Designing a Return to Activity Protocol for a Proximal Hamstring Rupture in a Collegiate Heptathlete: A Case Study

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Abstract

There are few return-to-activity protocols and functional tests specifically designed for a proximal hamstring rupture for athletic trainers to follow when clearing an athlete for return to activity. To address this problem, the purpose of this study is to describe and evaluate a return to activity protocol that includes functional testing for a post-surgical proximal hamstring rupture to assess readiness for return to activity. This case study collected data from a 20-year-old, 6ft 2in, 185lb (87.9 kg) collegiate heptathlete that ruptured his proximal hamstring that required surgical treatment. The student athlete's (SA) return to activity process is evaluated and explained. The SA went through numerous function tests to determine return to activity status. The first testing session was conducted 8 months post-surgery. He was then re-assessed 4 months later. During testing, the SA also wore accelerometers to gather more quantitative data to identify gait abnormalities due to the injury. The first round of testing revealed greater strength in his left (affected) leg compared to his right (unaffected) leg. The SA was not able to complete all the tests during the first round of testing due to muscular fatigue and soreness, suggesting low muscular endurance at that point in time. Thus, he was not cleared to return to activity and continued to do rehabilitation exercises to increase the endurance of the hamstring muscles. The second round of testing was completed 4 months later which revealed that he had gained endurance in the hamstring muscles and his strength had increased. At this point, he was cleared for full return to activity. This return-to-activity protocol with specific functional tests could serve as a template for other athletic trainers who are seeking to return an athlete to full activity after suffering a proximal hamstring rupture (See Appendix I).

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Introduction

Background and Setting

Athletic trainers are key players in an athletes' return to activity. It is very important to understand what constitutes the return-to-activity process as an athlete who returns to activity too soon will be at increased risk of reinjury. There are four main components of the return to activity process: injury evaluation, surgery, rehabilitation, and functional testing (Prentice, 2017). All of these components play a huge role in the athlete's success when they return-to-activity. When returning an athlete to activity near the end of their injury, there is a rehabilitation protocol and a return-to-activity protocol that is followed for most post-surgical injuries. However, there are no published return-to-activity protocols that include functional testing for a proximal hamstring rupture. The purpose of this case study was to design an individualized return-to-activity protocol for a proximal hamstring rupture in a collegiate athlete that included functional testing.

Statement of the Problem

Schmitt et al. (2012), stated that there is little evidence suggesting a valid functional test to determine return to activity status after a hamstring injury. Currently, the return-to-activity protocol includes multiple functional tests that stress the muscle and provides quantitative data that can be compared to the unaffected leg. There are many studies on anterior cruciate ligament (ACL) tears and what functional tests are best when returning an athlete to activity (Davies et al., 2017, Wilk et al., 1994). When designing this return-to-activity protocol some of the tests done were taken from an ACL protocol because the tests stress the hamstring in addition to the ACL.

In addition to functional tests that stress the hamstring muscle strength there also needs to be tests that stress the deceleration phase, eccentric phase of the hamstring and single leg (SL) tests.

College heptathletes participate in almost every event in track and field. The majority of these events require jumping and single-leg power, necessitating the importance of stressing single leg tests for this particular athlete. As such, the testing protocol involved activities such as a single leg jump landing, hop test for distance and time, broad jump, vertical jump and triple hop. Heptathletes also require muscular endurance due to the nature of their competition; they are often competing over a two-day period with three events the first day and four events on the second day.

Research Aims

This case study's objectives are 4-fold: 1. injury evaluation, 2. surgical procedure, 3. rehabilitation, and 4. functional testing. This case study will help other athletic trainers if they ever have an athlete that has a torn proximal hamstring. Other athletic trainers can take the information seen in this study and adopt and adjust it to fit their athlete, if they have the same or a similar hamstring injury. The authors in this case study aimed to have this SA be cleared for return to activity by the end of the second round of testing (strength 5/5, no pain in any range of motion, and SA will be able to finish the second round of testing without fatiguing).

Approach to the Problem

The case study subject, a collegiate student-athlete did functional testing over a 3-day period. He performed the same warm-up and cool down each day. The first day was focused on jumping with both legs. Starting with the double leg jumps first helped develop confidence in the athlete to jump off both legs with great eccentric control (Davies et al., 2017). The second day focused on sprinting drills and the third day focused on single leg jumping. Over the course of the study, this student athlete completed several sport-related activities, including a single leg hop test for distance and time, broad jump, vertical jump, triple hop, as well as 20m, 60m, and 200m sprints. The athlete also wore a trunk-mounted micro-electrical measurement system (MEMS) containing a GPS antenna, accelerometer and gyroscope (STATSports Apex) during the testing (APEX, 2020). The unit was mounted between the scapula using a manufacturer provided vest. The SA also wore two ankle monitors from IMeasureU (IMU Sensor, 2019), each housing an accelerometer and gyroscope to measure forces transmitted through the feet and ankles.

Literature Review

Anatomy

Hamstring tendon injuries are among the most common musculoskeletal injuries in athletes (Belk et al., 2019). However, a traumatic rupture of the proximal hamstring origin is an uncommon injury (Rust et al., 2014). According to Rust et al. (2014), most frequent cause of a proximal hamstring tear is waterskiing. The most common injury to the hamstring is a hamstring strain to one of the three hamstring muscles. A muscular strain occurs when excessive stress is placed on the muscle tissue that results in separation or tearing of the muscle fibers or the tendon (Prentice, 2017). The three hamstring muscles are called the semimembranosus, semitendinosus, and the biceps femoris, which all originate at the ischial tuberosity. Figure 1 shows the semitendinosus muscle insertion on the medial surface of the tibia, the semimembranosus muscle insertion on the medial tibial condyle, and the biceps femoris muscle insertion on the lateral aspect of the head of the fibula (OrthoInfo, 2015). The closer the injury is to the ischial tuberosity, the more likely it is that the injury will take longer to heal because it sometimes involves the tendon, which often requires surgery. When an athlete suffers an injury, there is a return to activity process that is followed. Each athlete or patient will be different and will heal differently but it is very important to follow this process to return the athlete back to their sport. The first part of this process is an injury evaluation, second is surgery (if warranted), third is rehabilitation, and last is functional testing (Prentice, 2017).

