Clinical Commentary/Current Concept Review

The Need To Change Return to Play Testing in Athletes Following ACL Injury: A Theoretical Model

Kevin Wilk, PT, DPT, FAPTA[1,2] [a], Zachary M Thomas, PT, DPT, OCS, CSCS[3], Christopher A Arrigo, MS, PT, ATC[4], George J Davies, PT, DPT, ATC, CSCS[5,6,7]

[1] Vice President National Director Clinical Education & Research, Champion Sports Medicine, Select Medical, [2] Director of Rehabilitative Research, American Sports Medicine Institute, [3] Sports Physical Therapy Fellow, Champion Sports Medicine, [4] Advanced Rehabilitation, [5] Physical Therapy, Georgia Southern University, [6] Coastal Therapy & Sports Rehab, [7] Gundersen Health System

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The incidence of knee injuries in sport, particularly involving the ACL, appears to be increasing yearly, especially in younger age athletes. Even more concerning is the frequency of ACL reinjury also appears to be increasing year after year. Improving the objective criteria and testing methods used to determine return to play (RTP) readiness following ACL surgery is one aspect of the rehabilitation process that can significantly help in reducing reinjury rates. Currently, the majority of clinicians are still using post operative time frames as their number one criterion for clearance to RTP. This flawed method demonstrates an inadequate reflection of the true unpredictable, dynamic environment athletes are returning to participate in. In our clinical experience, objective testing to allow for clearance to sport participation following an ACL injury should incorporate neurocognitive and reactive testing due to the nature of the injury typically occurs because of failed control of unanticipated reactive movements. The purpose of this manuscript is to share a neurocognitive testing sequence we currently employ consisting of 8 tests in 3 categories: Blazepod tests, reactive shuttle run tests, and reactive hop tests. The use of a more dynamic reactive testing battery may decrease the reinjury rates when an athlete is cleared for participation by measuring readiness in chaotic circumstances that are more truly reflective of the sporting environment the athlete is working to return to and in the process give them a greater sense of confidence.

INTRODUCTION

It is estimated there are between 200,000 to 250,000 anterior cruciate ligament (ACL) knee injuries sustained annually in the United States, resulting in approximately 150,000 to 165,000 ACL surgeries each year.[1,2] The incidence of these serious knee injuries appears to be increasing yearly, especially in high school aged athletes. More troublesome than the frequency of ACL injuries, is the rate of reinjury also appears to be increasing year after year. Investigators have reported reinjury rates following ACL surgery to range as high as 30-39%.[3,4] This rate of reinjury results in as many as 4 in every 10 surgeries being attributed to reinjury. This level of reinjury following ACL surgery is unacceptable. In these instances, the athlete has already suffered one significant knee injury, undergone surgery, and worked through the rehabilitation process afterwards only to suffer another ACL injury to either the opposite or the previously reconstructed knee. As health care providers we need to critically examine every available way to reduce ACL reinjury rates. One area that can significantly help in reducing these reinjury rates is improving the methodology used in return to play (RTP) testing following ACL surgery.

The cause of these unacceptably high reinjury rates has been attributed to a number of factors. First, there is a surprising overall lack of RTP testing generally utilized in making RTP decisions. Barber-Westin and Noyes[3] reported in a large meta-analysis and systematic review of 716 articles that only 13% utilized objective criteria in determining readiness to return an athlete back to participation following ACL surgery. This lack of testing is extremely disappointing when you consider that a reduction in reinjury rates has been demonstrated by utilizing objective RTP testing in the decision-making process.[5–7] Second, athletes are returning to participate in sport without completing the entire rehabilitation process, often due to insurance plan limitations, an inability to afford rehabilitation follow-

a Address all correspondence to Dr. Kevin Wilk, 200 Montgomery Hwy, Suite 150, Birmingham, AL, 35216

ing the exhaustion of benefits, or self-discharge. Each of these factors results in incomplete rehabilitation, placing the athlete at risk of reinjury. Third, is the frequent lack of high-level activities and functional sport-specific challenges during the rehabilitation process. When an athlete is not challenged in a similar environment, with replicating demands matching those of the sport, they are often returning to the result inadequately prepared and therefore a higher risk of reinjury. Next, is the fact that most of the RTP tests currently in use are single task drills with anticipated movements. Sports are seldom single task activities and often involve unanticipated movements. Brophy et al[8,9] and others[10,11] have reported the majority of soccer injuries sustained to the female player occurred during defending and/or with unanticipated reactive movements. For example, a soccer player may be performing soccer drills with other players to create an environment of distraction, controlled chaos, and dual tasking. This combination of variables and the hierarchy of tasks inherent to sport makes single task drills insufficient to assess RTP readiness. Lastly, the athlete often goes back to their sport or activities unprepared and at risk of reinjury for a combination of the reasons listed above.

