back squat performance. Instruction for the back squat must be clear, concise, and age appropriate (22,23). If an athlete continues to demonstrate incorrect back squat technique, the practitioner should attempt to re-emphasize the instructions and/or provide a visual demonstration of the desired movement (e.g., instructor demonstration, peer observation, video analysis). If performance remains hindered, the practitioner is encouraged to then use corrective cueing in an attempt to improve technique.

Cueing can assist in correction for miscomprehension of instructions and poor neuromuscular coordination and recruitment. Cues can be in the form of verbal instruction, physical manipulation, and/or visual aids; all of which have potential to aid an athlete in achieving the desired technique and mechanics during the back squat. Verbal cueing, such as simple word instruction, can assist a person to modify their technique by helping them to cognitively focus on a specific positional deficit or movement phases. An example of a simple verbal cue for each of the 10 back squat criteria is presented in Table 1 (22). Physical cueing, such as light tactile guidance from a coach or training aid (e.g., resistance bands), can support the desired correct positioning that can benefit a myriad of related deficits. For example, a practitioner can lightly press on the lateral portion of the individual's knees during the descent phase of a squat if they tend to demonstrate active valgus, or inward knee movement, as a means of providing a proprioceptive cue to correct positioning. In addition, visual cues, such as video footage of correct form or the use of a mirror, can support an individual to self-correct their form as initial corrective strategies. Practitioners can significantly help their athletes identify and prioritize back squat deficits with targeted cueing strategies that are specific to an athlete's most egregious deficits. Specific and prioritized cueing can help optimize an individual's performance response and adaptions to the back squat.

Instructions or feedback provided by practitioners is often directed to body movements (e.g., "keep your knees over your toes") (1). Regarding motor learning, this type of attentional focus is termed internal focus. However, an external focus of attention is induced when an athlete's attention is directed toward an outcome (1). External focus instructional strategies may enhance cueing and skill acquisition more efficiently than internal focus strategies and increase the transfer of improved motor skills to sports and daily living activities (1). Research of motor learning has demonstrated beneficial effects of instructions that induce an external focus (1). For example, newly learned motor skills with an external focus may be more likely to become automatic and retained. An example of using an external focus during the squat is to have an athlete visualize sitting back for a chair (1). Although the current discussion breaks down squat technique into several position and movement criteria, which may promote internal focus on discrete body movements, it is recommended for practitioners to use external focus feedback strategies when possible to improve motor learning and retention of correct squat technique (1).

If an individual's performance improves immediately through direct means of improved instruction or simple cueing (verbal, physical, and visual), it is probable that their primary limitation from performing the back squat with correct form was due to their unfamiliarity with the movement pattern that they were being asked to

Table 1 Verbal cues for the back squat	
Criteria	**Cue**
Head position	Hold head flat
Thoracic position	Pinch shoulders together
Trunk position	Point bellybutton forward
Hip position	Square your hips
Frontal knee position	Keep knees apart
Tibial progression angle	Straighten your shin
Foot position	Grip the floor with your heels to descend
Descent	Reach back for a chair
Depth	Thighs are parallel to the ground
Ascent	Lead with your chest

perform. If the individual is still unable to achieve desired exercise technique through feedback attempts, neuromuscular deficiency, strength and stability, or mobility limitations may be at the root of their failure(s). Consistent inability to demonstrate desired technique can be addressed next with targeted corrective exercise to ameliorate the specific deficits (22).

TARGETED EXERCISE PROGRESSIONS

The corrective exercise progressions presented in this commentary are organized into the 3 major deficit categories: neuromuscular, strength and stability, and mobility limitations. The BSA differentiates the analysis of the back squat into 10 specific criteria to guide practitioner's assessment of the athlete. In the current commentary, we propose 3 associated progressive exercises to target each specific deficit category (neuromuscular, strength and stability, and mobility) for each criterion (22). Each proposed exercise is supplemented with a description of the desired exercise. In addition to each description, a rationale, cue, and a picture example of an athlete demonstrating the exercise are provided.

The progression scheme is designed to begin with the first corrective exercise for a category and continue to correct a particular biomechanical deficit. However, some athletes may respond to different exercises over others due to variations in anthropometrics, skill sets, and training age. Therefore, the progression tool is only a supportive tool second to a practitioner's best judgment that should be based on the principles of pediatric exercise science and practical experience. It is outside of the scope of this commentary to include proposed volume and intensity (e.g., sets, resistance) for these exercises as these factors should be individualized and relative an athlete's entire training regimen. Nonetheless, it is highly recommended that an athlete demonstrates consistent and sound technique at lower intensity activities and volume before increasing these exercise prescription variables. In addition, practitioners should be cognizant and thoughtful of each individual's biological, training, and cognitive ages when integrating the back squat into the training program (23).

The selected exercises use a mixture of cueing, compensatory assistance, and resistance. When instructing the back squat, it is important to differentiate between cueing and compensatory assistance. Compensatory assistance from the instructor provides external physical assistance to improve exercise performance, whereas cueing is strictly cognitive feedback that requires the individual to use their inherent strength and mobility qualities without additional external assistance. Compensatory assistance makes an exercise easier to perform to guide an athlete's awareness of correct form and how correct form should feel. For example, a practitioner can provide an athlete with assistance such as using a horizontally held dowel rod for the athlete to hold during a back squat. With assistance, the athlete can more easily reach back into a squat to learn what it feels-like to properly recruit posterior chain musculature by "reaching back." Resistance provides a stimulus that counteracts an individual's inherent strength and mobility for the primary purpose of strength and stability training. Moreover, resistance training not only promotes the strengthening of muscles but also may provide a physical stimulus to make an individual more cognitively aware of their technique to promote correction. For example, during a front squat, an athlete is made consciously aware of a load pulling their trunk into flexion, and they must focus on recruiting their back musculature to counter this tendency. As a result, they are improving their neuromuscular ability to maintain their trunk at the desired angle due to this physical stimulus. Typically, if an athlete's technique improves when resistance is applied as a stimulus, neuromuscular deficiency or lack of understanding of a desired task may be the most probable limitation for inadequate performance.

Several strategies are suggested in this article to help guide the correction of back squat performance. It is warranted that deficits are corrected 1 at a time, and the most egregious deficit should be the targeted focus. By focusing on 1 deficit at a time, modifying mechanics will be more manageable and goal driven. In addition, more egregious deficits may be driving other

observed deficits that may naturally improve after the first deficit is corrected. Some trial and error should be expected; however, a practitioner must first and foremost ensure safety of their participants. If an athlete indicates pain or discomfort during any of the following exercises, it is advised to immediately cease training and consult a qualified health care provider.

BACK SQUAT CRITERIA

Similar to The Back Squat: A Proposed Assessment of Functional Deficits and Technical Factors That Limit Performance (22), corrective intervention of the back squat will be discussed in 3 comprehensive domains that highlight 10 technique criteria (22). These criteria are comprised of neuromuscular, strength and stability, and mobility improvement strategies to guide systematic corrective intervention.

DOMAIN 1: UPPER BODY

- Head Position.
- Thoracic Position.
- Trunk Position.

DOMAIN 2: LOWER BODY

- Hip Position.
- Frontal Knee Position.
- Tibial Progression Angle.
- Foot Position.

DOMAIN 3: MOVEMENT MECHANICS

- Descent.
- Depth.
- Ascent.

DOMAIN 1: UPPER BODY

Domain 1 focuses on the musculoskeletal components of the head, neck, and torso that are responsible for maintaining postural control during the back squat.

Head position. **Corrective strategy**

Most athletes will possess adequate neck stability and mobility to execute the back squat. Neck stability is essential to provide support to the cervical vertebrae (4). Verbal and tactile cues will generally be sufficient to assist an athlete to recognize and maintain a neutral head position throughout the squat. Adequate strength, stability, and physiological range of motion are imperative for more intense variations of the back squat that integrate external resistance. When instructing head position during the back squat, ensure that the athlete can self-identify and maintain a neutral head position throughout the squat before increasing intensity. It is not recommended to perform corrective training exercises if there is any discomfort to the head or neck. Mobility limitations or pain may indicate a more substantial underlying medical problem. It is warranted to seek advice from a qualified medical professional if the athlete has prolonged neck or head limitations during the unloaded back squat. Table 2 shows exercises that are recommended to improve head position awareness, neck strength and stability, and neck physiological range of motion for the squat.

Thoracic position. **Corrective strategy**

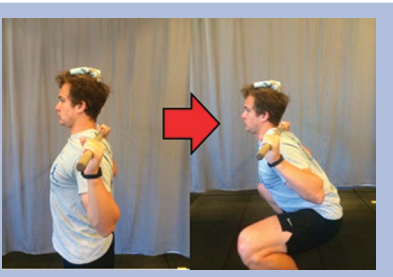
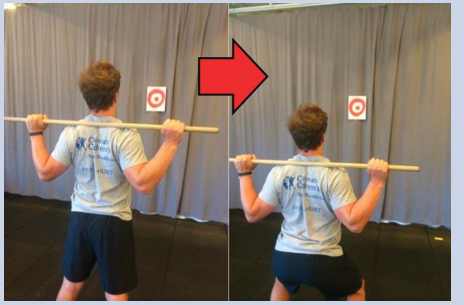
Corrective schemes for the thoracic position should focus on ensuring an athlete has the abilities to tightly retract the shoulder blades and hold the chest up and open throughout the squat to promote ideal thoracic spine support. Practitioners may benefit from using neuromuscular focused corrective exercises initially to address lack of scapular retraction, forward rolled shoulders, and/or a chest that is not held upward. The athlete should be given cues, which can help them disassociate their upper torso from their lower torso as chest position is independent from trunk angle. Verbal cues such as "keep your chest up," "pinch shoulder blades together," and "bend the bar around you" will encourage a proper setup with thoracic position before movement initiation. If necessary, a practitioner can provide tactile cueing to the athlete's shoulders to correct position and to encourage the athlete to maintain correct posture throughout the exercise. A training technique is to place a finger between the athlete's shoulders and instruct them to pinch the finger with their scapulae throughout the squat. In addition, the wooden dowel used in this assessment serves to assist the athlete in assuming a correct chest and shoulder position. If the athlete continues to demonstrate poor thoracic position during the back squat, then the deficit may be due to strength limitations of the upper back and/or lack of mobility. In particular, excessive tightness of the chest may hinder an individual's ability to widen their chest and retract their scapulae. For example, upper crossed syndrome, where an individual has tight pectorals and upper trapeziuses with weak deep neck flexors, rhomboids, and lower trapezius, affects posture as seen with increased cervical lordosis and thoracic kyphosis, elevated and protracted shoulders, and rotation or abduction and winging of the scapulae (14). Mobility exercises of the chest along with strengthening exercises of the upper back may help athletes improve their ability to tightly retract their scapulae. Table 3 shows corrective exercises proposed to improve deficits in thoracic positioning during the back squat.