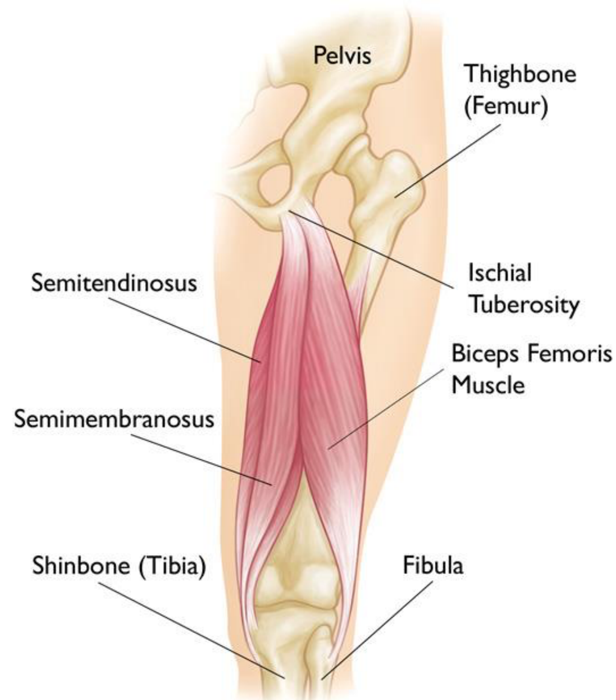


Figure 1. *Musculoskeletal anatomy of the hamstring muscle group. (Normal Hamstring Anatomy, 2015)*

Injury Evaluation

The injury evaluation includes a series of questions, observation, palpations, range of motion measurements, and strength assessments performed by the athletic trainer and/or the team physician (Prentice, 2017). With a muscle injury, the focus is on the palpation aspect to see if there are any "step-offs" (or divots) that you feel in the muscle, which would indicate a possible muscle tear. A range of motion evaluation is then performed, followed by manual resisted muscle tests to identify any decreases in strength (Prentice, 2017). An athlete presenting with decreased hamstring strength would indicate a hamstring strain. Strength is measured in a numerical value: grade 5 is normal-100% strength, grade 4 is good-75% strength, grade 3 is fair-50% strength, grade 2 is poor-25% strength, grade 1 is trace-10% strength, and grade 0 is zero-0% strength (Prentice, 2017). Each manual muscle test is performed on the unaffected leg in order for comparison. A hamstring strain, no matter how minor, is important to treat at the onset of injury; continuing to use the muscle without letting it heal can lead to a chronic hamstring tear over time (Belk et al., 2019).

Surgical Procedure

Some hamstring injuries can be rehabilitated, and the athlete can return to their sport quickly, while some more serious injuries require surgical treatment. Belk et al. (2019) stated that acute ruptures of the proximal hamstring tendon are often the result of eccentric overloading of the tendon whereby the hip is hyperflexed and the ipsilateral (or same side) knee is extended. If the tendon completely avulses off of the bone, then it must be surgically repaired because it will cause a significant disability without intervention (Belk et al, 2019). However, if the tendon is only partially torn off of the ischial tuberosity, then there may not be a need for surgery. In Belk et al. (2019) and Pipsoar et al. (2017), researchers agree that at least two tendons need to be ruptured and the tendon must be retracted ≥2 cm to warrant surgery.

The surgical repair is performed while the patient is prone position on the surgical table. A transverse incision along the gluteal crease is performed and the gluteus maximus is retracted to expose the hamstring tendon (Belk et al., 2019, Larson 2009, Piposar et al., 2017, Rust et al., 2014). This incision at the gluteal fold is about 5-8 cm long and can be extended distally as needed, particularly in chronic cases or if the tendon is retracted more than 2 cm (Rust et al., 2014). Next, the ischial tuberosity is located, and the sciatic nerve is protected before the hamstring tendons can be reattached to the ischial tuberosity (Larson 2009). In a chronic case, scar tissue may be present and will need to be debrided before proceeding. The hamstring tendons are then sutured to the ischial tuberosity using one to five suture anchors (Belk et al., 2019). Once the hamstring tendons are attached, the surgeon closed the gluteal fascia and finishes suturing the incision. Larson (2009) stated that a brace is typically worn for the first 6 weeks, with the knee locked at 90 degrees of flexion for 2 weeks, 60 degrees of flexion for 2 weeks and 30 degrees of flexion for the final 2 weeks. However, each surgeon has a different plan of action when it comes to knee braces and crutches.

Gait Abnormalities

When an athlete is injured and undergoes surgery, the neuromuscular control of that limb can be diminished, and physical training is required to regain proper control. The neuromuscular system monitors and controls constant changes in limb angular velocity (Wilk et al., 1994). Post-surgery, the body's ability to monitor changes during simple activities like walking is temporarily reduced; elite level athletes are also often concerned with the possibility of reinjury, so they will tend to compensate and create gait abnormalities. During the initial round of post-surgical functional testing, the athlete is expected to have muscle weakness as well as gait abnormalities and asymmetry. Clinicians anticipate some compensation with the athlete favoring the injured leg compared to the non-injured leg. Along with neuromuscular deficits, athletes may be apprehensive, fearing re-injury.

Once neuromuscular and psychological deficits are identified, the athlete undergoes rehabilitation exercises of the hamstrings and surrounding muscles to regain strength and control of both the involved and non-involved limbs. Following rehabilitation, a second round of testing is performed. It is anticipated that the athlete will show minimal compensation, having regained both strength and neuromuscular control as well as confidence in performing various movements.

Accelerometers complement the functional test being performed. These devices record accelerations (or impacts) near to foot during walking, running, jumping and change of direction task. They provide quantitative measurements of gait symmetry (see equation below). Gait symmetry is calculated by the percent difference between right and left impacts. Zero percent indicates complete symmetry. Positive values indicate an asymmetry with more impact experienced by the right foot. Negative values indicate the opposite.

$$Symmetry = \frac{(Right\ Impact - Left\ Impact)}{Average\ Impact} \times 100\%$$

In many cases, the clinician can detect asymmetry by observation. It may be visually clear that the athlete is "limping" or applying less force on the affected limb. Accelerometer data and symmetry scores give the evaluator a quantitative value that can be compared between activities as well as between measures made during the rehabilitation progression.

Rehabilitation

After surgery, the patient starts rehabilitation at or around week four post-op (Piposar et al., 2017). According to Larson (2009), rehabilitation for a chronic hamstring repair should start at week six and with the patient coming out of the brace and weaning off the crutches at week six. If the patient is an athlete, it is recommended to start basic range of motion rehabilitation exercise at week two with a physical therapist and/or an athletic trainer. The athlete or patient may come off of the crutches at or around week four if it is an acute repair (Rust et al., 2014).

Most rehabilitation protocols consist of phases and each phase focuses on a goal. The phases are split up by weeks, the first phase usually lasts until week 6. The first phase's focus is on protection of the repaired tendon and pain control. Then Phase II is from 6 weeks to 3 months and this phase's focus is to normalize gait, good control and no pain with functional movements including step up/down and squats. Phase III usually starts at month 3 and Phase IV usually starts at month 4 or 5 and its focus is on having good control and no pain with sport and work in specific movements (Piposar et al., 2017, The University of Wisconsin Health Sports Rehabilitation, 2017). Phase I, rehabilitation protocols consist of gentle range of motion, gait training, and core strengthening exercises in the first phase (Larson, 2009). In Phase II and III, strengthening exercises are done with both legs and in a short arc of motion. Later in Phase III, there will be single leg exercises that include both hip and knee movement (The University of Wisconsin Health Sports Rehabilitation, 2017). Phase IV is usually the last phase and where the focus shifts from rehabilitation exercises to return to sport functional drills (The University of Wisconsin Health Sports Rehabilitation, 2017). The key concept regarding the phases is the patient cannot progress to the next phase unless they have met all the requirements for the previous phase.