The present RTP testing methodology is underutilized and when employed not satisfactorily effective to appropriately determine RTP readiness of the athlete following ACL surgery. Most decisions are made in the Physician's office, based solely on physical examination and subjective reporting. Typically, when RTP testing is performed, it is not done in the same environment or with sport specificity. Testing needs to be conducted with an emphasis on the performance of multiple tasks, neurocognitive challenges, and motor control. RTP decisions should be made by a team of health care providers looking at the athlete's readiness from a variety of viewpoints to make an informed decision based on subjective, objective and functional data. RTP criteria should not be a single event to determine readiness to return athletes to all levels of sport.

RTP testing for the lower extremity following ACL surgery has been discussed extensively in the literature since the mid 1980's. There are over 500 articles that present various testing procedures and protocols. These testing procedures include single leg hop testing, shuttle running, balance testing and functional movement screening, isokinetic testing, and limb symmetry index assessment to list just a few.[12–19] While these tests are all good measures of what they are designed to assess, they all test a single task, and none involve reactive assessment. Even the tests used that replicate drills employed in sport training, are simply drills and not truly specific sport related activities. These tests are good, serve a vital purpose and we recommend them as tests to assist in determining rehabilitation progression.

Historically all these tests have been referred to as RTP tests. They are more appropriately tests suited to determine athlete readiness to begin progression through rehabilitation, running, jumping, agility drills, or other transitional programs. They are not true measures to assess readiness to return to competitive play. These tests are predictable, in that the athlete is asked to perform a specific movement or task and is evaluated based on their resultant performance of this movement. In sports, there are numerous unpredictable movements that the athlete must perform, most of these are reactive in nature and have multiple stimuli occurring simultaneously. Therefore, to effectively assess return to play readiness during the recovery after ACL surgery, the RTP tests must measure those types of sport activities, movements, and reactions. The problem is these tests do not assess reaction time, dynamic stabilization, dynamic reaction movements and do not tell us if the athlete is ready to initiate competitive practice or return to competitive play.

Although there are limitations in the previous metrics for clinical decision making for RTP, it is important to recognize some of the research of the tests which provide the criteria to progress to the neurocognitive testing. Refer to the list below for an example checklist or functional testing algorithm for a criterion-based approach for progression through rehabilitation and in preparation for using the advanced testing methods.[20]

- VAS/NPRS
- PROs
- Kinesiophobia
- Anthropometric measurement for effusion
- Static balance/Dynamic balance
- AROM/PROM – Knee/PF
- Strength Testing – TLS: LSI, Unilateral ratios, Allometric scaling to BW
- Special Tests for ligament stability: Lachman's, Pivot Shift, KT1000/2000
- Walking/running gait analysis
- Functional movement patterns
- Jump Test
- Hop Tests
- T-drill hop test
- Change of Direction Test
- LEFT (adds acceleration/deceleration [anterior/retro] and acute fatigue factor

Even though the "missing link" is the neurocognitive reactive testing, there must be preparatory testing that leads to criterion-based metrics that prepares the patients to perform the neurocognitive reactive testing. Therefore, criteria that can be used to determine the patient's readiness for performing these advanced neuro-cognitive reactive tests are described in Table 1.

The purpose of this manuscript is to present a proposed testing and RTP model we currently use clinically. This RTP testing includes neurocognitive testing, reactive motor control testing, dual tasking, and psychological readiness with the main focus on reactive unanticipated test movements.

NEUROCOGNITIVE TESTING

Appropriate testing of RTP readiness following ACL surgery, should not only assess if the athlete appears ready to resume play but also be directed toward minimizing the

Table 1.

