The influence of HUMAC training on balance and range of motion in an Achilles tendon repair patient: A case study

Nicole Harrison

Florida Southern College Exercise Science

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Faculty Advisor: Dr. Sara Terrell

Abstract

Introduction: A tear or rupture in the Achilles tendon may require surgery and extensive rehabilitation to fully recover. Balance training is an important aspect of rehabilitation of an Achilles tendon repair. The HUMAC balance board system provides multiple training programs as well as balance tests to utilize in a therapy program. Although, the influence of a 10-week HUMAC balance board training intervention on balance and range of motion (ROM) in an Achilles tendon repair patient was unclear. **Purpose:** The purpose of this study was to determine the influence of a 10-week HUMAC therapy intervention on balance and ROM in an Achilles tendon repair patient. **Methods:** One Achilles tendon repair patient who was receiving rehabilitation at a physical therapy clinic in central Florida took part in this study. The participant completed the HUMAC m-CTSIB and BESS testing weekly and utilized various HUMAC programs for balance rehabilitation at least twice a week. ROM was also measured. Descriptive statistics and t-tests with an alpha level of 0.05 were used in data analysis. **Results:** After the training, the average score for the pre-test on the m-CTSIB was 144.4 and declined to 142.8 ($p < 0.153$). The average number of errors for the pre-test on the BESS was 3.71 errors and declined to 1.71 errors ($p < 0.046$). Plantarflexion ROM increased to 32 degrees (23.1% change), dorsiflexion increased to 28 degrees (380% change), and inversion increased to 24 degrees (20.0% change). Eversion slightly decreased to 22 degrees (-8.3% change). **Conclusions:** Based on the results of the BESS, ROM measurements, as well as the path length and velocity aspects of the m-CTSIB, a 10-week HUMAC therapy intervention helps return a patient to normal functioning in an Achilles tendon repair therapy program.

Key Words: Achilles tendon; balance; rehabilitation; HUMAC; BESS

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Literature Review

Introduction

The Achilles tendon plays an important role in balance, walking, running, and many other lower body movements. A rupture of the Achilles tendon may require surgery. There are multiple methods utilized for surgical repairs, and the best surgical treatment method is often chosen based on the specific patient needs. However, all Achilles tendon rupture patients will need physical rehabilitation to regain strength, range of motion, balance capabilities, and more.

Balance involves a complex feedback system. The body has sensory receptors that function to input information, integrate it, and cause a motor output to occur. Many critical receptors for balance are located distally at the foot and ankle. An Achilles rupture results in reduced use of the ankle while it heals. During the rehabilitation period, it is important to train balance to regain critical sensory feedback.

Rehabilitation for an Achilles tendon repair can include traditional approaches to therapy such as neuromechanical and functional characteristics of injured versus non-injured legs, maximal voluntary contractions of surrounding musculature, and early weight-bearing versus non-weight-bearing programs.

A novel Achilles tendon therapy approach recently explored in research is using Wii Balance Boards for rehabilitation therapy. This board is considered cost effective, portable, and user-friendly (Guzman & Aktan, 2016). Using a Wii Balance Board or similar technology may be a viable rehabilitation technique to return a patient to their prior level of functioning.

Therefore, the purpose of this review of literature is to discuss the function of the Achilles tendon, explore mechanisms influencing balance, assess traditional rehabilitation techniques, and examine the role of technology such as the Wii Balance Board or the HUMAC Balance System in rehabilitation programs.

Achilles Tendon

The Achilles tendon is composed of fibrous tissue and connects the calf muscle to the calcaneus, or the heel bone. It plays an important role in running, jumping, and other movements involving the lower extremities. The Achilles tendon can rupture from a variety of movements and forces placed on it. An Achilles tendon rupture is defined as the tendon being torn fully or partially, usually behind the ankle (*Musculoskeletal: Achilles Tendon Rupture*, 2014).

Figure 1. Achilles tendon and surrounding musculature. The figure outlines the muscles of the calf and location of the Achilles (Google Images).

The Achilles tendon connects to the gastrocnemius and soleus (*Musculoskeletal: Achilles Tendon Rupture*, 2014), as seen in Figure 1. When the Achilles tendon pulls on the heel bone, the ankle plantarflexes, which is when the toes point down. The Achilles tendon also assists in pushing a person forward while walking or running. Achilles tendon ruptures occur often in athletes participating in sports requiring explosive acceleration or maximal effort, as well as in older individuals who lose flexibility (Barber, McGarry, Herbert, & Anderson, 2008).

An Achilles tendon rupture can occur from slipping movements, deep lunging movements, medical conditions, medication combinations, tendonitis, and more. Some symptoms that may occur after an Achilles tendon rupture is pain in the heel or calf and a feeling of not being able to control the movement of the foot upwards.

A rupture of the Achilles tendon is a serious injury - it may require surgery and will require a long rehabilitation process whether a surgical repair was the chosen treatment or not. Not only does strength of the surrounding musculature need to be improved after being in a cast, but range of motion and balance need to be reestablished due to the loss that will occur from not using that ankle for so long. Proper treatment of a rupture is vital to return to normal activities.

Balance

Balance is the ability to maintain the body's center of mass over its base of support (Watson & Black, 2008). Physical therapists can work with patients to achieve proper balance. After an injury, such as an Achilles tendon tear, balance training plays a key role in the rehabilitation program.