In phase I, patients perform quad sets, ankle pumps, abdominal isometrics, and passive knee range of motion with no hip flexion during knee extension and scar tissue mobilization (The University of Wisconsin Health Sports Rehabilitation, 2017). In phase II, patients begin non-impact balance and proprioceptive drills starting with double leg then progressing to single leg, stationary biking, gait training, and hamstring strengthening with the knee flexed, and hip and core strengthening (The University of Wisconsin Health Sports Rehabilitation, 2017). In Phase III the hamstring strengthening continues by adding in running drills, although there was no sprinting introduced until Phase IV. Also added is impact control beginning with two feet and progressing to one foot and single plane activities. In Phase IV patients continued to strengthen the hamstrings adding in Nordic hamstring curls and single leg deadlifts with dumbbells, for example. They also continue hip and core strengthening and started doing sport specific balance and proprioceptive drills.

Functional Testing

Testing Protocol. When the patient moves into phase IV of the rehabilitation protocol, they begin to focus on sport specific activities (The University of Wisconsin Health Sports Rehabilitation, 2017). Before they are cleared to return to activity, they must pass a group of functional tests. These tests assess endurance, strength and overall ability to perform at the same level as the unaffected leg, keeping in mind which leg is the dominant leg (Piposar et al., 2017). For a proximal hamstring repair, tests would be done that stress hamstring strength and deceleration and single leg movements. Schmitt et al. (2012), stated that there is little evidence suggesting a valid functional test to determine return to play status after a hamstring injury. The patient goes through multiple tests that stress the eccentric phase of the hamstring as well as hamstring deceleration and strength for this return to activity protocol. For example, the single leg hop test for distance compares strength of the uninjured and injured leg. Sprinting tests that force the patient to slow down fast at the end are used to evaluate deceleration of the hamstring muscle. The patient typically performs SL hop tests for distance and time, broad jumping, vertical jumping, and triple hop tests. These tests compare the strength power of each legs as well as engage the hamstrings. Another test that can be done is testing the peak hamstring strength with a Biodex machine, an isokinetic dynamometer, used to measure the isokinetic strength of a particular muscle (Feiring, 1990, Piposar et al., 2017). The use of accelerometers can supplement performances in the various tests. When worn attached to the ankle, they estimate ground impacts with each foot strike. Right to left asymmetry can then be used to identify possible compensation of the injured limb during testing. It is expected that the patient will show asymmetry during the first round of testing. It is hoped that by following the rehabilitation protocol, the asymmetry diminishes as the patient improves the functional test scores.

Jumping Tests. Patients typically progress through a series of jumping tests, starting with both legs and then working towards single leg jumping. Starting with the double leg jumps first will help develop confidence in the athlete that they can jump off both legs with great eccentric control (Davies et al., 2017). In the final phase of hamstring rehabilitation, the focus is on functional movements and eccentric strengthening in the lengthened state (Schmitt et al., 2012). Schmitt et al. (2012) stated that there is little evidence suggesting a valid functional test to determine return to activity status after a hamstring injury. It is important to stress the muscle in its eccentric phase which is when the muscle is forced to work while being elongated (Prentice, 2017). Both hip flexion and knee extension must be incorporated when testing the hamstring at its true functional length. Thus, jumping tests are important when evaluating hamstring functionality (Schmitt et al., 2012).

Sprinting Tests. A highly effective way to stress hamstring deceleration is sprinting drills; this causes the athlete to engage the hamstring and then as they slow down abruptly it puts stress on the hamstring because the hamstring is forced to work in an eccentric range of motion. The sprinting drills were important in this return to activity protocol because it stressed the eccentric phase as well as stressed the athlete's endurance. If the athlete is not able to keep up and they begin to fatigue quickly, this can predispose them to reinjury. When creating this return to activity protocol for this athlete it was important to have a fatigue factor in the terminal phase of clinical testing as well as tests that stimulate a real-case sport activity scenario (Davies et al., 2017).

Summary

When an athlete sustains an injury, there is a return to activity process that must be followed to help get the athlete back on the field, court, or track. It is very important to understand what goes into a return to activity process because if an athlete returns to activity too soon, then there is an increased risk for reinjury. There are four main components of the return to activity process which are injury evaluation, surgery, rehabilitation, and functional testing (Prentice, 2017). All of these components play a huge role in the athletes' success back on the field. The most important aspect of a return to activity process is the rehabilitation and the functional testing. These two go hand in hand and one cannot do one without having done the other. That is, the effectiveness of the rehabilitation program cannot be evaluated without testing and testing is not warranted unless the athlete has undergone rehabilitation activities. If the athlete has not been doing rehabilitation that will help strengthen the hamstring or the athlete returns to play too soon, the door to possible re-injury may be opened. If functional testing does not reveal positive comparisons between the surgical and non-surgical leg, an athlete should not return to activity and should do more rehabilitation. Belk et al. (2019) states that over 90% of patients undergoing repair of a complete or partial proximal hamstring tendon tear can be expected to return to sport regardless of the tear type.

Methods and Materials

Injury Evaluation

This case study was done on a 20-year-old, 6ft 2in, 185lbs male heptathlete who was diagnosed with a proximal hamstring rupture. The student athlete had originally injured his left hamstring when performing a 60m dash during competition. He stated his pain was in the muscle belly of the biceps femoris. Initially when the SA injured the hamstring, muscular strength was evaluated as a grade 4/5 with pain in the hamstring. Then before the first round of testing the athlete was back to a grade 5 with no pain. SA then did rehabilitation exercises to strengthen the muscle over the course of ten days. He then began light weight room exercises and a progressive running protocol though the next month. SA continued maintenance rehabilitation exercises and did not complain of any more pain. Approximately six months after the initial injury, the SA went water skiing and landed "hard" on a wave. The SA stated that he felt a "pop" then located his pain to under his gluteal muscles. He stated that the pain was the same pain that he felt with his previous hamstring injury six months prior. SA presented the next couple of days with swelling and discoloration on the back of his left leg by his hamstring and gluteal muscles. Discoloration was identified by a picture taken with the SA's cell phone. He then saw a Kinesiologist who worked with him through this pain. The Kinesiologist stated he was healing well. He returned to campus and continued rehabilitation to strengthen the hamstring. He was participating in practice and was pain free with no limitations on performance or function.

Two months after the water-skiing incident, the SA participated in a pole vault training session that was described as "hard" (high training load). After the session, he began to notice some discomfort in his left hamstring again. The athletic trainers (ATC) placed him on a conservative rehabilitation program. He progressed and regained strength but was never able to compete or practice at the level that he needed. The SA could not sprint at 100% nor jump at 100%. At that point the ATC scheduled him to be evaluated by a physician. The physician suspected a proximal hamstring tear due to the amount of swelling and discoloration seen in the picture on the SA's cell phone. The physician ordered an X-ray and an MRI. The X-ray was negative for a fracture and the MRI showed evidence of a full thickness tear of the left hamstring tendon, involving all three of the hamstring muscles (semimembranosus muscle, semitendinosus muscle, and biceps femoris muscle) that originate at the ischial tuberosity. There was also a mild distal retraction of the tendon of about 2.4 cm. This was unexpected as the SA had been able to engage in near-full participation in the weight room and at practice. The SA was then referred to the orthopedic surgeon for a surgical consult. The physician discussed possible treatment via Platelet-Rich Plasma injection but wanted the orthopedic surgeon's opinion first.