Trunk position. **Corrective strategy**

Trunk position corrections are primarily focused to address excessive trunk flexion and/or rounding (kyphosis) of the lumbar spine. If the athlete demonstrates excessive trunk flexion, verbal commands, such as "point your belly button straight ahead" or "straighten your torso," may be helpful for the athlete to improve their posture. Furthermore, instructing the athlete to hold their arms overhead or use a light load to hold may provide a physical stimulus to position their trunk more erect.

If posterior pelvic tilt or kyphosis (rounding of the back) is present during the maneuver, corrective strategies should first aim to ensure the athlete learns to obtain and maintain a natural, lordosis of the lumbar spine. This can first be demonstrated during normal standing activities. Once it is clear that the athlete understands the desired

Table 2
Head position

Exercise	Description	Purpose	Cue	Example
Neuromuscular				
Deficit: insufficient head and neck proprioception for maintaining a neutral head position throughout the back squat. Poor disassociation of gaze from head position				
Targeted correction: obtain ability to self-identify neutral head position. Disassociate neutral head position from gaze during squat. Must be careful with exercises for the neck by performing only smooth and controlled motions that do not cause pain or discomfort				
Head tilt and return to neutral: lateral and flexion/extension	Tilt head to side, moving ear toward the shoulder on the same side, approximately half way to shoulder and return the head to neutral position. Hold the rest of the body still and rigid. Repeat on other side. Perform same instructions for cervical flexion and extension by tilting chin upward and downward	Identify neutral head position	Slowly tilt chin	
Bean bag head drills	Perform back squat while balancing a bean bag (or similar lightweight object) on head as a guide for neutral head position	Promote constant neutral head position throughout the squat with a physical cue	Flat head	
Gaze target drills	Place a target on a wall at approximately eye level of the athlete 5–8 ft away. Retain eye focus on the target without deviating head position from neutral throughout squat	Disassociate head position from gaze	Keep eyes on the target	

(continued)

Table 2 (continued)

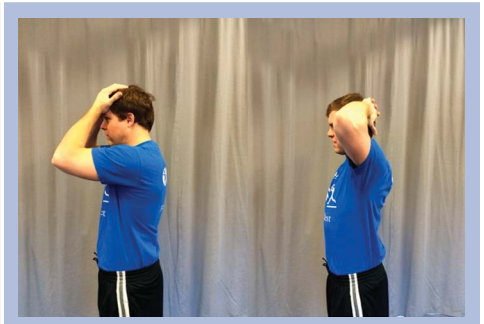
Strength/stability				
Deficit: insufficient neck stabilization strength to maintain the head in neutral alignment throughout the entire squat				
Targeted correction: improve strength and stability of trapezius, cervical extensors, and cervical flexors. Must be careful with exercises for the neck by performing only smooth and controlled motions that do not cause pain or discomfort				
Isometric head press: lateral	Place open hand against the same side of the head. Press hand firmly against the side of the head, while also pressing the head against the hand to equally counter force. Hold the rest of the body still and rigid. Hold for 10 s. Repeat on other side	Improve lateral cervical flexor strength	Firmly press head against hand	
Isometric head press: forward and backward	Forward: place 1 hand on the forehead and press firmly, while also pressing the head against the hand to equally counter force Hold the rest of the body still and rigid. Hold for 10 s. Backward: place 1 hand over the other on back of the skull above the inion, while also pressing the head back against the hands to equally counter force. Hold the rest of the body still and rigid. Hold for 10 s	Improve cervical isometric strength	Firmly press head into hands	

Table 2 (continued)

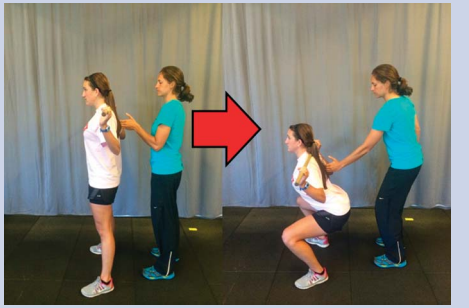
Trapezius shrug	Stand upright with arms relaxed to the sides. Raise shoulders to pull them toward ears without bending elbows. Pause and hold, then lower shoulders back to starting position. Hold the rest of the body still and rigid. Hand held resistance may be used to increase intensity	Improve cervical and scapular strength, important for proper head and shoulder positioning	Pull shoulders up to ears	
Mobility				
Deficit: insufficient physiological range of motion of the neck				
Targeted correction: obtain sufficient mobility of the neck. Must be careful with exercises for the neck by performing only smooth and controlled motions that do not cause pain or discomfort				
Cervical flexion/extension	Tilt chin toward the chest. Attempt to touch the chin to the chest or as far as possible without pain or discomfort. Then, tilt chin upward as far as possible without pain or discomfort. Move head in a slow and controlled manner. Hold the rest of the body still and rigid	Improve cervical mobility in the sagittal plane	Chin to chest	

(continued)

Table 2 (continued)

Lateral flexion	Tilt head to the side toward shoulder. Only tilt head 45° or as far as possible without pain or discomfort. Pause and return to neutral position. Hold the rest of the body still and rigid. Repeat on opposite side	Improve cervical mobility in the frontal plane	Ear to shoulder	
Neck rotations	Slowly rotate head approximately 90° or as far as comfortable up to 90°. During rotation, hold the body still and rigid. Pause and then return to the starting position	Improve cervical mobility in the transverse plane	Look over shoulder	

Table 3
Thoracic position

Exercise	Description	Purpose	Cue	Example
Neuromuscular				
Deficit: lack of scapular retraction, flexed spine, or shoulders rolled forward during squat. Difficulty dissociating upper torso from lower torso				
Targeted correction: obtain tight scapular retraction and a rigid chest up position throughout the entire squat. Generate ability to disassociate upper torso from lower torso				
Scapular pinch throughout squat	Perform back squat while trainer holds fingers between an athlete's shoulder blades. Attempt to pinch trainer's fingers by retracting shoulder blades and holding chest up. Maintain pinch throughout the entire exercise	Physically cue athlete to retract shoulders and hold chest up	Pinch my fingers with your shoulder blades	
Good morning	Assume starting position for the squat stance and position chest up with dowel rod in back squat position. Perform isolated trunk flexion while maintaining chest up. Maintain tight upper back throughout the exercise. Knee joint should slightly flex on the descent and straighten out on the ascent	Exercise fortifies chest up position independent from trunk angle	Lower torso forward while keeping chest up	

(continued)

Table 3 (continued)

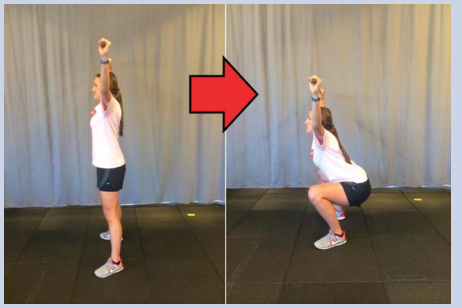
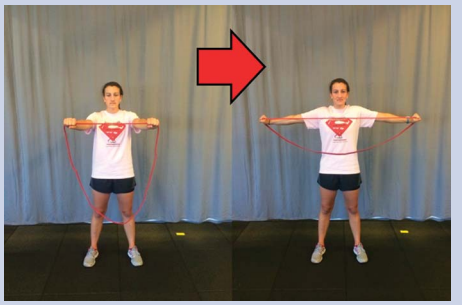
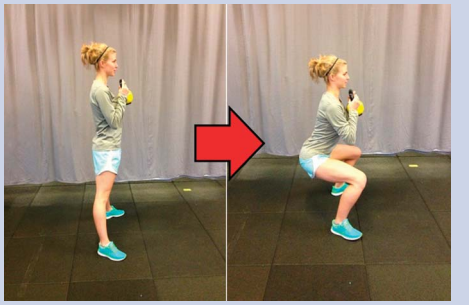
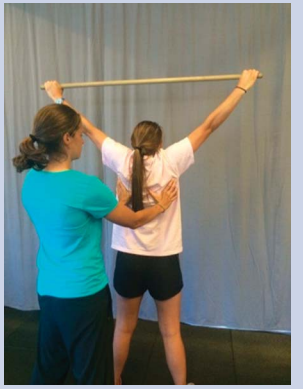
Squat with overhead press	Perform back squat. At apex of squat, hold position and press dowel straight up over head by extending elbows. Return dowel to back squat position and ascend back to starting position	This exercise improves chest up position during the apex of squat depth	Press dowel directly overhead	
Strength/stability				
Deficit: inability to maintain chest up position or scapular retraction, which may be due to weakness of the spinal erectors, trapeziuses, or rhomboids				
Targeted correction: improve upper back strength to develop stable upper torso for squat				
Band pull apart	Make 2 fists and hold arms straight out in front with palm side down. Pull arms slightly past 90° backward until shoulder blades pinch. Slowly return to start position. Grab both halves of the band and try a narrower grip for increased resistance	To strengthen trapeziuses and rhomboids (parascapular muscles)	Keep arms straight	
High pull	Set up in quarter squat position with chest up and arms down straight. Hold dowel in overhand grip. Forcefully pull the dowel to clavicle height. Increase resistance as appropriate	Improve upper back strength especially the trapezius muscles	Pull straight up	