There are three main components to the sensorimotor control system that help the body maintain the center of mass over its base of support and are shown in Figure 2 (Watson & Black, 2008; Hoffman, n.d.). The first step of achieving balance is sensory input. Whether it be through

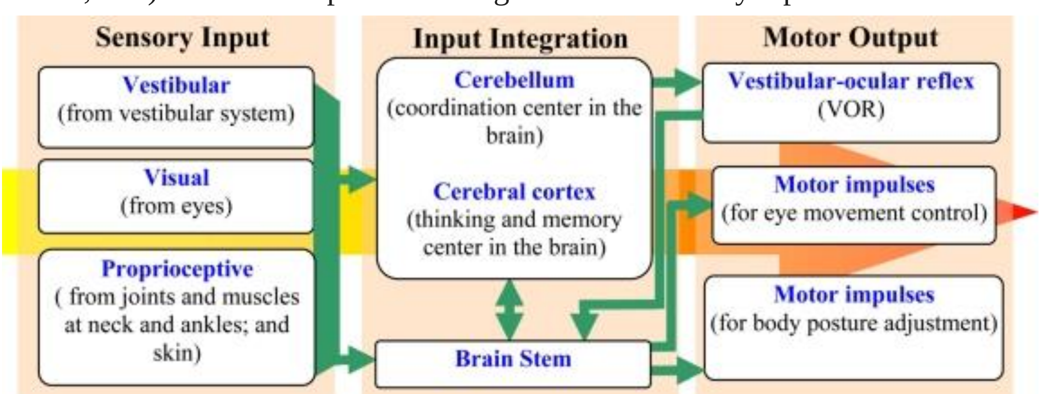

Figure 2. Sensorimotor Control System. This figure outlines the three step process that helps maintain balance. (Zeng & Zhao, 2011).

vision (sight), proprioception (touch) or the vestibular system (motion, equilibrium, and spatial orientation), the body acquires information to utilize. The eyes, muscles and joints, and vestibular organs are the parts of the body that contain these receptors to process information. There are sensory receptors in the retina in the eyes that process visual stimuli. In muscles and joints, sensory receptors respond to stretch or pressure (Watson & Black, 2008). These sensory receptors located distally in the feet and ankles input information when the Achilles or surrounding musculature are stretched or have pressure applied to them. The parts of the inner ear called semi-circular canals and otoliths also provide critical input. The semi-circular canals assist in keeping vision clear, and the otoliths are able to sense the position of the head relative to the body (Hoffman, n.d.).

The next step in the sensorimotor control system is integration, when balance information is sent to the brainstem where it is sorted and integrated with learned information from the past. The cerebellum and cerebral cortex provide that learned information to compare it to what is being received at that time. The information from the muscles and joints may override the visual system at times (Watson & Black, 2008). There may also be a need to rely on one system more than the other. For instance, when someone is walking in the dark, their visual system cannot contribute so their brain will use information from their legs and inner ear to keep their balance (Hoffman, n.d.).

Finally, as integration takes place, the brain stem sends impulses to muscles that control movement of the eyes, head, neck, trunk, legs, and more to allow the person to maintain their balance; this is the motor output process of the sensorimotor control system. With repetition, it becomes easier for these impulses to travel along the nerve pathway, a concept termed facilitation (Watson & Black, 2008). Pathway facilitation is the reason athletes practice the same movements so often - even if a movement is complex, the more it is repeated, the easier and more automatic it will become. All of these feedback mechanisms can be disrupted by damage to one or more of the components through disease, injury, or the aging process (Watson & Black, 2008). Thus, a torn Achilles tendon can disrupt the feedback mechanisms coming from the lower leg. Retraining sensory receptors of the lower leg is critical to restoring function in an Achilles tendon repair patient.

Furthermore, a study by Kenyon & Blackinton (2011) examined several individual constraints to movement. One constraint is action, where there could be impairments in the motor system that affect muscle tone and strength or range of motion. Another constraint is perception - this involves factors that affect or limit the internal registration or integration of sensory information. The person could have a decreased awareness of their body in space, or interpret visual information incorrectly. Lastly, cognition is a constraint to movement that relates to attention, emotions, or motivation. If a person has a fear of falling, they may be less likely to perform a movement that places them on one leg with a smaller base of support (Kenyon & Blackinton, 2011). Authors stated that physical therapists may not fully understand the impact of attentional issues on their patient's function and motor control, which may increase a patient's risk of a fall or decrease the impact of the therapy exercise. In the case of an Achilles rupture patient, the constraint to action will influence rehabilitation success. Patients may lack muscle tone, strength, and range of motion when they first begin therapy due to their leg being in a cast for weeks prior. They also may be fearful to perform certain movements, not wanting to risk re-rupture, contributing to the cognition constraint. Physical therapists must be aware of constraints when selecting balance exercises to perform, whether they be traditional or technologically advanced. Technology such as the Wii Balance Board may reduce constraints, especially to cognition, and facilitate better exercise outcomes.