Surgical Procedure

Upon consultation, the orthopedic surgeon recommended surgery to reattach the proximal hamstring to the ischial tuberosity. The orthopedic surgeon stated that if the SA was not an athlete, then surgery was probably not necessary. The surgeon also commented that it was very rare to see this type of injury in a person this young and that he usually only sees this type of injury in the older population. The main reason for this surgery is because the patient is an athlete, needing to compete at a higher level than he was able to do at that point.

The SA had surgery in approximately six months after the original injury and one month after the pole vault training session. Following surgery, the surgeon stated that this was a chronic hamstring rupture and there was a large amount of scar tissue around the tear. The SA was placed in a rehabilitative functional knee brace after surgery. The protocol followed was identical to that described in the Literature Review (see “Rehabilitation” and “Functional Testing”).

MEMS Data Collection

During the functional testing the SA wore a trunk-mounted micro-electrical measurement system (MEMS) containing a GPS antenna, accelerometer, and gyroscope (STATSports Apex) (see Figure 2). The unit was mounted on the back, between the scapula using a manufacturer-provided vest. The Apex unit was used to evaluate the athlete’s running speed, acceleration and deceleration, impacts, and step balance. The athlete wore two ankle monitors from IMeasureU each housing a Blue Trident sensor (accelerometer and gyroscope). They were strapped around each ankle above the medial malleolus (IMU Sensor, 2019). The sensors and IMeasureU software measures impacts experienced on the right and left leg, the attenuation on both legs, gait disturbances and asymmetries, and total steps (IMU Sensor, 2019). The benefit of these units is that they will provide more quantitative data for use in his return to activity progression. Functional testing using the wearable technology devices was done eight months post-surgery then again four months later. This data aided the ATC in making more quantitative evaluations concerning return to activity and make better judgements on the effectiveness of the return to activity protocol success.

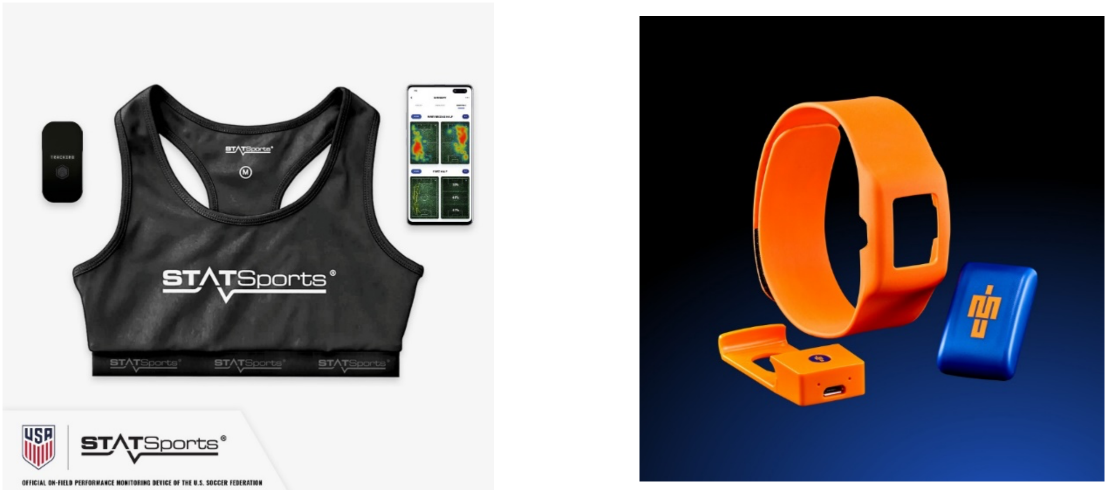


Figure 2. *STATSports Vest & Sensor, left and IMeasureU Blue Trident Sensor, right (APEX, 2020, IMU Sensor, 2019).*

Daily Testing Plan

Tables 1 and 2 illustrate the plan for the functional testing for this SA. The testing was done over the course of 3 days. Each day consisted of the same warm-up and cool down followed by stretching and 20 minutes of icing (see Table 2). The explanation of each functional test is below. The athlete was asked at the beginning and end of each day to rate their pain level from 0-10, 0 being no pain at all and 10 meaning they are in so much pain an ambulance is needed. The SA was then asked if he had any comments on the pain he was feeling.

Table 1: *Overview of the three days of functional testing.*

Day 1-Inside	**Day 2-Outside**	**Day 3-Inside**
Pain Level at start: scored 0-10	Pain Level at start: scored 0-10	Pain Level at start: scored 0-10
Moist Hot Pack 15’	Moist Hot Pack 15’	Moist Hot Pack 15’
Warm-Up	Warm-Up	Warm-Up
Single Leg (SL) 9” Box Jump Landing	Range of Motion Measurements	SL Hop for Distance
Vertical Jump for Height	Quadricep Girth Measurements	SL 6m timed Hop
Broad Jump	20m Dash 50%, 75%, 100%	SL Triple Hop for Distance
T-Cone Agility Drill	60m Dash 50%, 75%, 100%	Crossover Hop for Distance
Cool Down – (Jog 2 laps)	Cool Down – (Jog 2 laps)	200m Dash 50%, 75%, 100%

Static Stretching Bilaterally – (Hamstring, Quadriceps, Glutes, Groin and Calves)	Static Stretching Bilaterally – (Hamstring, Quadriceps, Glutes, Groin and Calves)	Cool Down – (Jog 2 laps)
GameReady – (20 minutes on High Pressure)	GameReady – (20 minutes on High Pressure)	Static Stretching Bilaterally – (Hamstring, Quadriceps, Glutes, Groin and Calves)
Pain Level at End: scored 0-10	Pain Level at End: scored 0-10	GameReady – (20 minutes on High Pressure)
Comments from SA:	Comments from SA:	Pain at End: scored 0-10
		Comments from SA:

Table 2: *Warm-Up plan for each day.*

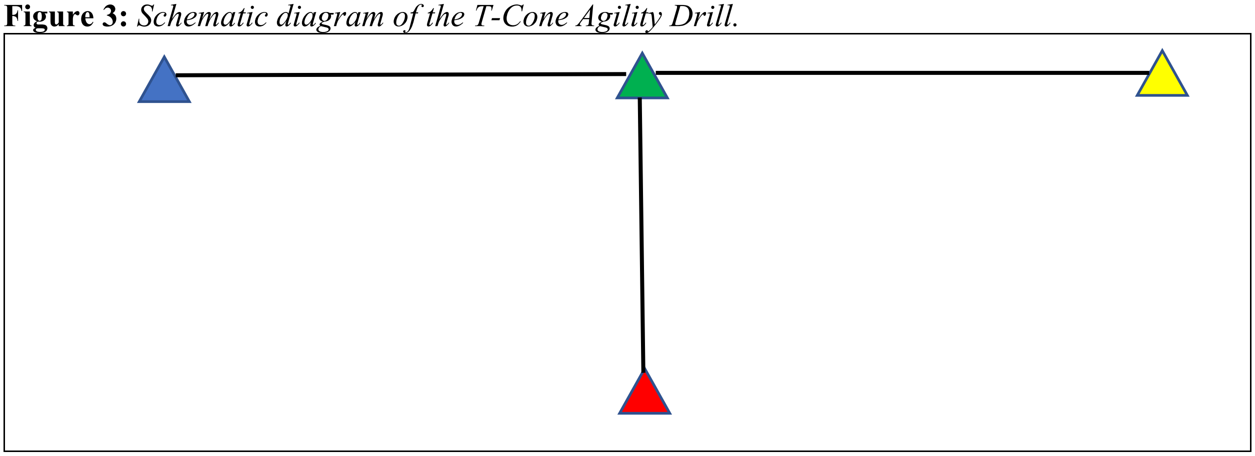
Warm-Up:
Jog 2 laps around indoor track or 1 lap around outside track.
High Knees- down and back 10m
Butt Kicks- down and back 10m
Carioca- down and back 10m
A-skips – 10m
B-skips- down and back 10m
A to C-Skips- 10m
High Skips- down and back 10m
Walking Lunges- 10m
The Greatest Stretch- 5m
Standing Hamstring Stretch- 10 seconds ballistic and 30 second hold
Leaning side to side hamstring stretch- 2x15 seconds each leg
Standing Quadriceps stretch- 2x15 seconds each leg
Walking Scoops- 10m
Jog- down and back 10m

Functional Tests

After a warm-up, the functional tests administered to the athlete were the Single Leg (SL) 9-inch box jump landing, vertical jump for height, T-cone agility drill, SL hop test for distance, SL 6m timed hop, SL triple hop for distance, crossover hop for distance, broad jump, and short sprinting drills at 20m and 60m. In addition to those tests, thigh girth and range of motion of the hamstring at the hip and at the knee were measured. The testing was three days long and he performed the same warm-up and cool down each day. He was also asked to rate his pain on a scale of 0-10 at the beginning and end of each day. He ended each day with ice to help prevent inflammation, using the Game Ready device (GRPro 2.1) for 20 minutes on high pressure (Cold and Contrast Therapy Units, 2020). Two of the testing days during the first session were held inside, on an indoor track and the other outside on the outdoor track. During the second session of testing all three days of testing were done inside on the indoor track.

T-Cone Agility Drill. This drill was used to assess the SA's acceleration and deceleration control. This drill focuses on body movement by changing directions constantly (see Figure 3). Left side: Start at the red cone and sprint to the green cone and turn left 90°. Then sprint to the blue cone, turn 180° around the blue cone, and sprint through the yellow cone. Right side: Start at the red cone, sprint to the green cone and turn right 90°. Then sprint to the yellow cone, turn 180° around the yellow cone, and sprint through the blue cone.

Figure 3: *Schematic diagram of the T-Cone Agility Drill.*



Range of Motion and Thigh Girth Measurements. Girth measurements of the quadricep muscles were taken to see if there were any significant strength deficits. A tape measure was used to measure the circumference of the thigh in inches at 9" above the patella, 6" above the patella, and 3" above the patella. For range of motion measurements, a full circle universal plastic goniometer was used. For hip flexion and extension, the axis of the goniometer was placed at the greater trochanter, with the moving arm parallel to the femur and the stationary arm parallel to the midline of the abdomen as prescribed by Prentice (2017). For knee extension and flexion, the axis of the goniometer is parallel with the lateral condyle of the femur, the stationary arm is parallel with the femur and the moving arm is parallel to the fibula (Prentice, 2017). The normal degree of motion for hip flexion is 125°, knee flexion is 140°, hip extension is 10°, and knee extension is 0° (Prentice, 2017). Directly after most lower extremity surgical procedures in most patients, there is decreased quadriceps strength, which can be objectively assessed with a girth measurement. It is very common for the dominant leg to be a bit larger due to its preferred use by the person. The next measurement was range of motion, this was taken to see if the SA could work through all ranges of motion.

Jumping Tests. Multiple tests were put together that stress the eccentric phase of the hamstring as well as hamstring deceleration (see Figure 4). The single leg hop tests, vertical jump tests, and the broad jump test stress both the eccentric and deceleration phases as well as activating the gluteus maximus, gluteus minimus and gluteus medius. Activating the gluteus muscles will prevent valgus drop (or inward caving at the knee) when the SA lands.

Hop Test Guidelines			
SL Hop for distance	***SL 6m timed Hop***	***SL Triple Hop for distance***	***Crossover Hop for distance***
Stand on one limb and Hop as far forward as you can, landing on the same limb.	Perform large single legged hops in series over 6 meters.	Perform 3 successive hops as far as possible & land on the same leg.	Perform 3 hops as far as possible crossing over the marking on each hop.

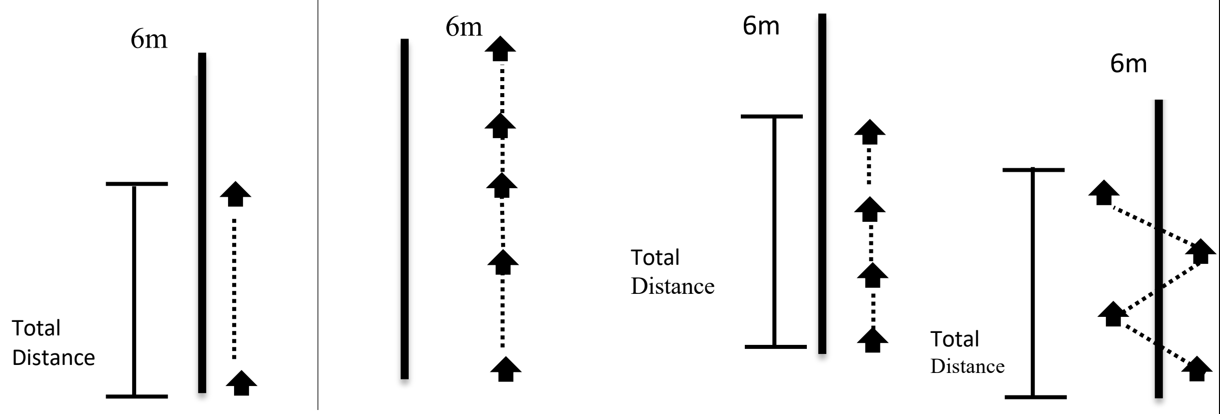


Figure 4: Hop Test Guidelines: Instructions for how each hop test is to be performed *(Functional Testing Guidelines for ACL Reconstruction PDF, 2015).*

Sprinting Tests. With this athlete being a heptathlete, many drills can be effective. However, until he actually starts sprinting and jumping, his readiness to return to sport fully is not known. The SA performed three different sprinting drills one at 20m, 60m, and 200m. At each of these distances, trials were completed at 50%, 75%, and 100% of maximum perceived effort gaged by the SA themselves. It was expected that there would be an increase in speed from the 50% to 75% with the first and second round of testing. The sprinting drills at 100% speed should also show his maximum speed and we should see an increase in speed during the second round of testing.