Measurements	Methods of Assessments	Objective Criteria
Pain[21]	VAS/NPRS	<3 during & after therapeutic exercises
PROs[22]		
Kinesiophobia[23,24]	ACL-RSI	> 55 points
Posture	Posture Grid	LSI/WNL
Gait/Running/Movement Analysis	Qualitative Analysis	WNL
Knee effusion	Anthropometric measurements /Sweep Test	<1 cm. LSI
Palpation		No c/o pain
Balance/Proprioception[25]	Static Dynamic	WNL-LSI WNL/LSI
AROM[26,27]	Goniometry Digital gonios	<10% LSI
PROM[26,27]	Goniometry, Qualitative end feels	< 10 % LSI
Special Tests	Lachman's/ Pivot Shift	Negative Negative
Muscle Strength[28] *(Total Leg Strength-TAS)* *Core, Hip, Knee, Ankle*	HHD, Isokinetics	<10% LSI, %BW, Norms
Muscle Power *(Total Leg Strength-TAS)* *Core, Hip, Knee, Ankle*	HHD, Isokinetics Force Plates	<10% LSI, %BW, Norms; RFD
Muscle Endurance *(Total Leg Strength-TAS)* *Core, Hip, Knee, Ankle*	Isokinetics Force Plates	<10% LSI, %BW, Norms
Functional Tests[29–35]	Jump Tests Hop Tests T-Drill Hop Test Change of Lateral Direction Test LEFT	% - Height <10% -LSI; % Height; Norms <10 % - LSI <10% - LSI Norms

risk of reinjury. To accomplish this, testing must be more dynamic, sport oriented, and even unpredictable in nature. A neurocognitive testing battery must include measures of reactive response and incorporate sport-type reactions and movements. Testing must also be safe, easy to perform and measure, and require minimal equipment to complete. Neurocognitive testing is a way to measure various aspects of cognitive function non-invasively. These cognitive functions include things like reaction time, multi-tasking, attention, memory, and perception. Short tests designed to assess these functions produce objective measures that can be compared to standard scores or to an individual's baseline scores when available. Readiness to return to sport involves more than just the readiness of the musculoskeletal system. The neurocognitive system is a vital aspect of sport due to the constant use of cognitive functions such as reaction time and multi-tasking. Reaction time testing has been shown to be highly reliable and can be used to assess an athlete's cognitive and athletic ability.[36] Musculoskeletal injuries affect the neurocognitive system as well, so assessing and training this system can lead to better outcomes when determining readiness to return to play. Simon et al[37] demonstrated that the addition of a neurocognitive and anticipatory component to the traditional hop test series resulted in a statistical difference in performance and may improve functional return to sport testing. When comparing reactive versus preplanned agility testing, Serpell et al[38] demonstrated a difference in mean reaction time between elite and subelite groups in the way in which they contributed to perceptual skills and/or reaction ability. All of these factors combine to make the incorporation of neurocognitive training and testing elements crucial to advancing the effectiveness of RTP testing following ACL surgery and help to minimize the risk of reinjury as the athlete returns to competition.

PROPOSED TESTING SEQUENCE

The neurocognitive testing sequence we currently employ consists of a total of 8 tests in 3 categories: Blazepod tests, reactive shuttle run tests, and reactive hop tests. Testing is performed sequentially using 3 Blazepod tests, 2 reactive shuttle runs and finally 3 reactive hop tests. Adequate rest and recovery are allowed between tests. Based on the duration of the tests, the patients are permitted a 1-3 minute rest between tests. The testing measures are:

Figure 1. Lateral slide test with light targets (Blazepods Inc.)

Each target light is 60 inches apart.

Figure 2. Four corner target light test (Blazepods Inc.)

Each light target is 21 feet apart.

BLAZEPOD TESTS

BLAZEPOD LATERAL SLIDE TEST

The lateral slide test begins with four Blazepods positioned in a straight line five feet apart (60 inches). (Figure 1) The pods are configured in a randomized pattern using a single target color (blue) and five distracting colors (purple, green, orange, red, and yellow). One pod will light up the target color (blue) and the remaining three will be lit in distracting colors. Lights are set to transition on a hit and with zero-time delay between each transition. The athlete is instructed to begin in the center of the pods and will shuffle laterally targeting the blue light. Athletes are required to maintain a mini squat in an athletic position throughout the test and must avoid hopping or running between lights. Another individual will be tossing a soccer ball towards the target light. The athlete is instructed to catch the ball, tap the target light then toss the ball back while locating the next light and shuffling to it in a good athletic ready position. Once the test begins the goal is to tap as many lights as possible in 30 seconds. The total number of taps as well as average reaction time is calculated and scored following completion of the test.