Additionally, a study by Olchowik, Tomaszewski, Olejarz, Warchoł, Różańska-Boczula, & Maciejewski (2015) examined sensory and motor components of the body balance control system in men and women. The different tests included the Sensory Organization Test, which assessed body balance under various stimulations of the sensory system, and the Motor Control Test, which evaluated postural reactions in response to unexpected platform translations (Olchowik et al., 2015). Researchers determined that the human balance system can be affected by mental and physical fatigue, neurological disorders, physical exercises, body weight, BMI, age, and gender. The amplitude response of the right and left lower limb were both significantly dependent on gender, with men scoring higher on the medium and large translations while there was no gender difference for small translations. In the absence of visual information, women showed greater ankle-muscle activity and lesser hip-muscle activity in comparison to men. When automatic corrective responses were needed, the response amplitude for both limbs was greater for men (Olchowik et al., 2015). Men may be able to respond quicker to changes in the environment around them, but with more hip activation than ankle activation. This should be considered when observing performance of rehabilitation patients during balance exercises. A physical therapist must be aware that a male Achilles tendon repair patient may be able to perform better during quick reaction balance exercises due to the use of their hips to facilitate the movement more than their ankles, which would be the target area of training of the exercises. If the patient were a female, the therapist could be more confident that the balance exercises are targeting the ankle area, so gender must be considered.

The human balance system is a complex system that incorporates input from various components, requires brain integration and response, and action from muscles of the body. Rehabilitation exercises must incorporate exercises which facilitate challenges to the sensorimotor control system. Closed kinetic chain exercises such as standing on one leg, standing on one leg with ball toss, and taking away visual feedback are example exercises to train balance used in traditional rehabilitation programs, but additional considerations in exercise selection is warranted.

Concepts to Consider in Exercise Selection

Achilles tendon rehabilitation involves using a variety of exercise techniques and approaches to programming. Besides consideration of balance challenges, therapists must consider the duration of the exercise program and the timing and extent of weight bearing.

For example, a study conducted by Wang et al. (2013) examined the neuromechanical and functional characteristics of athletes' legs who had gone through Achilles surgery, comparing their injured leg to their non-injured leg and to the legs of non-injured athletes as controls. All athletes had maximum voluntary contraction (MVC) of the calf musculature measured. MVC's were assessed in plantarflexion, at the tibialis anterior, and during a hopping test and a balance test. Compared to the controls, the repaired leg had less rate of force development during explosive plantarflexion, less ROM during ankle dorsiflexion, a shorter one-leg hopping distance, and a lower star excursion balance test score (Wang et al., 2013). Since the average post-surgery time of these athletes was 6.7 months, the authors concluded that a 6-month physical therapy program is best to combat these deficits. The results showed that balance, explosiveness, hopping, and calf muscle activation are important aspects to train during therapy.

Exercises such as the star excursion balance test, double or single-leg hops, and calf raises could accomplish this.

Another study aimed to develop an appropriate progression of exercises for patients following an Achilles repair surgery (Mullaney et al., 2011). The researchers placed electrodes on the soleus and gastrocnemius of 10 participants to measure maximum voluntary isometric contractions (MVICs) and to measure EMG activity during eight therapeutic exercises of the lower extremities (Mullaney et al., 2011). The results of the testing concluded that toe raises elicit the least EMG activity out of all of the exercises, at 11% of MVIC. EMG activity was significantly higher than the others in the hopping exercise (128.9% MVIC), (Mullaney et al., 2011). This information allowed researchers to produce a therapy plan in three phases: Early (0-6 weeks) – 0-20% MVIC, toe raises; Intermediate (6-9 weeks) – 20-60% MVIC, balance board, prone ankle pumps, plantarflexion t-band, lateral step-up, walking; Late (>9 weeks) – >60% MVIC, single heel raise, and hopping (Mullaney et al., 2011). This plan illustrates a proper exercise progression for an Achilles patient to use in a physical therapy program, but when to start that program is still unclear. This study also indicates the challenges with weight bearing.

To explore weight bearing, 98 Achilles tendon repair patients participated in a study to determine the effect of weight-bearing as tolerated (WB) versus non-weight bearing (NWB) on daily activities (Suchak, Bostick, Beaupre, Durand, & Jomha, 2008). All subjects performed ankle range of motion (ROM) exercises daily after a 2-week post-op appointment, but patients in the WB group were encouraged to become fully weight bearing while the NWB group was instructed to use crutches for 4 more weeks (Suchak et al., 2008). At 6-weeks post-op both groups added higher difficulty exercises and at the 12-week visit, exercises were again advanced and a unilateral heel raise on the injured leg was added (Suchak et al., 2008). In conclusion, the study showed that at the 6-week visit, the WB group reported significantly better results in physical functioning and vitality. In the WB group, 43% of patients reported little to no limitations while only 9% of patients in the NWB reported none (Suchak et al., 2008). Earlier weight bearing was more beneficial to recovery and quality of life according to these results. In relation to balance, the longer a patient is non-weight bearing, the less familiar it becomes for nerve impulses to travel along a certain nerve pathway, referring back to the term facilitation. Therefore, earlier weight bearing allows for less time to lose the balance capabilities that have been engrained into the body through nerve pathways.

Another study looked into whether early rehabilitation is more effective than conventional rehabilitation in Achilles tendon repair patients (Kim, Choi, Jang, & Choi, 2017). Some patients were in a below the knee cast immobilization for 4 weeks' post-op before starting WB in a functional brace. The other patients were in a short leg splint for 2 weeks' post-op before starting WB in a functional brace. Both groups followed the exact same protocol, which consisted of single leg stance and single leg heel raise (Kim et al., 2017). The results of the study showed that the cast group took 4 weeks longer to return to work than the WB splint group, ($p < 0.032$). In the final follow-up at one year after surgery, the cast group scores on the AOFAS and ATRS were 89 points and 79 points, while the splint group scored higher with 93 points and 81 points, showing better functioning in the splint group (Kim et al., 2017). Early weight-bearing had a better outcome on return to work, unlike the results of the Suchak et al., (2008) study where there was no difference between groups.