Table 3 (continued)

Front squat	Hold lightweight object, such as a small medicine ball or kettlebell, at chest height. Perform squat exercise. Focus on maintaining upright torso. Increase resistance as appropriate	Strengthen back musculature and promote postural control during squat	Lead with the object during ascent	
Mobility				
Deficit: excessive tightness in chest, potentially due to upper crossed syndrome, which hinders an individual's ability to open chest and retract scapulae				
Targeted correction: improve pectoral and shoulder mobility				
Backward arm circles	Stand tall with arms straight and out to sides with palms up. Perform 10 reverse circles in a slow controlled motion. Start with small circles and work up to larger circles	Improve shoulder mobility	Slow, large controlled circles	

(continued)

Table 3 (continued)

Wall slides	Stand tall with back, head, and buttocks against a wall. Hold arms against the wall at 90° with palms outward. Extend arms upward as high as possible while attempting to keep back, head, and buttocks in contact with the wall. Hold for 10–15 s and return to starting position. Work to maintain maximum contact on the wall with the body as mastery improves	Improve shoulder mobility	Keep back on the wall	
Scapular press	Stand tall with dowel in back squat position. Perform a press to move the dowel above head with elbows extended. To accentuate the upward rotation of scapula, lift the shoulders towards the ears, and feel the scapula rotate upward. Hold for 10 s	Correct lack of upward rotation of the scapula	Press shoulders up and extend	

position, more dynamic spinal extension and antiflexion exercises may be warranted to help them correct spinal flexion deficits with neuromuscular focused exercises and corrective cueing.

Lack of mobility of the hip flexors (iliopsoas) and trunk flexors (abdominals) can also inhibit the athlete's ability to obtain correct trunk posture. The squat movement requires sufficient spinal mobility to assume and maintain slight lordotic posture. Otherwise, individuals may tend to take forward posture and place excessive intradiscal pressure to the low back, especially if the head is forward as well. If the athlete flexes at the spine before approximately 120° of hip flexion when squatting, they may have restriction in the posterior fibers of the Iliotibial (IT) band that insert into the gluteus maximus or lack of lumbar control. If an athlete demonstrates excessive trunk flexion and/or a kyphotic lumbar spine during the back squat, the exercise progressions demonstrated in Table 4 are recommended.

DOMAIN 2: LOWER BODY (TRIPLE EXTENSION)

Domain 2 encompasses the musculoskeletal components of the 3 major joints (ankle, knee, and hip) of the lower body associated with the movement phases of the squat exercise.

Hip position. ***Corrective strategy***

The hip position criterion focuses on the frontal plane position of the hips. Constructive feedback is encouraged to help the athlete concentrate on keeping their hips level and to resist the tendency to overcompensate with their dominate side as observed with mediolateral hip dropping. Cues, such as "stay square" and "keep your hips even," can be verbalized to promote pelvic stabilization. A visualization strategy to use is to instruct an athlete to envision an invisible column that surrounds them or envision them as a piston of a motor, which can help them stay within the confines of the column by not allowing their hips to move mediolaterally. If hip position remains uneven, asymmetric strength of the hips or hip immobility may be the culprit for an observed deficit. The exercise progressions in Table 5 are recommended to promote level hips throughout the squat.

Frontal knee position. ***Corrective strategy***

Knee valgus or varus can be improved with neuromuscular training that incorporates various forms of immediate feedback. Progressions of triple extension resistance exercises and progressive plyometric training have been shown to decrease valgus knee moments (21). Cues that instruct the athlete to keep their knees apart during both descent and ascent are recommended. Elastic bands placed around the knees can provide a tactile cue that promote athletes to press their knees outward to assume proper knee mechanics during the squat. In addition, using a mirror or providing video evidence of frontal plane movement deficits (e.g., dynamic valgus) to an athlete can assist them in becoming self-aware of an often unknown movement deficiency.

Emphasis on improving the strength and function of the athlete's gluteal complex may have the greatest effect on limiting valgus knee angle during squatting (3,7,8). Weakness of the gluteus medius and maximus may result in coupled femoral internal rotation and adduction during the squat, which contributes to observed dynamic knee valgus. Since the gluteal muscles have a large role in both femoral external rotation and abduction, exercise selections that improve the strength and control from these powerful muscle groups will likely translate to the reduction of knee valgus during squatting (24). Suggested exercises include variants of the squat exercise that have a focus on recruitment and activation of the posterior chain.

Valgus can also be influenced by quadriceps dominant muscle recruitment relative to the hamstrings (6). Extensive research of anterior cruciate ligament injuries in the female athlete population has shown that low hamstring to quadriceps ratio is directly associated with dynamic valgus knee movement (6,9,11,20,27). Exercises that strengthen the hamstrings are warranted for those individuals who demonstrate active knee valgus. Phrases, such as "knees out," "spread the floor," "tear out of the outsides of your shoes," will help give the athlete some internal cueing, which may lead to improved biomechanics. The exercise progressions in Table 6 are recommended to optimize knee frontal plane control during the back squat.

Tibial progression angle. ***Corrective strategy***

Tibial progression angle deficits may be best targeted with movement exercise cues focused at the hip joint and potentially with mobility improving exercises for the lower leg. Practitioners may be best advised to avoid specific cues that restrict forward knee movement as this can migrate more load onto the lumbar spine (25). Typically, tibial progression angle, influenced by passive dorsiflexion at the ankle joint, will be influenced by flexibility of the calf musculature and mobility of the ankle joint. Alternatively, the athlete could maintain their heels on the ground and have excessive tibial progression angle due to a quadriceps dominant squat. Providing cues, such as "sit back into the squat" and "drive through the hips" are appropriate here. Video cueing of the athlete may be appropriate to influence self-evaluation of their tibial progression angle as it may be difficult to self-assess from the lateral perspective in real time. It is imperative that the heel maintain contact with the ground as tibial progression angle is monitored. If the athlete continues to demonstrate excessive forward tibial translation, the exercises in Table 7 are recommended to help ameliorate this technical deficit.

Foot position. ***Corrective strategy***

The athlete should be encouraged to keep their entire foot on the ground throughout the squat with pressure toward the lateral aspect of the foot

Table 4
Trunk position

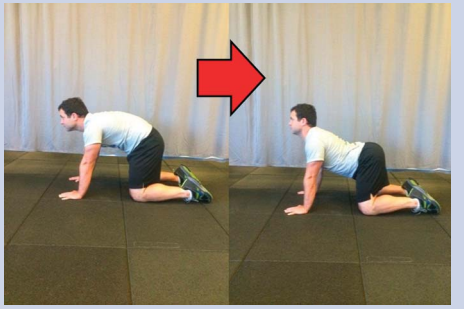
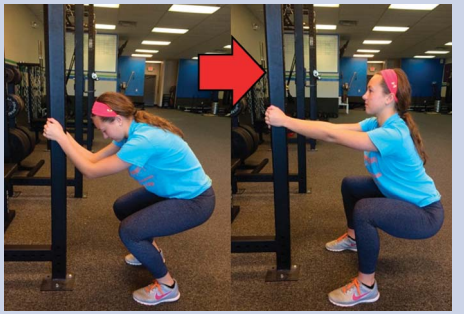
Exercise	Description	Purpose	Cue	Example
Neuromuscular				
Deficit: excessive trunk flexion and/or rounding (kyphosis) of the lumbar spine during squat				
Targeted correction: improve awareness for and proprioception of appropriate trunk angle parallel to tibias and neutral, slight lordosis lumbar spine position				
Cat/cow	Assume quadruped position on knees and hands. Practice alternating from rounded back posture to arched back posture	Identify difference between lordotic and kyphotic positions	Dip spine down and round spine up	
Ball wall squat	Pin a ball (similar to small Swiss ball) between the lower back and wall. Squat down while keeping ball pinned against the wall. The ball will roll up to the shoulder blades. Ascend and repeat	Exercise facilitates a more vertical trunk position because horizontal force from wall serves as assistance. Ball rolling encourages the correct spinal curve	Slide down the ball	

Table 4 (continued)

Pole squat and fix	Perform squat near a sturdy pole or column. At apex of squat, use column as assistance to pull torso into correct position and hold. Heels must remain on the ground	Assistance to help athlete self-generate and learn correct deep hold position	Hold pole and fix	
Strength/stability				
Deficit: inadequate core strength to maintain torso parallel to tibias and lack of lower back tightness to generate stability. May be due to trunk extensor weakness and hip extensor weakness				
Targeted correction: improve trunk stability, trunk extensor strength, and hip extensor strength to maintain slightly extended lordotic position and trunk parallel to the tibias throughout the squat				
Plank	Hold plank position with emphasis on maintaining a slight lordotic curve throughout the exercise	Improve isometric strength of the back musculature and promote correct lumbar spine position	Straight as an arrow	

(continued)

Table 4 (continued)