Results

The Results section presents data obtained during the first and second testing sessions. Specific tests performed each day are described followed by the testing results.

Testing Session 1

T-Cone Agility Drill. For the T-Cone Agility drill, when the SA had to plant on the affected leg, it was observed that the SA took longer to turn around the cone then when he planted on the unaffected leg. This showed that the SA had some hesitation, compensation, and decreased confidence in the affected limb. The T-Cone Agility Drill showed that the right side averaged to be faster than the left side (Table 3).

T-Cone Agility Drill		
	Unaffected Leg-Right	**Affected Leg-Left**
Trial 1	**4.82 sec**	**4.90 sec**
Trial 2	**4.72 sec**	**4.70 sec**
Average	**4.77 sec**	**4.80 sec**
Comments:	When the SA had to plant on the affected leg, I observed that the SA takes longer to turn the cone then when he plants on the unaffected leg.	

Table 3. Results of the T-Cone Agility testing for session 1.

Range of Motions and Thigh Girth Measurements. In the first round of testing there were not significant differences in girth measurements or in range of motion measurements (Table 4). The left (affected) side had a larger girth measurement than the right side. The range of motion for the right side (unaffected) was very similar to the suggested degree of motion. The left was slightly decreased compared to the right, but it was all close to the suggested degree.

Range of Motion Measurements				
	Hip Flexion	**Knee Flexion**	**Hip Extension**	**Knee Extension**
Unaffected Side-Right	**124°**	**140°**	**17°**	**0°**
Affected Side-Left	**128°**	**130°**	**20°**	**0°**

Thigh Girth Measurements			
	Unaffected Side Right	**Affected Side Left**	**Difference**
9" Above Patella	**23"**	**23"**	**0"**
6" Above Patella	**21 ¼"**	**21 ¾"**	**½"**
3" Above Patella	**17 ¼"**	**17 ½"**	**¼"**

Table 4. Results of the range of motion and limb girth evaluations.

Jumping Tests. The first round of single leg hop testing showed that the athlete's strength was comparable to both legs and that he could work through the eccentric range of motion (Table 5). It also showed that his left leg was stronger than his right. This athlete is left leg dominant so he will always be stronger on the left compared to the right. The fact that his strength was comparable shows us that he was ready to return to sport fully based solely on his strength measurements.

Single Leg Hop Tests			
		Unaffected-Right	**Affected-Left**
SL Hop for Distance	**Trial 1**	**2.52m**	**2.70m**
	Trial 2	**2.73m**	**2.79m**
	Average	**2.64m**	**2.74m**
SL 6-meter timed Hop	**Trial 1**	**2.16 sec**	**1.93 sec**
	Trial 2	**1.65 sec**	**1.73 sec**
	Average	**1.91 sec**	**1.83 sec**
SL Triple Hop for Distance	**Trial 1**	**7.63m**	**7.97m**
	Trial 2	**8.29m**	**8.33m**
	Average	**7.96m**	**8.15m**
Crossover Hop for Distance	**Trial 1**	**6.45m**	**7.21m**
	Trial 2	**7.49m**	**7.32m**
	Average	**6.97m**	**7.26m**
Comments:	SA had a 3-minute break between hop tests.		

Table 5. Results of the single leg hop testing.

Visual analysis of the hops indicated there was a valgus collapse on both sides when the athlete did his 9" box jump landing (Table 6). This indicated that the gluteus muscles were not activating to prevent the knee from collapsing in. The plan to fix this was adding in more gluteus activation exercises. He also complained of some pain when doing the box jump landing.

Single Leg-9" Box Jump Landing	
Able to land with a 5 second hold?	**Yes**
Good body mechanics (ball-midfoot landing, knees flexed, trunk midline)	**Yes**
Complaints of pain?	**Yes**
Comments: *Knee valgus collapse on both sides*	

Table 6. Qualitative assessment of the box jump landing

With vertical jumping the athlete did significantly better on the left than the right side (Table 7). When the SA was landing there also was some knee valgus collapse like in the box jump landing. His broad jump was measured from toe to toe. The coach was present and the athlete was able to increase the distance on the last jump because the coach told him to go more vertical.

Vertical Jump for Height			
	Trial 1	**Trial 2**	**Average Height**
Unaffected Side-Right	**60cm**	**57.5cm**	**58.75cm**
Affected Side-Left	**65cm**	**70cm**	**67.5cm**
Both Legs	**95cm**	**90cm**	**92.5cm**

Broad Jump	
Trial 1	**3.06m**
Trial 2	**3.04m**
Trial 3	**3.32m**
Average	**3.14m**
Comments	This was measured toe to toe. Coach was present and told the SA to go more vertical and that helped Trial 3 increase in distance.

Table 7. Results of the vertical jump testing

Sprinting Drills. The results of sprint speed testing are shown in Table 8. The SA was not able to complete the 200m sprint on the last day of testing due to being fatigued and feeling very sore. This showed that the athlete did not have the endurance to return to sport safely, with him being so fatigued and sore this could have predisposed him to reinjury. It also showed that he needed to be doing rehabilitation work that increased the amount of time the hamstring was being engaged.

Sprinting Drills		***Comments:***
20m Dash	**Trial 1**	*The SA's rest was the walk back to the starting line. The SA also had a 3-minute break between the 20m dash and the 60m dash. The SA did not complete the 200m dash in this first round of testing due to fatigue and having some soreness in the surgically repaired hamstring.*
50%	3.23 sec	
75%	3.26 sec	
100%	2.80 sec	
60m Dash	**Trial 1**	
50%	8.90 sec	
75%	7.49 sec	
100%	7.53 sec	
200m Dash	**Trial 1**	
50%	N/A	
75%	N/A	
100%	N/A	

Table 8. Results of the sprint testing. The SA was unable to perform the 200m dash tests during this session.

Testing Session 2

During the second round of testing the SA repeated the same tests from the first session of testing to keep the data as accurate as possible. The only difference was that during round two of testing, the second day was done inside due to weather complications.

T-Cone Agility Drill. In the first round of testing in the T-Cone Agility drill, the SA had some hesitations, compensation and decreased confidence in the affected limb (Table 9). This was seen when the SA planted the left leg and turned around the cone. During the second round of the testing, the SA did not show any hesitation, compensation or decreased confidence. The SA showed an increase in speed during the second round of testing as well. The times for both legs were almost exact, which shows there is no hesitation, compensation or decreased confidence.

T-Cone Agility Drill		
	Unaffected Leg-Right	**Affected Leg-Left**
Trial 1	**4.69 sec**	**4.63 sec**
Trial 2	**4.56 sec**	**4.58 sec**
Average	**4.62 sec**	**4.60 sec**
Comments:	The athlete ran much faster during this round of testing. Both legs are almost exactly the same average.	