Based on the results from these studies, it may be concluded that early weight-bearing and incorporating a progressive exercise program based on MVICs are the most effective approaches to rehabilitation in an Achilles repair. The Wang et al. (2013) and Mullaney et al.

(2011) studies found balance and explosiveness to be important aspects to include at some point in their exercise program. Although, the Mullaney et al. (2011) study only utilized 10 voluntary participants, which could have an effect on the external validity of their program, as they may not be representative of the entire population. The Suchak et al. (2008) and the Kim et al. (2017) studies both had the WB groups begin using their injured leg at 2 weeks, while the NWB groups began at 6 weeks or 4 weeks. The Kim et al. (2017) study also manually changed the degree of dorsiflexion on the brace by 10 degrees weekly, which could play a role in the earlier start for the NWB group. The Wang et al. (2013) study showed less ROM during dorsiflexion, so manually adjusting it would be beneficial. Both of these studies had outcomes of greater functioning and no limitations in the WB group. Overall, earlier weight-bearing in longer rehabilitation programs that include balance and hopping exercises seem to be the most effective approaches to rehabilitation in an Achilles repair. Traditional exercises have been successful in an Achilles tendon rehabilitation program, but the effectiveness of incorporating newer technology should be explored as well.

Balance Board Methods

One of the newest approaches to balance testing and therapy stems from a popular gaming system. The Wii and Wii Fit exploded in the world of gaming. The board was created for users to stand with sensors to collect data from their positioning, weight shift, and more to play games (Figure 3). Lately, research has been investigating the use of these types of boards for balance rehabilitation and balance assessment.

Figure 3. Wii Balance Board

A study conducted by Lange, Flynn, Proffitt, Chang, & Rizzo, (2010) assessed the usability of an interactive gaming system specifically focused on training weight shift in a controlled manner. They used an iterative design process and recruited four male stroke patients to participate. Participants played a game where they had to shift their weight to move a balloon to collect stars and avoid rocks for 4-10 minutes at a time (Lange, et al., 2010). They completed a Borg Scale RPE questionnaire after the game. The results indicated that the patients found the game to be equally as strenuous as typical physical and occupational therapy, but more engaging. Some participants explained that this treatment distracted them from the movements they were doing. Therefore, they were more likely to complete movements they were normally afraid of doing, even though their body was physically capable of it. In other words, patients admitted they would be holding themselves back if it was not for the distraction (Lange, et al., 2010). This technology was able to decrease the cognitive constraints that traditional rehabilitation exercises may struggle to eliminate. There will be future testing to continue this process before a prototype is solidified, but these results and feedback from participants have been helpful in furthering the research in this area.

Another study evaluated the feasibility of using the Wii Balance Board (WBB) to assess postural stability across three time points post-concussion and to assess validity of the WBB with other traditional measures such as the BESS and ImPACT tests (Merchant-Borna, et al., 2017). The nineteen participants took part in a data collection of baseline BESS and WBB data pre-concussion and then three and seven days post-concussion. For the WBB, they only assessed the double-leg eyes closed (DLEC) stance for data collection. Post-concussion, the participants completed the ImPACT computer test as well (Merchant-Borna, et al., 2017). The results showed that testing the DLEC stance on the WBB may be an alternative to the BESS for assessing postural stability. The WBB also identified two participants as non-recovered, one on day 3 and one on day 7 post-concussion, that the BESS and ImPACT identified as cleared to return to sport (Merchant-Borna, et al., 2017). This study may indicate that the WBB may be able to detect postural stability more accurately.

Guzman & Aktan (2016) evaluated the Wii Balance Board (WBB) as an objective, user-friendly, cost effective, valid alternative tool for the measurement of postural stability in college athletes. They also compared the WBB to the BESS in measuring postural stability. They examined the test-retest reliability using twelve volunteers beforehand, and completed the full study with 91 collegiate football players. On the WBB, the participants had to perform double-leg and single-leg stances for 20-30 seconds each. For the BESS, the subjects were tested on a firm surface only, for three stances (Guzman & Aktan, 2016). The results showed a positive and direct correlation between the two instruments, based on the participant's scores. This accepted the hypothesis that the WBB is a reliable and valid tool when compared with the BESS, so they can be utilized equally in measuring postural stability (Guzman & Aktan, 2016). Future studies could investigate these measures in other collegiate athletes, or in non-athletes.