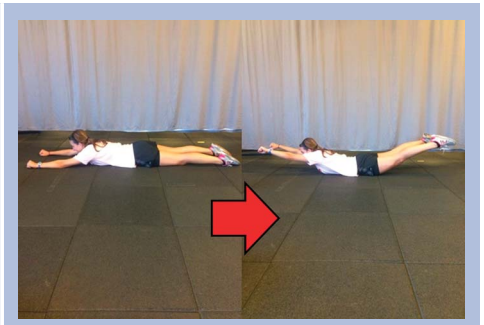
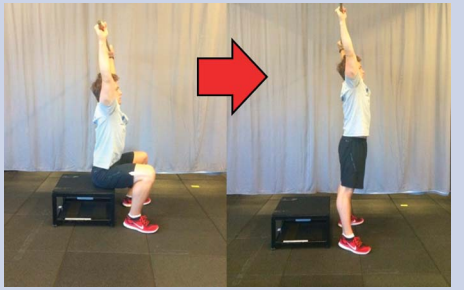
Superman	Lie flat on stomach with arms straight out in front and legs straight out behind. Keep arms and legs shoulder width apart for the duration of the exercise. Lift legs and arms simultaneously at least 6 inches off the ground. Keep each movement slow and controlled to prevent pulling muscles	Strengthen the lower back musculature	Raise chest and arms together	
Overhead squat	Perform squat with dowel directly overhead with elbows extended. Attempt to keep the dowel in this position throughout the entire squat movement. Correct arm and spine position to an upright position before ascent. Variation of this exercise is to perform a box squat with the dowel overhead (pictured).	Strengthen back musculature and promote erect trunk during squat	Keep the dowel behind your eyes	
Mobility				
Deficit: lack of mobility of the hip flexors (e.g., iliopsoas) and trunk flexors (e.g., abdominals)				
Targeted correction: improve spinal extension mobility to assume and maintain slight lordosis posture. Mobility of trunk flexors and hips flexors necessary for appropriate trunk angle				
Standing back arch	Stand up straight with hands on hips and thumbs on the lower back. Extend hips forward and push abdomen forward, while maintaining a slight arch in back. Hold for 10 s	Improve hip flexor mobility	Push hips forward	

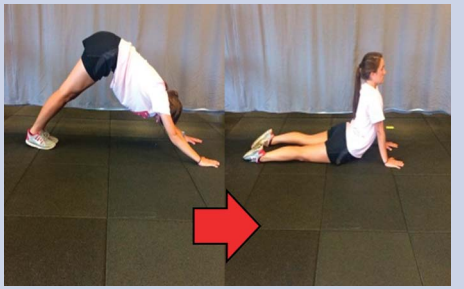
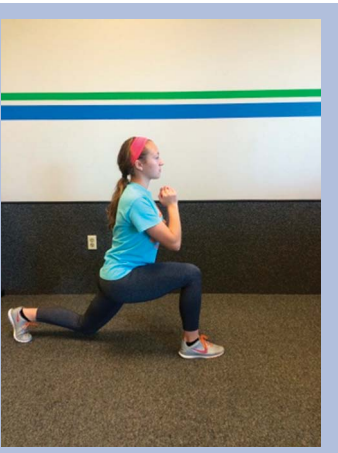
Table 4 (continued)				
Cobra	Lie on stomach with hands flat just outside of the shoulders. Extend elbows to lift torso off of ground. Place small arch in lower back and pull shoulders slightly backward. Keep hips on the ground for this exercise. Hold for 10 s	Improve trunk flexor mobility	Lengthen your abdomen	
Chaturanga	Begin in downward dog position. Extend hips, bend elbows, and lower torso into push-up position. Push-up into cobra position by arching back and raising chest. Keep hips elevated off of the ground for this exercise. Reverse back into push-up position and then back to downward dog	Improve trunk flexor mobility and core strength	Smoothly transition between each position	

Table 5
Hip position

Exercise	Description	Purpose	Cue	Example
Neuromuscular				
Deficit: hips are asymmetrical in frontal plane during squat with observation of mediolateral dropping				
Targeted correction: develop proprioception to maintain even hips and pelvic control throughout squat				
Single leg hip tilts	Stand tall on 1 leg. Tilt trunk and hip to 1 side, pause, and then correct back to neutral hip position	Obtain and identify even hip position	Even out hips	
Single leg squat	Stand tall on 1 leg with hips in a neutral position. Squat to at least parallel, while maintaining the line of the hips in frontal plane parallel to the ground. Push through the heel to return to the starting position. Perform box squat variation to start and graduate to no box as athlete gets stronger and masters the lift	Maintain even hip position during more difficult task	Keep weight on heel	
BOSU™/balance board squat	Perform squats on an unstable surface (i.e., balance board, AIREX™ pad, BOSU™). Can further challenge individual by attempting single leg squats on an unstable surface	Maintain even hip position during more difficult task	Keep hips square	

Table 5 (continued)

Strength/stability				
Deficit: lack of strength or stability of hip musculature or asymmetrical strength of hips				
Targeted correction: focus on hip abductor strength. Hip abduction exercises are important because they strengthen the muscles that stabilize the femur into the hip joint				
Side plank	Lie on side with forearm on the ground and top foot in front of the bottom foot. Lift the hips off of the ground. Isometric hold.	High recruitment of gluteus medius motor units	Stack hips and feet	
Split squat	Perform squats in lunge position. Let back knee come to a few inches above ground. At apex, front foot should remain flat and back foot heel can slightly raise off of the ground. Torso and front tibia are upright and parallel to each other	Generate higher demand from unilateral hip musculature in deeper hip and knee angles	Keep front shin straight	

(continued)

Table 5 (continued)

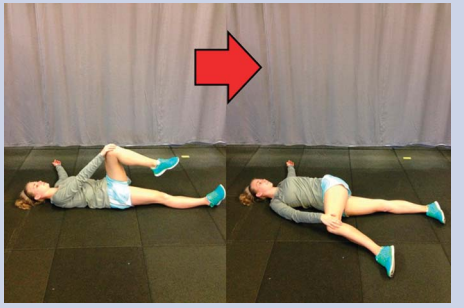
Duck walks	Stand with hands on hips and feet hip width apart. Squat down keeping torso upright. Step forward with right foot with toes pointing slightly outward. Pause. Repeat with left foot, returning feet to hip width	Trains gluteus medius and maximus, which are primary movers in the squat. Encourages upright torso position	Stay low with belly button pointing forward	
Mobility				
Deficit: lack of hip flexion range of motion				
Targeted correction: improve hip musculature to obtain physiological range of motion necessary to perform full squat, while keeping hip line parallel to the ground in the frontal plane				
Crossover stretch	Lie on back with legs extended. Lift left leg and bend the knee to the chest. Cross left leg over the right side of the body. Press the left leg to the floor with the right hand to feel a stretch. Repeat with the opposite side	To stretch hip musculature	Press the knee toward the floor	

Table 5 (continued)

Fire hydrant	In quadruped position, lift 1 knee laterally. Maintain constant knee angle and flat back	Improve lateral hip mobility	Keep back flat
Hip circles	Start in quadruped position (on hands and knees with flat back). Point 1 knee up and outward 90° while keeping knee bent at about 90° of flexion. Trace large circles with knee while maintaining flat back with slight lumbar lordosis. Perform 10 reps clockwise and 10 reps counterclockwise. Repeat on other leg	Improve hip mobility	Draw a circle with your knee

and the heel. Verbal cues, such as "keep heels down," "press down with heels," and "sit through the heels," can help optimize foot and ankle position, especially if the deficit is primarily neuromuscular in nature. If the sides of the foot come off of the ground due to excessive ankle inversion or eversion and cueing does not improve form, the limitation may be associated with ankle strength imbalances. The medial aspect of the foot rising off of the ground may not be as egregious of a deficit as the lateral aspect of the foot coming off of the ground. Placing excessive pressure on the inside of the foot may underlie undesirable knee positions, such as valgus. Inability to keep the heels down may be due to tightness in the posterior chain (e.g., gastrocnemius and soleus tightness). Posterior chain stretching and dynamic mobility drills can improve the ability to keep the heels down if the deficit is due to muscle tightness or immobility. It is important to remember that foot pronation can be a normal weight-bearing function of the foot when equal parts are shared by the multiple joints of the foot (rearfoot through forefoot); however, excessive pronation may limit the potential for a more rigid and stable base of support. Without an ideal base of support by which force can be adequately directed, squat performance may be diminished. If the athlete raises any part of their foot off the ground or demonstrates excessive foot pronation as well as ankle inversion or eversion, the exercise progressions in Table 7 are recommended.

DOMAIN 3: MOVEMENT MECHANICS

Domain 3 analyzes the kinematics of the squat and discusses the limitations from functional deficits on proper movement mechanics.