BLAZEPOD 4 CORNERS TEST

The 4 corners reactive test begins with four Blazepods positioned in a square 21 feet (252 inches) apart. (Figure 2) As in the first test the pods are configured in a randomized pattern where one pod will light up the target color (blue) and the remaining three will be a distracting color (purple, green, orange, red, and yellow). Lights are set to transition on a hit and with zero-time delay between each transition. The athlete is instructed to begin in the center of the pods and locate the blue light. Another individual will be tossing a soccer ball towards the target light. The athlete is instructed to catch the ball, tap the light then toss the ball back while locating the next light. Once the test begins the goal is to tap as many lights as possible in 30 seconds. Total number of taps as well as average reaction time is calculated following completion of the test.

BLAZEPOD STANDING RIGHT VERSUS. LEFT REACTIVE TEST

The standing right versus left reactive test begins with four Blazepods positioned in a rectangle 36 inches in length and 12 inches wide. (Figure 3) The pods are configured in a randomized pattern so that any of the four can illuminate with only one at a single point in time. Lights are set to transition on a hit, with zero-time delay between each. In this test both blue and red are set as the target colors which represents the color in which the single pod will illuminate. The athlete begins in double limb stance with their feet shoulder width apart between the four pods performing fast feet. If the pod illuminates blue they are instructed to hit it with their left foot and if red, then hit it with their right foot. After each hit the pods will change color and the athlete must react to contact the next target color. Once the test begins the goal is to tap as many target lights as possible in 15 seconds. Total number of taps, number of errors, as well as average reaction time is calculated following completion of the test.

REACTIVE SHUTTLE RUN TESTING

REACTIVE 10-YARD T SHUTTLE RUN TEST

The reactive 10-yard T shuttle run test begins with 4 cones positioned in a “T”. (Figure 4) The individual cone is positioned 10 yards from the other three which are each 5 yards apart forming a “T”. The athlete begins at the individual cone and is instructed to sprint towards the cone directly in front of them. Once two thirds to the first cone, the tester will call out right or left, signifying the direction the athlete will begin to shuffle laterally towards. They are instructed to slide laterally 5 yards to the furthest cone, tap it, then reverse and slide laterally 10 yards to the furthest cone in the opposite direction and tap it. Once they tap the second cone, they reverse slide 5 yards back to the middle cone. Finally, after taping the middle cone the athlete will pivot and run 10 yards back to the starting position. The goal is

Figure 3. Standing Right versus Left Reactive target light test.

Targets are placed 3 feet apart and the participant is instructed to tap the right foot to the red target & the left foot to the blue target.

Figure 4. Reactive 10-yard T Shuttle Run Test.

This test involves a 10-yard run then a side shuffle to one direction for 5 yards & then in opposite direction for 5 yards and then turn and run back to start line.

to complete the test as quickly as possible. The time begins when they start their run and stops when they pass the final cone.

REACTIVE 10-YARD L RUN TEST

The reactive 10-yard L run test begins with 4 cones positioned in a "T". (Figure 5) The individual cone is positioned 10 yards from the other three which are each 5 yards apart. The athlete is instructed to begin at the individual cone and sprint towards the cone directly in front of them. Once two thirds to the first cone, the tester will call out which direction the athlete will go. Once the direction is called, the athlete will turn in the direction named and sprint around the far cone. To finish the test the athlete will sprint back to

Figure 5. Reactive 10 Yard L Run Test.

This test is performed with a 10 yard straight run then a turn to instructed direction for 5 yards and then a turn back to start position.

the middle cone, pivot and then sprint back to the starting position, completing the "L". The goal is to complete the test as quickly as possible. The time begins when they start their run and stops when they pass the finally cone.

REACTIVE HOP TESTING

REACTIVE SINGLE LIMB HOP FOR DISTANCE

The reactive single limb hop for distance test begins with the athlete standing on one limb. The athlete is instructed to hop forward from the starting position as far as possible. (Figure 6) While in the air the tester will call out right or left designating the foot in which the athlete is required to land on. The goal of the test is to hop as far as possible and land solidly on the designated leg. Athletes must stick the landing for 2-3 seconds for the test to count. Three consecutive repetitions are performed, and the distance is averaged. The distance is measure from the starting line to the back of the landing leg heel.

REACTIVE SINGLE LIMB CROSS OVER HOP FOR DISTANCE

The reactive single limb cross over hop for distance test begins with the athlete standing on one limb. The test begins with the athlete hopping as far as possible off the single limb. While in the air the tester will call out the foot in which the athlete is required to land on, either left or right, crossing the center line of the testing field. (Figure 7) They will then complete the sequence by completing two more cross over hops on the same limb. The athlete is instructed to hop as far as possible with each hop and stick the final landing for 2-3 seconds. They will complete three consecutive repetitions and take the average distance between each test as the final score. The distance is measure from the starting line to the back of the athlete's heel at the final hop.