Moreover, another study examined the efficacy of a Wii balance board-based system (eBaViR) as a rehabilitation tool for balance recovery (Gil-Gómez, Lloréns, Alcañiz, & Colomer, 2011). This was a pilot randomized clinical trial in patients with acquired brain injury. There were 17 participants total that were randomly placed in a treatment group and control group. This system consisted of three games: Simon, Balloon Breaker, and Air Hockey, where therapists adjusted the level and parameters for each individual subject based on a pre-assessment of center of balance and anterior/posterior/medial/lateral weight shift abilities (Gil-Gómez, Lloréns, Alcañiz, & Colomer, 2011). The intervention included twenty one-hour sessions that occurred 3-5 times per week, where balance was also assessed by static and dynamic traditional tests, such as Berg Balance Scale, Anterior Reach Test, 1-minute Walk Test, Timed “Up and Go” Test, etc. The results suggested that virtual rehabilitation provided significant improvement in static balance compared to traditional treatment, based on the data from the BBS and ART, for example. This improvement could be attributed to the decrease in cognitive constraints while using virtual rehabilitation. Overall, the results suggest that both groups improved in the same way. The hypothesis was supported that the eBaViR is feasible, safe and potentially effective in enhancing standing balance (Gil-Gómez, Lloréns, Alcañiz, & Colomer, 2011). Balance board technology could be extremely useful for balance rehabilitation under static conditions.

In review of this research investigating the use of Wii boards for rehabilitation and balance testing, it appears the BESS lacks test-retest reliability and stability that the WBB provides (Merchant-Borna, et al., 2017; Guzman & Aktan, 2016). The BESS is scored based on an assessor’s judgement which increases the likelihood of error. If researchers do not count errors the same way, or lose focus while watching a patient, they could miss something. However, a computer program like a WBB, detects errors more precisely. The WBB is therefore more objective and provides a uniform way of collecting data. Even though one study described the concern that the balance board technology was not sensitive enough to detect all changes in movement (Lange, et al., 2010), a later study showed the WBB detects balance issues that the traditional human-scored tests cannot (Merchant-Borna, et al., 2017). Also, these studies provided the participants with multiple options for games to play (Lange, et al., 2010; Gil-Gómez, Lloréns, Alcañiz, & Colomer, 2011), creating a variety of incentives for the participant to direct focus which can reduce cognitive constraints that impact balance. Patients can favor their injured leg during exercise which may present challenges in therapy. Traditional balance exercises like single leg balance on the floor are important yet balance board programs allow patients to have fun and may reduce fear and constraints impacting improvements. Balance board therapy seems to be just as effective, if not more effective, than traditional methods in measuring and testing balance capabilities. However, the Wii Balance Board is not the only type of balance board technology utilized in a rehabilitation setting. Newer balance boards are being manufactured by other companies and may emerge as a popular rehabilitation training tool.

The HUMAC balance board software is one example of an emerging technology offering exercise training potential (Figure 4a). It operates very similarly to the Wii balance board and includes a variety of tests and games. It also provides the patient and tester with visual feedback

Figure 4a: HUMAC board and software set-up.

as well as numerical data. A common test to use with patients is the m-CTSIB test. It compares a patient's scores with normative data of their age. It also provides visuals and numerical data of the path they traveled while attempting to maintain balance on different surfaces, with and without visual feedback, in different stances. This information provided goes above and beyond any other assessment tool. An example of a successful performance above the norms of the patient's age is shown below, although the traces could be more centered without as high of a path length. The information in Figures 4b & 4c is provided by the HUMAC after every m-CTSIB test. It allows the researcher to compare results numerically and visually based on the

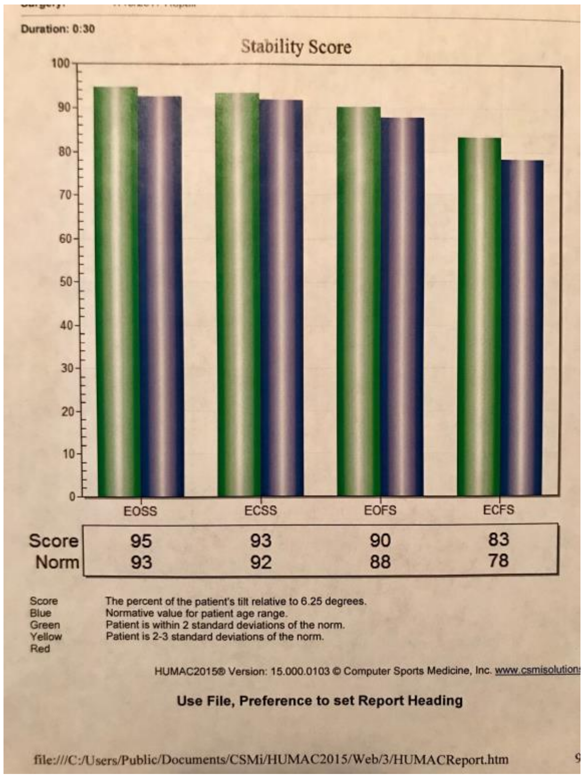

Figure 4b: HUMAC m-CTSIB Results – Graph.