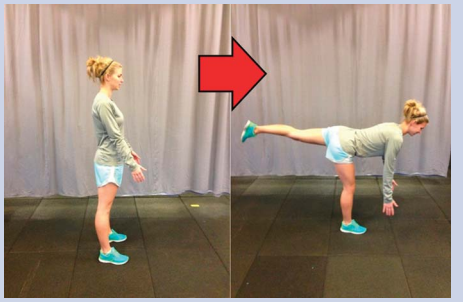
Descent. Corrective strategy

The descent should be initiated with the breaking of the hips ("hip hinging") while maintaining a rigid upright trunk (22). The corrective techniques for proper descent during the squat can include both a physical and proprioceptive stimulus to achieve desired descent

Table 6
Frontal knee position

Exercise	Description	Purpose	Cue	Example
Neuromuscular				
Deficit: active valgus during squat; increased hip adductor activation and increased coactivation of the gastrocnemius and tibialis anterior muscles leads to valgus				
Targeted correction: remove tendency to use active valgus strategy during squat				
Wide stance squat	Body weight squats with 1.5–2 times the shoulder width. Have athlete focus on keeping knees apart	Wide stance will promote knees to track over feet and avoid valgus collapse	Push knees outward	
Band squats	Use Theraband™ or practitioner's hands to encourage athlete to press outwardly against during body weight squat	A physical cue to push knees outward	Push knees outward	

Table 6 (continued)

Squat jump	Perform forward countermovement jump. Land softly in deep hold position with chest up	To promote keeping knees apart when jumping forward	Land with knees apart	
Strength/stability				
Deficit: passive valgus during squat motion				
Targeted correction: improve hip abductor, hamstring, and gluteus strength to reduce medial knee displacement				
Single leg Romanian deadlift	Stand with feet shoulder width apart with hands slightly more than shoulder width apart. Move 1 foot slightly behind the other, holding it a few inches off the ground. With back flat, slowly lower the torso toward front foot and allow free leg to float behind you for balance. Once the weight reaches mid-shin level, push through grounded heel to return to the upright position, and repeat on the opposite leg	To improve single leg knee stability	Make a "T"	

(continued)

Table 6 (continued)

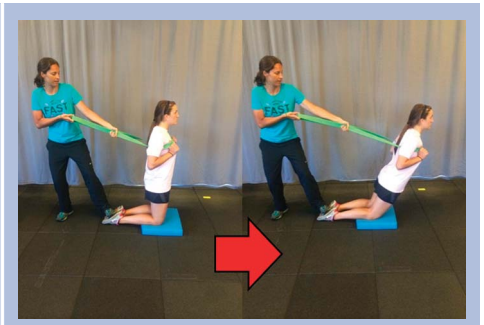
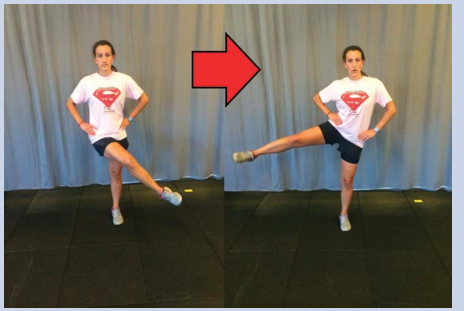
Russian hamstring curls	Kneel on the floor with feet behind and torso up straight. Hook feet under a bench or ask someone to hold ankles down. Cross arms on chest and keep hips extended. Slowly lower down to the floor. Lower forward as low as possible, and then raise back up	To improve eccentric hamstring strength	Lead with your hips when descending	
Single leg isometric squat and hold	Stand tall on 1 leg with line of hips parallel to the ground. Single leg squat to at least parallel and keep heel on the ground. Hold at apex of depth and return to extended knee position. Focus on keeping torso vertical and prevent medial knee movement of stance leg. Increase intensity of exercise by standing on an unstable surface	Single leg knee stability and strengthening exercise	Point knee straight	
Mobility				
Deficit: joint hypomobility causing altered front plane position (e.g., valgus) during squat				
Targeted correction: improve range of motion of hip adductors and hip internal rotators				
Standing leg swings	In standing position, swing leg laterally from side to side	To improve hip adductor mobility	Isolate hip	

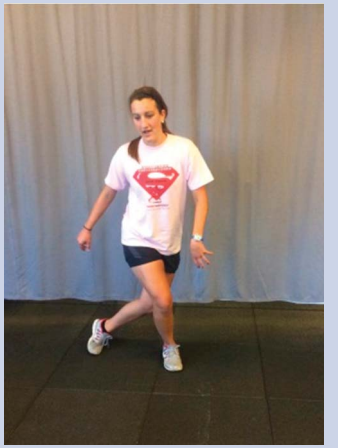
Table 6 (continued)				
Side lunge	Step out with one leg laterally and perform a lunge to 1 side. Repeat on opposite side	To improve hip adductor mobility	Keep nonlunging leg straight	
Carioca	Move laterally by stepping lead leg sideways and alternating the trailing leg in front of and behind the lead leg	To improve hip adductor and internal rotator mobility	Maintain upright posture	

Table 7
Tibial progression angle

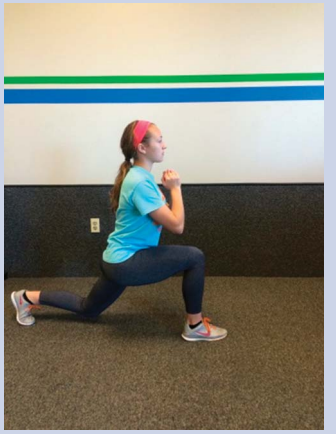
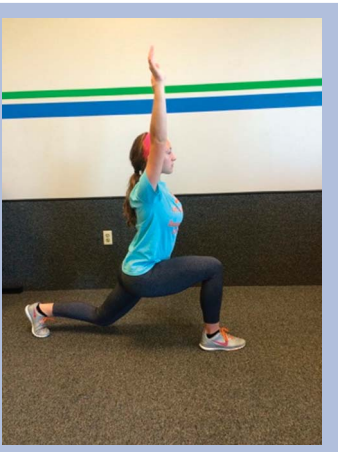
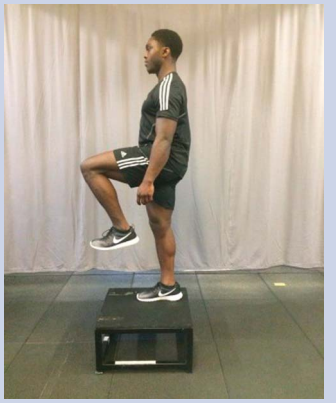
Exercise	Description	Purpose	Cue	Example
Neuromuscular				
Deficit: knee translates excessively over toes during squat, even with heel on the ground				
Targeted correction: develop awareness for correct tibial progression angle				
Lunge and hold	Athlete lunges. Trainer assists to improve TPA. Use trainer assistance (i.e., elastic band, dowel) if necessary	Identify correct tibial progression angle	Straight shin	
Walking lunges	Start with reverse lunges. Place weight in rear to keep shank upright. Step into next lunge without intermediate step (1 foot should always be in front of the other). Use skills and technique developed in reverse lunging to keep knee from excessive TPA even when moving forward	Inhibit excessive tibial progression angle when moving forward	Transfer bodyweight to back heel when moving backward	

Table 7 (continued)

Wall squat	Perform body weight squats with barrier (i.e., wall) at limit of tibial progression angle. Knees should not forcefully press against barrier at apex of depth	Physical cue to prevent excessive tibial progression angle	Reach bottom away from heels	
Strength/stability				
Deficit: lack of strength of posterior chain to keep knee from translating excessively over toes. Excessive tibial progression angle can be a result of weakness in calf and soleus, weak hamstrings, weak gluteus, or excessive quadriceps dominance relative to the hamstrings				
Targeted correction: improve posterior chain strength, especially calves, hamstrings, and gluteus maximus				
Step up	Find a box or step approximately 1 ft off the ground. Step onto box with 1 foot and use that foot to press other foot to the box. Step down first with second foot on the box. Ten repetitions. Repeat with other foot as the lead. Can use resistance to increase intensity	Ensure knee on step tracks in line with foot and without excessive tibial progression angle	Straight shin on ascent	

(continued)

Table 7 (continued)

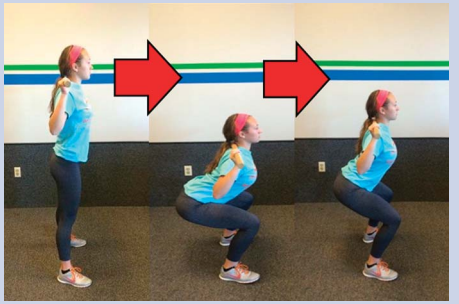
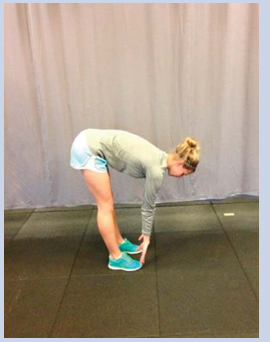
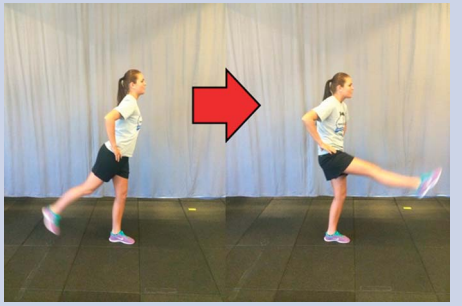
Heel touches	Stand on a step or box approximately 1 ft off of the ground. Have 1 leg hang off of the side. Perform single leg squat with opposite leg moving toward the ground. It is important to keep the pelvis even throughout the movement. Just before contact of the foot with the ground, use the foot on the step to press back up	Ensure knee on box is without excessive tibial progression angle and functions as a unilateral leg strengthening exercise to promote side to side strength symmetry	Press on box to ascend	
1 and 1/4 squat	Squat down for a 5-s count until thighs are parallel to the ground. Come up a quarter of the way at a slow and deliberate pace then descend back to parallel. Ascend to starting position	To ensure recruitment and strengthening of the vastus medialis oblique at the bottom of a squat	Slow and controlled speed	
Mobility				
Deficit: may not have adequate mobility of knee in sagittal plane. Lack of mobility of soleus and gastrocnemius				
Targeted correction: ensure adequate mobility of knee in sagittal plane by improving mobility of calf and quadriceps				
Toe touches	Stand upright. Reach down for toes. Stretch posterior chain	Improve mobility of knee and hip musculature	Reach for toes	

Table 7 (continued)