Table 9. Results of the Session 2 T-Agility Drill testing.

Range of Motions and Thigh Girth Measurements. In the first round of testing there were not many differences in girth measurements or in range of motion measurements (Table 10). The range of motion measurements in this second round of testing were less than the first round of testing. This may be due to soreness from practice the day before testing, which can hinder range of motion the following day. However, every range of motion was within the normal limits. The girth measurements were almost even on both sides. This suggests that the SA should not have any large strength deficits and should be close to the same on both sides.

Range of Motion Measurements				
	Hip Flexion	**Knee Flexion**	**Hip Extension**	**Knee Extension**
Unaffected Side-Right	**133°**	**136°**	**21°**	**0°**
Affected Side-Left	**140°**	**135°**	**22°**	**0°**
Thigh Girth Measurements				
	Unaffected Side Right	**Affected Side Left**	**Difference**	
9" Above Patella	**23 ¾"**	**23 ½"**	**¼"**	
6" Above Patella	**21"**	**21"**	**0"**	
3" Above Patella	**17 ¾"**	**18"**	**¼"**	

Table 10. Range of motion and thigh girth measurements for session two.

Jumping Tests. The first round of testing showed that the athlete's strength was comparable on both legs and that he could work through the eccentric range of motion. The second round of testing showed some improvements in both the right and left leg. During this day of the testing the athlete complained of feeling a bit under the weather and the results from the jumping tests showed this may have affected the scores. In the SL Hop for Distance test the first round of testing was almost 0.20m farther then the second round of testing (Table 11). However, the SL 6-meter timed Hop test was faster on the right leg the second time around but not on the left leg. This showed that the right leg got a little bit faster and stronger over the training period. The SL Triple Hop for Distance and the Crossover Hop for Distance tests also showed a decrease in distance. This could have also been affected by the SA not feeling the best. This is shown in the Table 11 below.

Single Leg Hop Tests			
		Unaffected-Right	**Affected- Left**
SL Hop for Distance	**Trial 1**	**2.32m**	**2.33m**
	Trial 2	**2.63m**	**2.00m**
	Average	**2.47m**	**2.46m**
SL 6-meter timed Hop	**Trial 1**	**1.63 sec**	**1.93 sec**
	Trial 2	**1.73 sec**	**1.99 sec**
	Average	**1.68 sec**	**1.96 sec**
SL Triple Hop for Distance	**Trial 1**	**7.04m**	**6.62m**
	Trial 2	**7.22m**	**7.23m**
	Average	**7.13m**	**6.92m**
Crossover Hop for Distance	**Trial 1**	**6.93m**	**6.90m**
	Trial 2	**7.08m**	**6.81m**
	Average	**7.00m**	**6.85m**
Comments:	SA had a 3-minute break between hop tests.		

Table 11. Results of the single leg hop tests.

During the first round of testing while the SA was doing the Single Leg-9inch Box Jump Landing, there was an obvious knee valgus collapse on both sides. With the additional training the SA still had a valgus collapse, but it was less obvious from the observer's point of view (Table 12). This showed that the gluteus muscles were firing more effectively. There also was no pain felt during the second round of testing.

Single Leg-9" Box Jump Landing	
Able to land with a 5 second hold?	**Yes**
Good body mechanics (ball-midfoot landing, knees flexed, trunk midline)	**Yes**
Complaints of pain?	**No**
Comments: *Knee valgus collapse on both sides but much less obvious then the first round of testing. No complaints of pain this time around.*	

Table 12. Qualitative assessment of the 9" box jump landing test.

For the vertical jump and broad jump tests the SA did not get a score that was better than the first round of testing but the 2nd jump on both was higher and longer than the first round of testing (Table 13). The first round he had much more of a valgus collapse while landing. Although the average was a little less than the first round, the SA had much better form and control on the jumping and landing this time.

Vertical Jump for Height			
	Trial 1	**Trial 2**	**Average Height**
Unaffected Side-Right	**48.26 cm**	**50.8 cm**	**49.53 cm**
Affected Side-Left	**66.03 cm**	**71.12 cm**	**68.57 cm**
Both Legs	**88.9 cm**	**77.47 cm**	**83.18 cm**

Broad Jump	
Trial 1	**3.08m**
Trial 2	**3.15m**
Trial 3	**3.16m**
Average	**3.13m**
Comments	**The average was a little less than the last round of testing. Athlete has better form and control this time around.**

Table 13. Results of the vertical jump and broad jump testing.

Sprinting Drills. The SA was able to complete the 200m sprint on the last day of testing this time (Table 14). This showed that the athlete was able to gain muscular endurance over the past couple of months that he did not have during the first round of testing. The additional training and rehabilitation that the SA did helped a great amount.

Sprinting Drills		*Comments:*
20m Dash	**Trial 1**	*This was measured via a stopwatch. The SA's rest was the walk back to the starting line. The SA also had a 3-minute break between the 20m dash and the 60m dash. The SA was able to complete the 200m dash during this round of testing.*
50%	3.55 sec	
75%	3.20 sec	
100%	3.06 sec	
60m Dash	**Trial 1**	
50%	8.36 sec	
75%	7.89 sec	
100%	8.00 sec	
200m Dash	**Trial 1**	
50%	34.36 sec	
75%	31.38 sec	
100%	25.55 sec	

Table 14. Results of the sprint testing.

Symmetry Data

Table 15 shows the symmetry data for the warm-up lap performed prior to each testing session. Gait symmetry was measured as the percent difference between left and right peak acceleration during running. Positive values indicate that the right foot experiences greater impact. As can be seen, there was considerable positive asymmetry during session one. This indicates that the SA was likely favoring the left or injured leg. By the second session, asymmetry was reduced and eliminated on the second and third day of testing.

	Gait Impact Symmetry	
Testing Day	***Session 1***	***Session 2***
1	*26.7%*	*4.3%*
2	*21.7%*	*-0.5%*
3	*11.1%*	*2.5%*

Table 15. Gait impact symmetry for both testing sessions measured during the SA warm-up lap, prior to testing.

Asymmetry results for the short sprints are shown in Table 16. For session one, there was asymmetry on the right side during all sprints. This increased with running speed. During session two, the symmetry scores had returned to near zero.

	Gait Impact Symmetry	
Distance - Speed	***Session 1***	***Session 2***
20m 50%	*8.4%*	*0.2%*
20m 75%	*15.6%*	*2.4%*
20m 100%	*25.3%*	*3.1%*
60m 50%	*11.6%*	*1.1%*
60m 75%	*16.2%*	*1.6%*
60m 100%	*26.3%*	*2.6%*

Table 16. Symmetry measures during the sprint tests.

Symmetry during the long (200m) sprints was determined during session two only. These are shown in Table 17. As can be seen, relatively little asymmetry was noted at any of the speeds tested.

Distance - Speed	***Symmetry***
200m 50%	*4.6%*
200m 75%	*2.4%*
200m 100%	*2.9%*

Table 17. Gait symmetry measures from the 200m sprints.