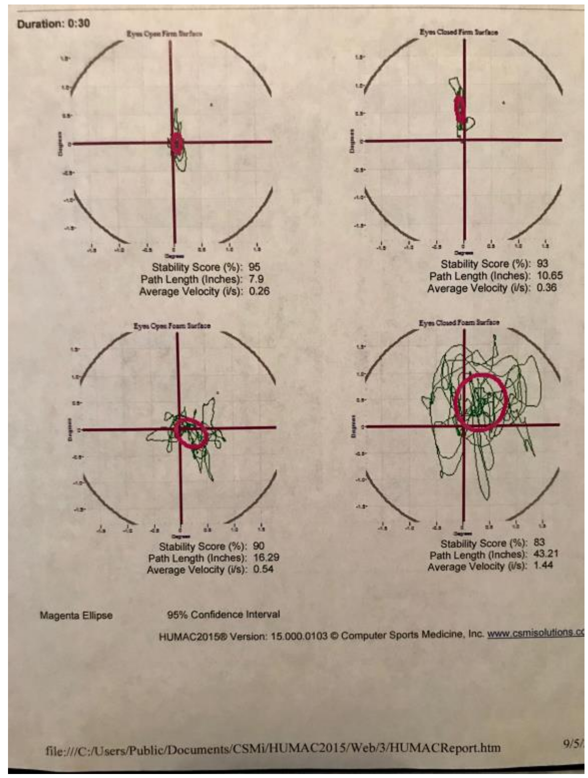

Figure 4c: HUMAC m-CTSIB Results – Trace.

chart and the traces. The scores are compared to the norms of the patient's age, as can be seen by the blue bar in Figure 4b. Figure 4c shows every shift in movement the patient made during the test. The goal of the traces is to have a small pink circle that is centered on the axis, and limited green trace outside of that circle. The information in Figure 4c also states the path length and average velocity of movement while the patient is attempting to stay centered. This test is commonly used for concussion patients, but there are no studies where the HUMAC m-CTSIB is utilized for monitoring the progression of an Achilles tendon patient who is also using the HUMAC for balance training. Figure 5a and

5b show example training programs. These are visuals on the screen that are available to the patient and physical therapist for the duration of the training. For Figure 5a, the patient must shift their weight to hover over the yellow dot, which will change locations throughout the training.

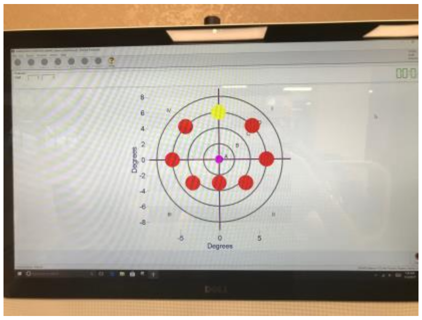

Figure 5a: HUMAC Training Program “Stability”.

Figure 5b: HUMAC Training Program “Roadway”.

For Figure 5b, the patient must shift their weight to stay within the bounds of the road. With the way the scores and results are presented, the HUMAC could be a useful tool for that situation. The HUMAC has not been studied in a balance rehabilitation setting. Therefore, it has not been determined if this balance software could be beneficial to include in an Achilles tendon rehabilitation program.

Problem Statement

Balance intervention is an important aspect of rehabilitation of an Achilles tendon repair. The influence of a 10-week HUMAC balance board training intervention on balance and range of motion in an Achilles tendon repair patient was unclear.

Purpose Statement

The purpose of this study was to determine the influence of a 10-week HUMAC balance board training intervention on balance and range of motion in an Achilles tendon repair patient.

Research Question

What was the influence of a 10-week HUMAC balance board training intervention on balance and range of motion in an Achilles tendon repair patient?

Null Hypothesis

The HUMAC therapy intervention will not improve balance and range of motion in an Achilles tendon repair patient.

Assumptions

The expectations of the participant without concrete proof were as follows:

It was assumed for this study that the patient would follow the requirements of the study and perform to the best of their ability during rehabilitation sessions, especially during testing. It was assumed that the patient would be completing their home exercise program and all instructed exercises when at therapy. It was assumed that the patient would be present at all scheduled appointments. Finally, it was assumed that the data was reflective of Achilles tendon repair patients receiving postoperative rehabilitation.

Definition of Terms

- **Achilles Rupture** - a condition where the tendon has become torn either fully or partially, usually behind the ankle but can also be a little higher where it joins the calf muscle (*Musculoskeletal: Achilles Tendon Rupture*, 2014).
- **HUMAC** (**Hum**an **A**ssessment **C**omputer) - HUMAC Balance software coupled with the Wii-type gaming board, utilized to measure and challenge balance capabilities with eight programs to choose from (HUMAC BALANCE, 2017).
- **Balance** - **Static** - ability to control postural sway while standing;

  Dynamic - ability to react to changes in balance and anticipate changes as the body moves (Rogers, 2016).

- **Center of Gravity (COG)** - a theoretical point where the weight force of the object can be considered to act; body's COG usually at the second sacral segment when person is standing in a neutral position (Bushman & Battista, 2014).
- **BESS** - a test used to assess the effects of mild head injury on static postural stability, also used for general balance testing; consists of three stances performed for 20 seconds each on a stable and an unstable surface, all with eyes closed and hands on hips; errors are counted (Moses, 2017). See Appendix C.
- **Tandem Stance** - toes of one foot to heel of the other; for BESS the back foot is the foot of the non-dominant leg (Moses, 2017).
- **HUMAC PROGRAMS** - see Appendix D (HUMAC BALANCE, 2017).

    Weight Shift – patient stands in a double leg stance and shifts their weight forward/backward or right/left, at varying levels of difficulty

    Limits of Stability – patient stands in a double leg stance and shifts their weight towards a circle when it lights up; they must hold their balance for a designated number of seconds until the light switches to another circle

    Roadway – the patient stands in double or single leg stance and shifts their weight to maneuver the dot so that it stays between the lines on the road as it moves along curves and hills

Summary

Balance and range of motion are important components of rehabilitation. Balance board therapy seems to be just as effective, if not more effective, than traditional methods in measuring and testing balance capabilities. Therefore, this study explored the efficacy of a HUMAC therapy intervention on balance and range of motion in an Achilles tendon repair patient.