Straight leg march	Walk forward with straight leg and opposite arm forward reach. Alternate sides on each step	Improve mobility of knee and hip musculature	Bring toes to straight arm	
Leg kicks: forward and backward	Stand upright and swing 1 leg forward and backward. Athlete may need a support to balance during this exercise	Improve hamstring and gluteal mobility	Swing toes to eye level	

TPA = tibial progression angle.

performance (Table 8). The key areas to focus targeted correction for descent deficits are to ensure adequate strength and mobility for a prescribed hip-hinge descent strategy, upright torso, and correct eccentric speed control. Practitioners should encourage athletes to initiate the back squat movement with a "break" at the hips and to immediately sit back on the heels. The athlete should be instructed to flex the hips, knees, and ankles to lower the body to the correct depth where the top of the thighs are at least parallel to ground without disjointed deviations noted at the knee, ankle, or hips. One of the most common deficits presented with descent of the back squat is the use of a knee focused strategy (pressing knees forward) rather than a hip focused strategy that reaches back with the gluteals during descent. Verbal cues of "reach back" with the hips or having the athlete perform the wall tap exercise (as described in Table 9) may help influence desired descent strategy. We propose that back squat descent should be prescribed to take at least twice as long as the ascent and descent should maintain a consistent rate throughout the entire range of motion. The athlete should avoid descending too rapidly or "collapsing" due to the loss of eccentric control near the apex of depth (15). Strengthening exercises that focus on the eccentric control of the posterior chain can help correct this particular deficit. Additional strength or mobility deficits in the trunk, hip, and lower extremity musculature may impair proper descent. Targeted interventions are listed in Table 9 to improve the athlete's ability to use the appropriate hip-hinge strategy, maintain a controlled movement speed, and maintain an upright torso throughout the back squat.

Depth. ***Corrective strategy***

At the proper depth, the femurs should be slightly below parallel to the ground, hips are back, tibias are positioned vertical, and feet are entirely on the ground. The most common deficit of depth during the back squat is from the athlete squatting to a position that is too shallow. Targeted feedback and cueing may be most advantageous to correct squat depth deficits. For example, physical cues, such as a box at the appropriate depth, can be used as a target. Athletes should use prescribed descent strategies that achieve thighs at least parallel to the ground. If the athlete cannot demonstrate desired technique throughout descent, it is recommended to use assistive strategies, such as a practitioner-held dowel (Table 10). While squatting below parallel can occur, it is not often detrimental to the athlete. If contraindicated based on existing pathology, excessive squat depth can be easily corrected with targeted cueing and feedback or box squat techniques.

Inability to achieve depth may also be due to a lack of lack isometric strength of the posterior chain to maintain bodyweight support at the apex of depth. Strengthening the posterior chain using isometric strengthening drills may help an athlete assume and maintain a deep hold position at the apex of the squat in good form. Furthermore, tightness in the posterior chain musculature and hip adductors may further limit the ability for an athlete to achieve appropriate depth. Mobility drills that support improvements in mobility of the hip adductors and posterior chain can facilitate an athlete's potential to achieve proper back squat depth. In some cases, inadequate hamstring strength may be the culprit of a back squat that does not achieve proper depth, and thus, hamstring mobility and stretching drills are warranted in some training scenarios. The exercises in Table 10 are intended to improve squat depth ability and form.

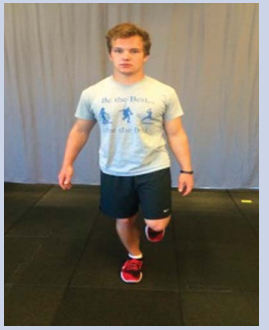
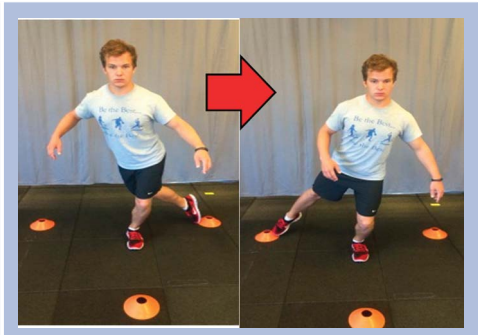
Ascent. ***Corrective strategy***

Assessing the underlying mechanisms associated with improper ascent technique is critical for targeted deficit correction. It is most important to ensure that the athlete drives with their hips as the primary mover and ascends while keeping their torso upright. The vertical distance between the hips and shoulders should be kept constant throughout the squat. Cueing that encourages athletes to "lead with their chest" or "rise with the shoulders" may be effective to ensure the athlete does not rise with their hips too quickly. If the athlete does rise with their hips too quickly, the vertical distance between the hips and the shoulder will decrease and will be a suboptimal movement strategy. Neuromuscular training that promotes hip drive (i.e., hip extension) is recommended as well as drills that encourage an upright torso position during ascent. Hip drive can be improved through various hip extension exercises that improve explosive concentric muscle actions of the posterior chain. Finally, it is important to ensure adequate mobility of the thoracic spine and hip flexor mobility to encourage execution of the prescribed ascent technique (22). The exercises in Table 11 are intended to target correction of the ascent movement strategy.

CONCLUSIONS

The corrective strategies for the back squat exercise are aimed to teach and generate competency in an essential functional movement for physical and daily living activities. The proposed corrective interventions are not intended to train athletes with the goal for maximum competitive load during the squat and the authors acknowledge that technical variants exist, which may increase the potential to achieve maximum back squat load. However, the current systematic approach is aimed to teach bodyweight squat technique that can serve as a precursor for more intense physical activity and training exercises (5,18,19). Furthermore, optimal movement strategy retention gained from the proposed targeted training plan may decrease the risk of injury during anticipated and unanticipated physical activity (23). The described methods for targeted exercise correction are designed to provide a systematic guide focused to improve biomechanical squat performance and rectify deficits that underlie undesirable movement patterns. Through the implementation of a corrective intervention plan for biomechanical back squat deficits, athletes young and old will be poised to achieve substantive gains in physical performance, decrease the risk of sports-related injury, and hopefully, increase their quality of life by

Table 8
Foot position

Exercise	Description	Purpose	Cue	Example
Neuromuscular				
Deficit: foot comes off of ground during squat not due to strength or mobility limitations				
Targeted correction: promote squatting mechanics that emphasize placing body weight on heels and even distribution of weight side to side of foot				
Single leg balance	Stand on 1 leg on stable surface with slight bend in knee, place other leg so foot is touching stance leg knee. Can use unstable surface more challenging variation	Develop flat foot stability awareness and balance	Grip the ground with your toes and heel	
Y balance	Standing on left foot with a slight bend in knee, attempt to touch 3 points with the right foot. Touches should be as light as possible and no weight transfer should occur. The whole stance foot should remain in contact with the ground the entire time. First, touch out in front as far as possible in good form, then 125° to the right and then 215°. Return to the original position. Repeat on opposite side in opposite direction	To maintain entire foot on ground even when shifting weight on a single leg	Do not place pressure on tapping foot	

(continued)

Table 8 (continued)

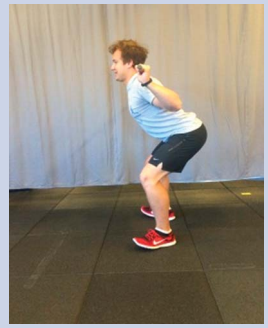
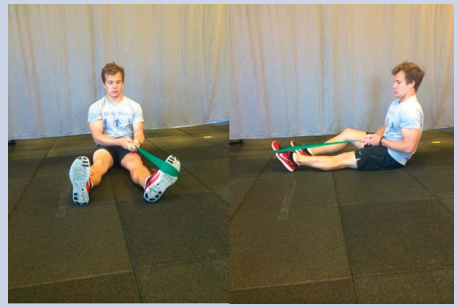
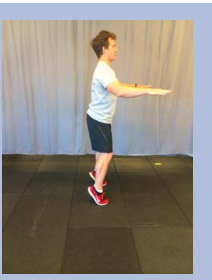
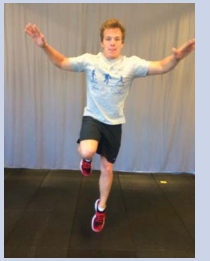
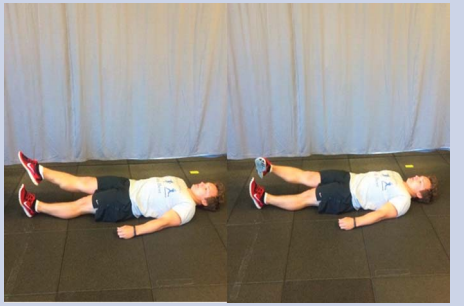
Toes-up squats	Squat with toes off of ground, place weight onto heels	Promote heel down mechanics	Lift toes off the ground	
Strength/stability				
Deficit: lack of or asymmetrical ankle strength and/or poor stabilization of ankle and foot. Foot rolls onto either side during squat				
Targeted correction: improve ankle and foot strength for drive and to keep whole foot on ground. Improve stabilization of ankle inverters and everters as well as intrinsic foot muscles to allow foot to pronate. Strengthening the plantar flexors with direct heel raises can enhance ankle joint stability				
Ankle band strengthening	Plantar flexion: using a resistance band around forefoot, hold the ends of the band with hands and gently push ankle down as far as you can comfortably and hold for about 10 s, then relax. Inversion/eversion: start by sitting with foot flat on the floor and pushing band outward against a band. Then, pull band in opposite direction	Strengthen ankle plantar flexors, inverters, and everters	Isolate ankle movement	

Table 8 (continued)