REACTIVE SINGLE LIMB ALTERNATING CROSS OVER HOP FOR DISTANCE

The reactive single limb alternating cross over hop for distance test begins with the athlete standing on one limb (Figure 8). The athlete is instructed to hop forward as far

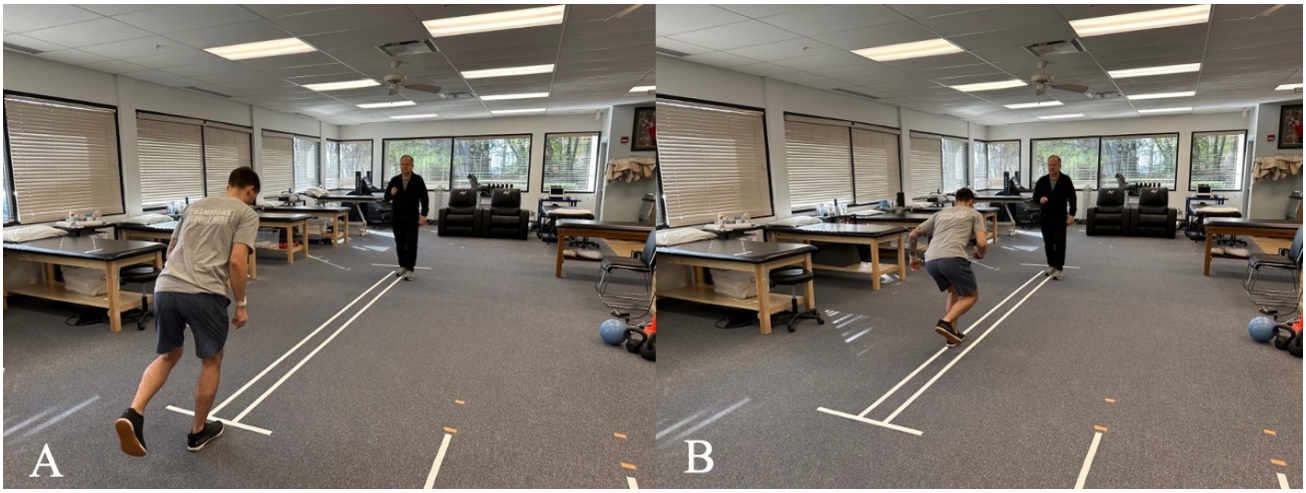

Figure 6. Reactive Single Leg Hop for Distance Test.

The participant stands on one foot and hops outward – as the participant hops, they are instructed which foot to land on.

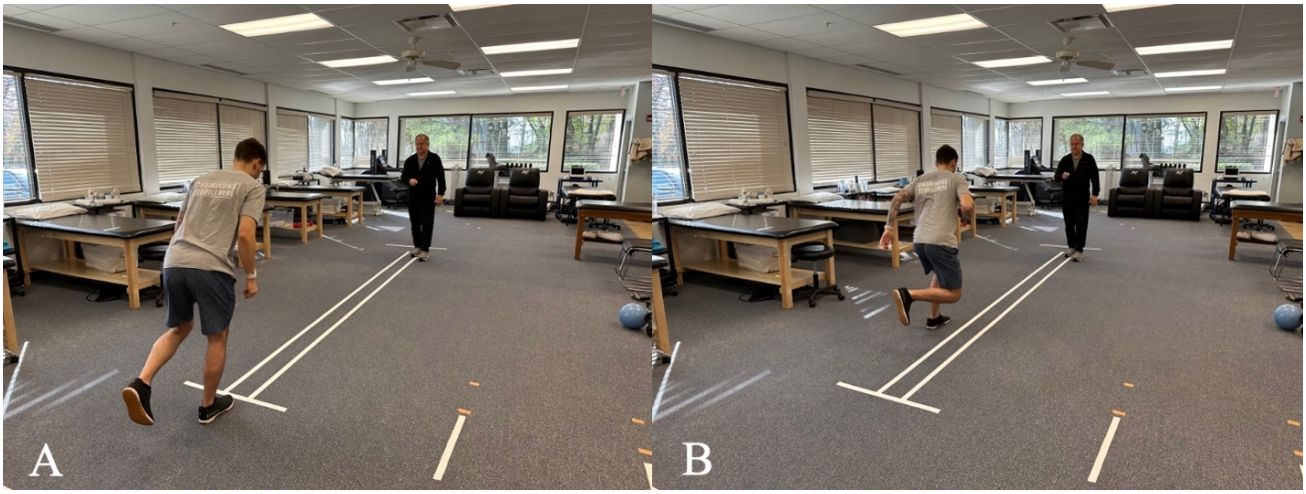

Figure 7. Reactive Single Limb Cross Over Hop for Distance Test.