Research Design & Methods

Study Type

The type of research used in this study was an equivalent time sample quasi-experimental design case study.

Study Population

The population for this study were Achilles tendon repair patients receiving postoperative rehabilitation.

Study Sample

The sample was an Achilles tendon repair patient who was receiving rehabilitation at a physical therapy clinic in central Florida. The sample size was one male (n=1). Convenience sampling was used as the participant was selected from one clinic where the researcher collected data for ten weeks.

Inclusion Criteria

The participant must have undergone an Achilles tendon repair surgery after tearing or rupturing their Achilles. The participant must have been at the start of their rehabilitation process with approval from the surgeon to partake in this type of therapy. The participant must have also signed an informed consent form prior to beginning the study.

Exclusion Criteria

The participant must not have undergone any previous balance therapy for this injury. If the participant was re-injured or could not fulfill the weekly meetings for therapy, they would be excused from the study. If the participant felt that they were unable to continue to participate in the study, then they would be exempt.

Protection of Validity

Internal validity is the level to which the changes in the dependent variable can be attributed to the researcher's manipulation of the independent variables. The participant only performed therapy that the researchers instructed them to do, limiting the threat of history, which is the outside activities the participant could be doing outside of the study. The same equipment was used every session, to reduce instrumentation threat. The same person directed the exercises which allowed for a better understanding of the relationship between the HUMAC therapy and the functionality of the patient.

External validity is the extent to which the results of the study can be generalized to the population depicted by the participants in the study. Convenience sampling was used as the participant in the case study was chosen from a local physical therapy clinic. The limited sample size of n=1 limits the external validity because it was difficult to generalize the results to an entire population of Achilles repair patients. Multiple treatment interference could have been a threat because the participant performed the same tests on a weekly basis. The Hawthorne Effect, or a change in performance based on an audience being present, could have also affected the participant's performance.

Instrumentation

The participant was tested on a HUMAC Balance System (CSMi) utilizing the HUMAC Balance Software on a Mac computer (see Appendix B). The CSMi foam rectangle piece was utilized for a portion of the test as well. There was also a walker present for safety purposes. The BESS was completed on the ground, but a gait belt was needed to tie around the patient in case the physical therapist who was assisting needs to stop them from falling (see Appendix C). A laptop was needed for the researcher to record results, as well as a printer to print out the HUMAC results for each m-CTSIB test. The participant was not paid for the study.

Methodology

The process began with a physical therapist in the central Florida area discussing with one of her patients the possibility of partaking in a study using HUMAC therapy. Then, the researcher completed an informed consent for the patient to sign and had an IRB approved. The physical therapist contacted the surgeon to make sure all of the activities the patient would be required to do for this study were acceptable at that point in their recovery. The study began during the patient's next appointment where they were tested on the HUMAC using the m-CTSIB test and then on the ground using the BESS. At each appointment, the patient also began with fifteen minutes on the AlterG (anti-gravity) treadmill at progressing levels of body weight and utilized programs on the HUMAC for balance rehabilitation exercises. Figure 6 shows the visual representation of the full methodology of this study.

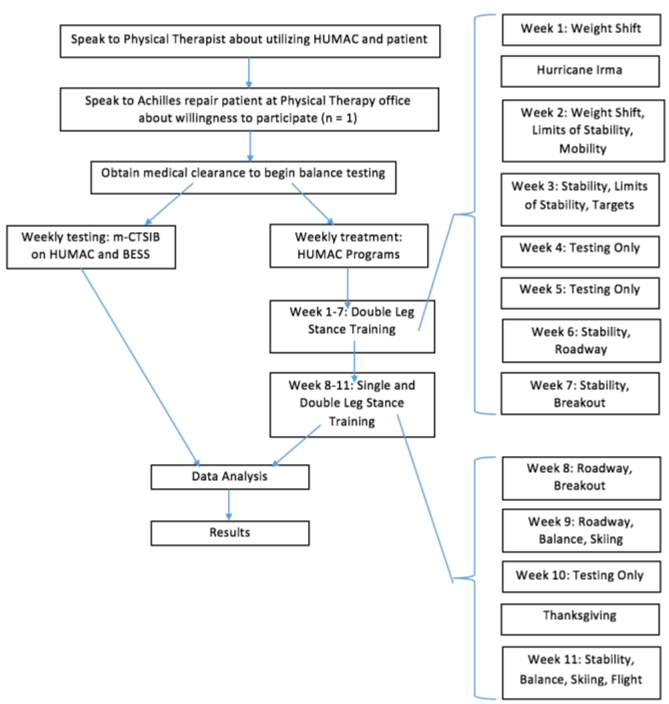

Figure 6. Methodology. The full methodology is outlined.

Testing Description

m-CTSIB (Modified Clinical Test of Sensory Interaction on Balance)

This test began with the participant standing on the HUMAC board with the middle of their feet lined up with the 7's on the horizontal axis, and the medial malleolus lined up with a letter along the vertical axis (see Appendix B). The participant was instructed to stand in a neutral position with their arms at their sides. They went through a series of four tests which were each 30 seconds long. The tests were: firm surface eyes open, firm surface eyes closed, unstable (foam) surface eyes open, and unstable (foam) surface eyes closed (*Objective Quantification of Balance & Mobility*, 2007). As they completed the test, the board monitored their center of gravity to determine their sway velocity, COG alignment, and more. This test can be used to determine a participant's balance capabilities compared to the norms of their age, as well as what needs to be improved in weight shift, COG alignment, and balance in general.