Calf raises	Start by transferring body weight toward your toes. Contract your calves and lift heels off of ground. Do not to rotate ankles. Lower down slowly, keeping body weight forward on your toes. Can also perform single leg calf raise for more challenge	Strengthen plantar flexors	Press down on balls of feet	
Single leg hops	Stand on 1 leg and hop in place attempting to land in the same spot each time. Repeat on opposite leg	To promote single leg eccentric control	Soft landings	
Mobility				
Deficit: lack of dorsiflexion mobility if heels come up off ground due to restricted Achilles tendon and tight soleus and gastrocnemius				
Targeted correction: achieve adequate ankle mobility to keep foot on ground throughout squat through lengthening of calf muscles				
Ankle rolls	Lie on back with hands to the side. Raise 1 leg up about 6–12 inches. Roll ankle clockwise 10 times and then counterclockwise 10 times. Maintain knee angle with slight flexion throughout. To increase complexity, attempt to draw the alphabet with the big toe	Achieve ankle mobility in 3 planes	Draw circles with the big toe	

(continued)

Table 8 (continued)				
Static calf stretch	Stand facing the wall. Place both of your hands onto the wall at chest height. Position your right leg back and your left leg forward—it should look like a staggered stance. Keep both heels on the ground and lean forward toward the wall. A tolerable stretch on the back of the extended calf should be felt. Hold for 20 to 30 s, switch legs, and repeat 3–4 times	Stretch gastrocnemius and soleus	Press heel toward the ground	
Heel walks	Walk on heels with toes off of the ground. Do not continue if pain or discomfort	Promote dynamic mobility of gastrocnemius and soleus	Point toes upward	

Table 9
Descent

Exercise	Description	Purpose	Cue	Example
Neuromuscular				
Deficit: knee dominant strategy instead of hip-hinge strategy as seen with excessive trunk flexion, excessive tibial progression angle, and/or heels coming off of the ground				
Targeted correction: teach athlete to use hip-hinge movement pattern. Time hip, knee, and ankle flexion together at even pace. Descent should be twice as long as ascent in duration				
Wall taps	Keep feet planted 2–3 ft in front of wall. Reach back to touch rear to wall and return. Focus on reaching back	Instill hip-hinge movement strategy by reaching back	Reach back for the wall	
Tempo squatting	Set exaggerated ratio for descent: ascent of squat (e.g., 5:1)	Fortify slow descent pace	Slowly lower to the box	

(continued)

Table 9 (continued)

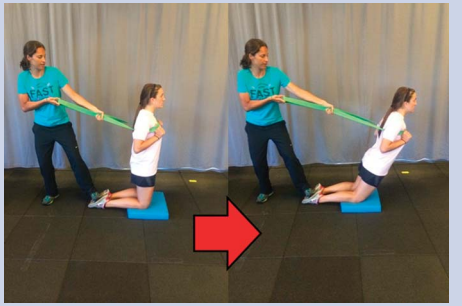
Assisted squatting	Trainer provides assistance (e.g., dowel rod or elastic band) for athlete to perform slow, continuous descent with hip-hinge strategy that recruits posterior chain musculature	Provide assistance to learn correct descent strategy	Sit to a chair	
Strength/stability				
Deficit: lack of lower limb eccentric strength control, evidenced by an overall lack of control of the tempo of the descent, with the athlete "dropping" into the apex of the descent. Descent timing is not 2:1 ratio with ascent				
Targeted correction: enhance eccentric muscle strength of the posterior chain musculature				
Eccentric focused kneeling fall	Kneel on comfortable surface with partner supporting ankles. Lean forward with neutral hips and attempt to hold body up as long as possible before catching yourself with arms in a push-up position. Do not perform this exercise if the athlete is unable to catch themselves and support their bodyweight with their arms. Can use band assistance similar to Russian hamstring curl	Eccentrically strengthen posterior chain	Lower as slowly as possible	

Table 9 (continued)

Box drop deep hold	Drop from a box with both feet landing simultaneously. Drop into deep hold position (position at apex of squat). Recommend to start at 1 ft height for depth jump and increase height systematically	Dynamically strengthen posterior chain during eccentric muscle action	Quiet landings	
Pause at descending levels	Divide descent into 5 even segments. Lower to each segment and pause before further descending. Consider using a box. Instructor can use verbal cueing to signal athlete when to move to each segment	Eccentric and Isometric strengthening of posterior chain. Isolate lower phase of descent to strengthen corresponding posterior chain musculature	Signal 5 depth levels using countdown of "1-2-3-4-5"	
Mobility				
Deficit: lack of lower limb mobility, leading to a forward trunk lean				
Targeted correction: improve lower limb range of motion with hip extensor emphasis				
Hurdler stretch	Sitting on bottom, extend 1 leg with toes up and bend the opposite leg so the sole of foot is on medial thigh of the extended leg. Reach forward with both arms in attempt to touch the toes (or past) of the extended leg to stretch the hip extensors	Stretch posterior chain relative to the squat	Reach past your toes	

(continued)

Table 9 (continued)

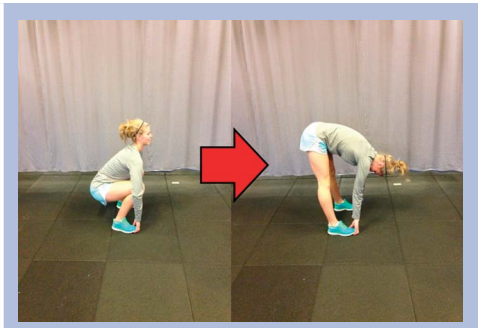
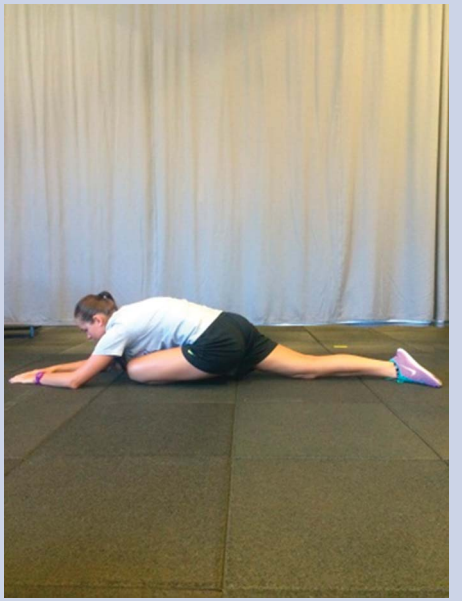
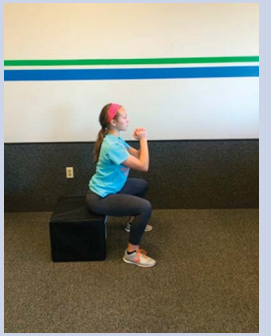
Hamstring stretch to squat	Stand with feet shoulder width apart. Squat down and grab tips of toes. Knees should shoot outside of arms slowly try to straighten legs as you stand until stretch is felt along back of thighs. Immediately descend again for the next repetition without letting go of feet	Stretch posterior chain relative to the squat	Slowly rise	
Pigeon pose	Sit on ground and tuck 1 leg underneath body, keeping knee bent. Fold body over the top of bent leg as the opposite leg is maintained straight	More intense posterior chain stretch	Reach forward	

Table 10
Depth

Exercise	Description	Purpose	Cue	Example
Neuromuscular				
Deficit: athlete does not achieve depth of thighs at least parallel to the ground				
Targeted correction: athlete improves awareness/proprioception of desired depth with good form				
Box sit	Athlete sits on box of desired depth height	Identify correct squat depth	Sit up tall	
Tactile/verbal cueing	Athlete descends to depth. Instructor uses verbal cueing to provide feedback as to proper depth or distance still to achieve max depth	Identify depth while supporting body weight	Indicate correct depth	

(continued)

Table 10 (continued)

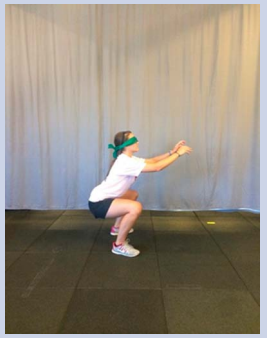
Eyes closed depth	Athlete performs squat with eyes closed to build proprioception for correct depth	Improve proprioception for depth awareness	Indicate correct depth	
Strength/stability				
Deficit: athlete lacks posterior chain eccentric and/or isometric strength to maintain deep hold				
Targeted correction: improve eccentric and/or isometric strength of posterior chain				
Assisted squat and hold	Assisted squat to provide assistance at apex of squat for isometric hold	Provide assistance to train with isometric muscle action for the desired depth	Reach buttocks away from heels	

Table 10 (continued)

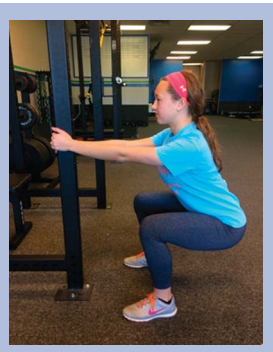
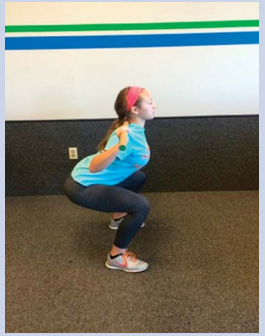
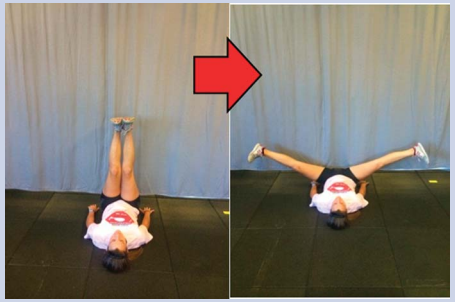
Pole hold	Athlete uses a sturdy column or pole to assume and maintain deep hold as long as possible. Athlete should try to use pole as little as possible and only use assistance to fix position as needed	Train with isometric muscle action for the desired depth with assistance to fix	Straighten shins and torso	
Deep hold	Athlete maintains chair position with thighs parallel to ground and torso parallel to tibias	Train with isometric muscle action for the desired depth with no assistance at correct depth	Sit as if in a chair	
Mobility				
Deficit: difficulty achieving depth due to tightness in posterior chain and hip adductors				
Targeted correction: improve mobility of lower extremity musculature to achieve depth				
V stretch	Sit on ground. Position legs straight above on wall. Spread legs apart for groin stretch	Stretch hip adductors	Spread legs until you feel a stretch and hold	