The participant stands on one foot and hops outward – as the participant hops, they are instructed which foot to land on and they must cross over the center tape. They will then complete the sequence by completing two more cross over hops on the same limb.

as possible. While in the air the tester will call out a foot on which the athlete is required to land, either left or right. The athlete will then complete the sequence by performing two more cross over hops successively on alternating limbs. The athlete is instructed to hop as far as possible with each hop and stick the final landing holding for 2-3 seconds. They will complete three consecutive repetitions and take the average distance between each test. As with the other tests the distance is measure from the starting line to the back of the athlete's heel.

Videos of the drills and tests in this manuscript can be found here: VIDEO FOLDER.

LIMITATIONS

Although these are examples of some of the tests that are currently being used clinically because of ecological validity, nevertheless, we have to acknowledge the limitations of these tests. The tests have not been tested for reliability, validity or predicative validity regarding follow-up effectiveness for athletes to return to play, return to performance or prevention of reinjury.

CONCLUSION

The current state of RTP testing following ACL surgery is inadequate and does not reflect the true unpredictable, dynamic environment athletes are returning to. Not only is there a need for better utilization of RTP testing for predicting readiness, the significant incidence of reinjury must also be drastically reduced. These needs require both an improvement in the type of tests utilized and the overall use of subjective, objective and functional RTP testing in determining readiness to resume unrestricted activity. It is our hope that presenting this theoretical model for the use of neurocognitive testing in assessing athletic readiness that

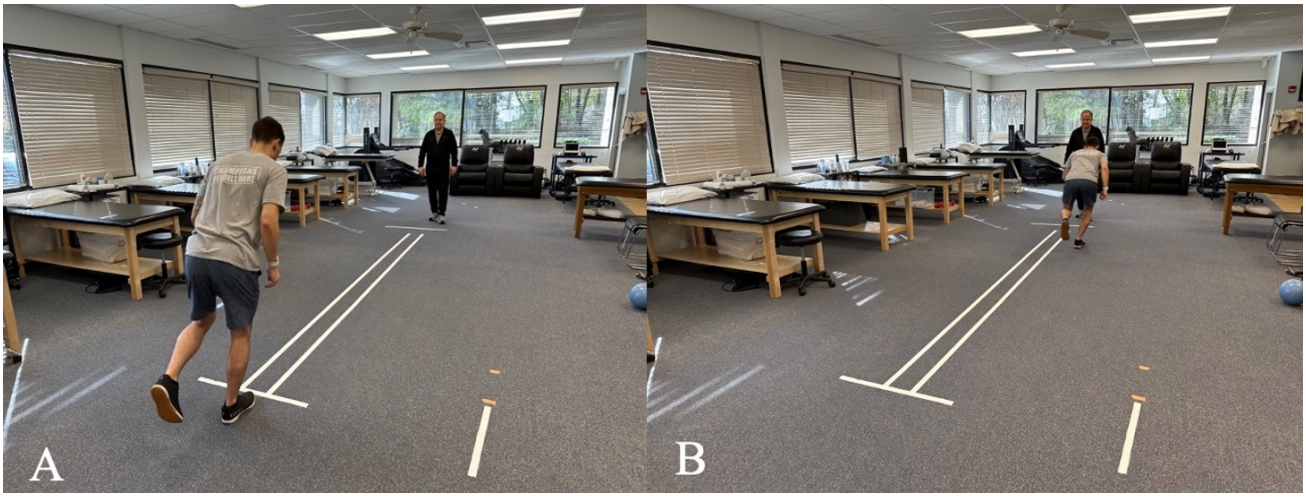

Figure 8. Reactive Single Limb Alternate Cross Over Hop for Distance Test.

The participant stands on one foot and hops outward – as the participant hops, they are instructed which foot to land on and they must cross over the center tape. The athlete will then complete the sequence by performing two more cross over hops successively on alternating limbs.

more critical thought will be placed on the type of testing needed to help determine when an athlete is capable of returning to sport. Also, the use of a more dynamic testing battery may decrease the reinjury rates when an athlete is cleared for participation.

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