The initial measures of symmetry indicate that the SA had considerable asymmetry toward the left side. This indicates that he was placing more force (or landing with greater impact) on his right leg versus the left. That is, he was favoring the injured leg. This asymmetry was reduced during the second testing session. By this point in the rehabilitation protocol, his gait symmetry had returned to values with the normal range.

Discussion

Project Outcomes and Results Analysis

The first round of testing showed us that the SA needed further rehabilitation and training to be at competition level. He showed deficits in muscular strength and girth. Single leg hop testing indicated a power deficit as well as balance issues on the affected side. During running activities, there was large asymmetries at all speeds. Following 4-5 months of continued rehabilitation, most deficits were corrected or eliminated, performance measures such as sprint speed and jump heights and distances, were improved and gait asymmetries returned to within expected values. After the athlete's second round of testing, which showed improvements through testing also in his form, he was cleared for competition by the athletic trainers and team physicians. Further, the SA's competitive performance was markedly improved compared to prior to injury. This suggests that the rehabilitation program employed (and described in the literature review) was quite successful in returning the SA to full competition. This study also indicates the need for comprehensive functional testing in evaluating and adjusting the rehabilitations program. By having these results in hand, athletic trainers can make proper modifications in training to meet the demands of activity. They can also be used to ensure a steady progression to return to activity. This will aid the athlete in making steady progression without raising the risk of reinjury.

Implications, Impacts, and Recommendations

It is important as an athletic trainer to be aware of your athlete and what stage of healing and rehabilitation the SA is in. If the athletic trainer pushes the athlete and they are not ready physically, then this can predispose them for possible reinjury. Every SA heals differently and has a completely different injury even if it may have the same name. The intent of this return to activity protocol was created as a base and may be used and adapted to any athlete or person with a proximal hamstring rupture. This SA competed in his first heptathlon less than one month after testing session two. He was able to finish the competition and had very minimal pain afterwards. The SA explained the pain as normal muscle soreness. The SA scored 300 points above his personal best and also had a personal best in three of the seven events. The SA then continued to do preventative exercises to reduce risk of reinjury. At the end of the Indoor Track and Field season (approximately six weeks post-testing), this SA competed at the Conference Championships Meet. The SA scored a total of 5350 points which broke the school record. It was 385 points more than the previous meet. He also had lifetime personal bests in five of the seven events and ended up winning a bronze medal.

This specific SA progressed a great amount from the first testing session to the second and was cleared to return fully to their sport. It would be interesting to see how other athletes returning to sport from a proximal hamstring tear do using this same protocol. A future project for this athlete particularly would be to see how he does if we were to do this testing again after the track and field season is completed. One revision that I would make to this project would be having an official measuring the jumps and a timing device to record the times of the sprinting tests would be beneficial. It would make the data more accurate. However, not everyone has access to these devices, so it is not necessary.

Limitations. Some limitations with the COVID-19 regulations required the SA to return to home for the spring and summer months. The original plan was to do the rehabilitation with him the entire time, post-surgery so that the data collected were consistent. He used a Physical Therapist back home and records received were not very specific but there were indications that he was meeting all of the goals set. When he returned to campus, he was considered a close contact to someone that tested positive for COVID-19 which delayed his start by 14 days.

Another limitation is that the jumping drills were not measured by an official. With the vertical jump test, I wish that I had used a jump mat to get more quantitative data. The timed drills were also not measured by officials or the same person for every timed drill. Due to the pandemic, we also did not have access to a Biodex machine, as suggested by most ACL return-to-play protocols, so we were not able to collect that additional data in relation to hamstring strength. We also acknowledge that the temperature outside will be very different in September than in January, which may potentially affect the data collected in an outdoor environment and effect the GPS data acquired. Finally, this athlete is left side dominant, which could suggest a small bias in our data when compared to the contralateral side. As an athletic trainer I also suggest that there be baseline data taken on each athlete if possible, to be able to compare throughout the rehabilitation process.

Dissemination Plan

This information could be useful to any athletic trainer that encounters a hamstring injury, specifically a proximal hamstring tear. There are numerous different journals that this information could be published in. For example, the Journal of Athletic Training, Athletic Training and Sports Health Care, International Journal of Athletic Therapy and Training, Journal of Athletic Medicine, Sports Health and the Journal of Sport Rehabilitation. The Journal of Sport Rehabilitation would be a great journal to publish this information in because this journal's focus is devoted to rehabilitation of sport and this information is based on rehabilitation aspect of this injury. Another journal that would be Sports Health or Athletic Training and Sports Health Care because these two allow case reviews or case studies to be published.

The National Athletic Trainers' Association (NATA) has many different seminars each year that this information could be presented in via a paper or poster. There is a yearly seminar with NATA that this could be presented at as well. In addition, each state is in a specific district within NATA, and they have their own smaller seminars in which this information could be presented via poster or presentation. NATA also has newsletters, an education journal and a blog that this information could be submitted to. This could be a great way to get a synopsis of this information out as a preview before it is submitted into a journal.

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Appendix I

Return to Activity Protocol for Proximal Hamstring Tears

Name: ____ **Date:** ___________

Injury: _________________________________ **Date of Surgery:** ________________

Affected Side: ___________________________ **Weeks Post Surgery:** ______________

Functional Testing Profile

Range of Motion Measurements				
	Hip Flexion	**Knee Flexion**	**Hip Extension**	**Knee Extension**
Unaffected Side-Right				
Affected Side-Left				

Thigh Girth Measurements			
	Unaffected Side Right	**Affected Side Left**	**Difference**
9" Above Patella			
6" Above Patella			
3" Above Patella			

Single Leg-9" Box Jump Landing	
Able to land with a 5 second hold?	**Yes or No**
Good body mechanics (ball-midfoot landing, knees flexed, trunk midline)	**Yes or No**
Complaints of pain?	**Yes or No**
Comments:	

Functional Testing Profile Cont'd

Vertical Jump for Height			
	Trial 1	**Trial 2**	**Average Height**
Unaffected Side-Right			
Affected Side-Left			
Both Legs			
Comments:			

Broad Jump	
Trial 1	
Trial 2	
Trial 3	
Average	
Comments:	

Single Leg Hop Tests			
		Unaffected-Right	**Affected- Left**
SL Hop for Distance	**Trial 1**		
	Trial 2		
	Average		
SL 6-meter timed Hop	**Trial 1**		
	Trial 2		
	Average		
SL Triple Hop for Distance	**Trial 1**		
	Trial 2		
	Average		
Crossover Hop for Distance	**Trial 1**		
	Trial 2		
	Average		
Comments:			

Functional Testing Profile Cont'd

Sprinting Drills		*Comments:*
20m Dash	**Trial 1**	
50%		
75%		
100%		
60m Dash	**Trial 1**	
50%		
75%		
100%		
200m Dash	**Trial 1**	
50%		
75%		
100%		

T-Cone Agility Drill		
	Unaffected Leg-Right	**Affected Leg-Left**
Trial 1		
Trial 2		
Average		
Comments:		