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Table 10 (continued)

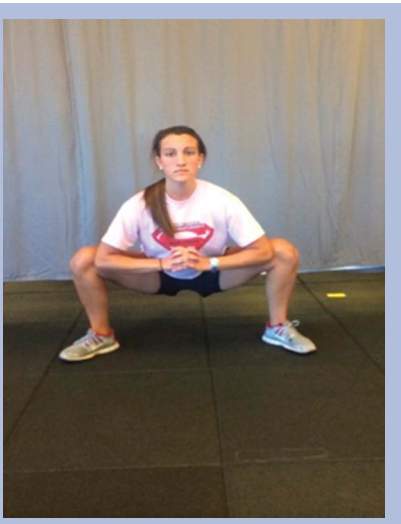
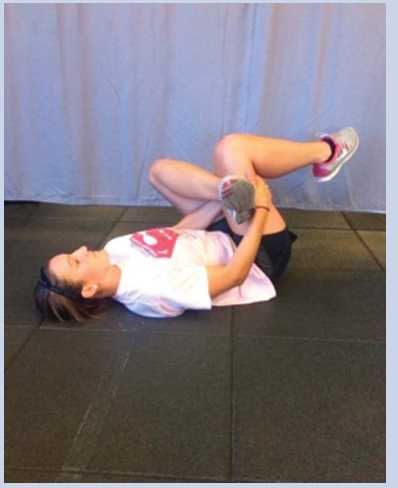
Sumo stretch	Squat down with bottom lower than knees and torso upright. Press outside of elbows against the inside of the knees to feel groin stretch	Stretch hip adductors	Push out against knees	
Figure 4 stretch	Lie on back with knees bent and feet off of the ground. Cross the left leg over the right thigh. Reach through legs and gently pull the right thigh toward the chest until a stretch is felt in the buttock and hip of the right leg. Repeat for opposite leg	Stretch piriformis	Pull thigh to chest	

Table 11
Ascent

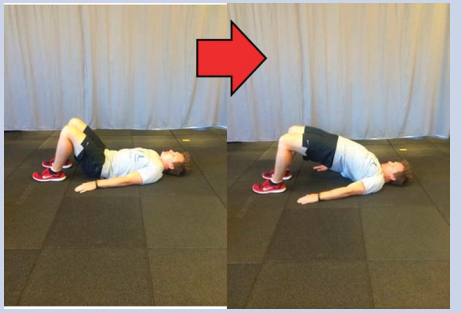
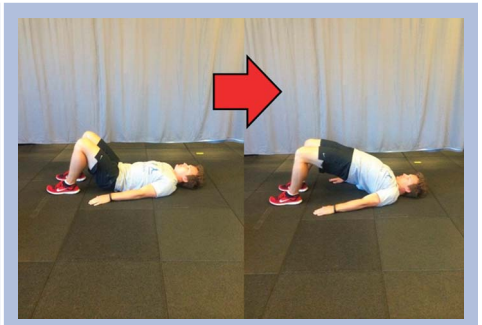
Exercise	Description	Purpose	Cue	Example
Neuromuscular				
Deficit: athlete does not drive with hips as primary mover or hips rise too quickly in relation to the shoulders				
Targeted correction: athlete uses hips as primary mover and maintain shoulders and hips the same distance apart throughout ascent				
Glute bridge	Lie supine with feet flat on the floor with heels close to buttocks. Place hands palm down by sides. Push hips upward with shoulders still in contact with ground. Hold and lower	Emphasize hip drive	Hips to the ceiling	
Hip thrusts	Perform continuous glute bridges in a controlled manner. Emphasize driving upward with the hips	Emphasize hip drive	Hips to the ceiling	

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Table 11 (continued)

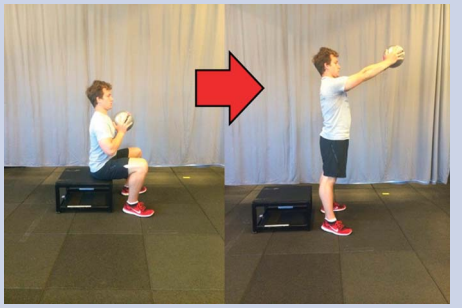
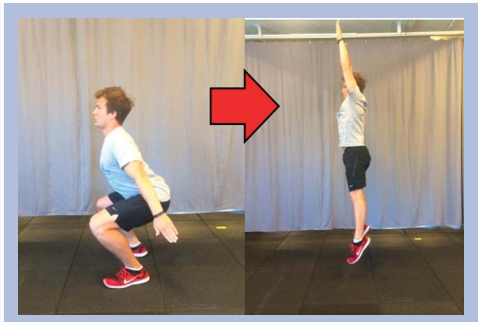
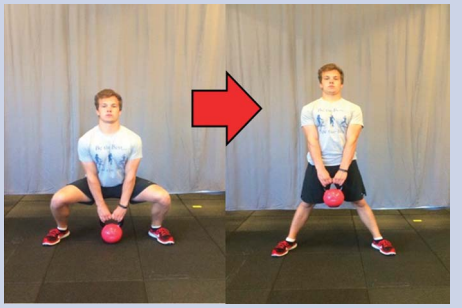
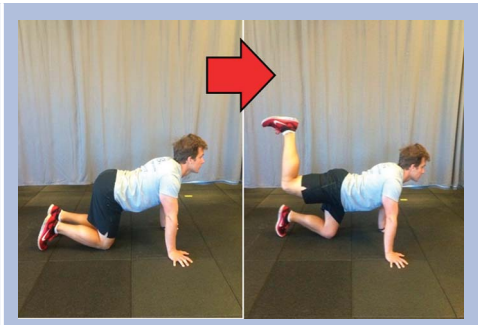
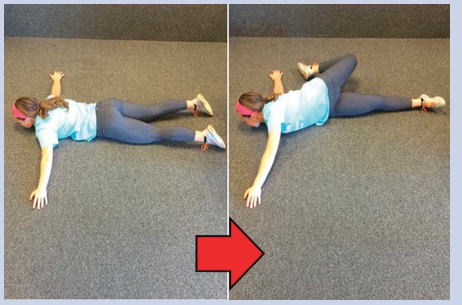
Ball lead squat	Hold ball chest height. Perform squat with emphasis of leading with the ball during ascent	Promote leading with the chest during ascent	Lead with the ball	
Strength/stability				
Deficit: posterior chain and hip extension concentric muscle action weakness				
Targeted correction: improve concentric strength of posterior chain				
Box sit to stand	Place a plyometric box or chair behind the athlete. The height of the box should be slightly higher than the approximate depth of their observed fault. The height of the box should gradually be reduced to work toward full depth capability	Promote hip drive and pushing through heels to ascend	Press down on heels and use hips to stand	
Vertical countermovement jump	Athlete squats down to available depth while maintaining form and immediately jumps vertically	Train using an explosive concentric exercise of posterior chain	Explode upward and use soft landings	

Table 11 (continued)

Sumo deadlift	Squat down to weights/bar, grasp them, and stand up by raising hips and shoulders at same time, keeping the weights/bar close to thighs. Finish in neutral, extended position. Reverse in a slow and controlled manner to lower back to the ground	Strengthen posterior chain and improve postural control	Keep chest up, press down on heels, through with hips	
Mobility				
Deficit: lack of thoracic spine and hip flexor mobility				
Targeted correction: improve thoracic spine and hip flexor mobility				
Lunge hip flexor stretch	Lunge with back knee on the ground. Extend torso backward. Repeat on opposite side	Static hip flexor stretch and thoracic spine stretch to improve mobility	Lean back	

(continued)

Table 11 (continued)

Donkey kicks	In quadruped position, kick backward with sole of foot toward the ceiling. Maintain knee flexion angle	Hip flexor mobility exercise that emphasizes a postural position relative to the squat	Plant footprint on the ceiling	
Scorpion	Lie flat on stomach with arms straight out to the sides and with legs together and extended. Flex the left knee to raise lower left leg toward the ceiling. Twist at the hips to reach the left foot over to the right side of the body. Attempt to keep arms and chest flat on the ground. Once opposite foot is as close to opposite hand as possible, return to start and immediately go the other direction with the other leg	To stretch the lower back, gluteus, and hamstring mobility	Keep chest on the ground	

promoting a movement pattern that will support lifelong participation in physical activity.

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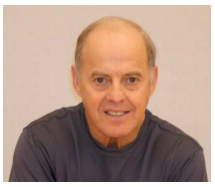

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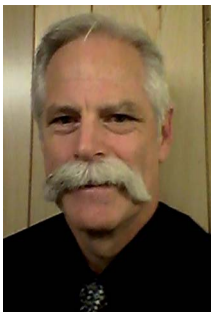

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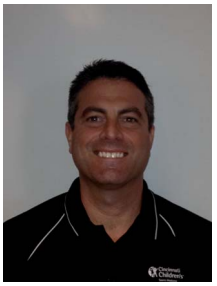

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