BESS Test (Balance Error Scoring System) (see Appendix C)

This test was performed on the ground only, adding in the same foam pad utilized for the m-CTSIB test for a few sections. The researcher was timing and observing for errors while an assistant monitored the participant who was wearing a gait belt for safety. The three stances the participant performed included double leg stance, single leg stance, and tandem stance (Moses, 2017). All positions were held for 20 seconds with the participant's hands on their hips and eyes closed. For single leg stance, the participant was standing on their non-dominant leg.

HUMAC Programs

All programs utilized for therapy are outlined with a visual aid for reference in Appendix D. However, Table 1 shows which week each training program was used.

Table 1. HUMAC programs used for therapy each week.

Program	Weight Shift	Stability	Mobility	Limits of Stability	Targets	Roadway	Breakout	Skiing
Weeks Utilized	1, 2, 3	2, 3, 4, 5, 6, 7, 8, 9, 10	3	4, 5	4, 5, 6	6, 7, 8 (single leg wk 8)	8, 9	9, 10

Safety, Anonymity, & Confidentiality of Human Subjects

The participant in this study was not identified by name or by any distinguishable characteristics released in published information. There was minimal risk in this study, as all actions were approved by the surgeon and there was always a spotter or walker present during the balance testing activities. An informed consent was signed by the participant before partaking in the study. All paper data was stored in a lock box that only the researcher had a key to, and all numerical data in Excel was password protected. The participant was allowed to leave the study at any time without consequence.

Data Analysis

Descriptive analysis as well as a dependent t-test were used to determine differences in scores pre- and post-intervention. The level of significance was set at ($\alpha \leq 0.05$).

Results

All data from each week's testing, m-CTSIB, BESS, and the ROM measurements, were condensed into graphs and tables for comparisons. A t-test was used for the m-CTSIB, BESS, and ROM data analysis. The results of the m-CTSIB and ROM were not statistically significant ($p = 0.153$ and $p = 0.146$), but the results for the BESS were statistically significant ($p < 0.046$).

m-CTSIB Results

The primary scores on the m-CTSIB were high, within the normal range for the participant's age for all four stances. The first week was compared to the results on the very last testing session. Overall, the scores on the m-CTSIB improved from the first week to the last week for the Eyes Open Foam Surface only, according to the data in Figure 7 and Figure 8.

Figure 7. Weekly scores on the m-CTSIB split up by stance.

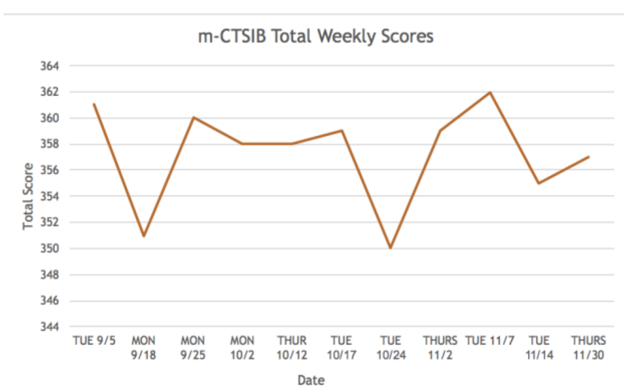

Figure 8. Weekly scores on the m-CTSIB test combined into totals.

Figure 9a shows the comparison of scores from the first week to the last week of the intervention, as well at the norms based on the patient's age.

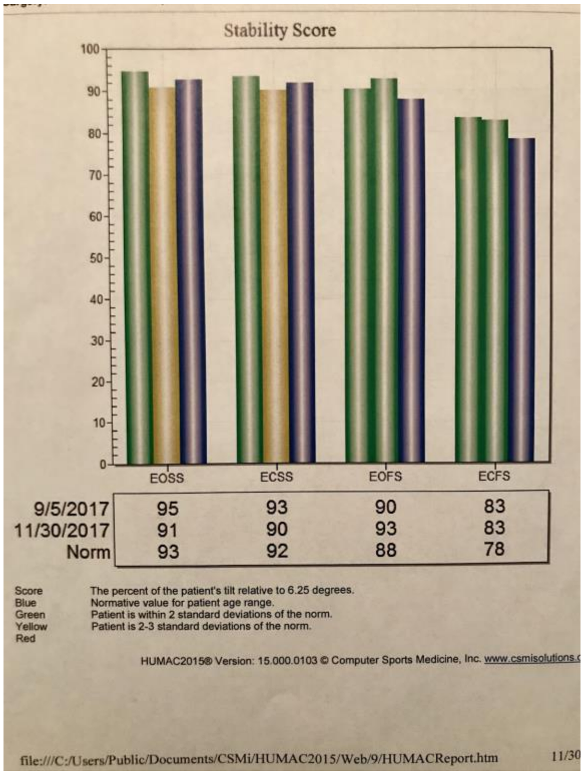

Figure 9a. Numerical results 9/5/17 compared to 11/30/17 (pre/post) for m-CSTIB test.

Figure 9b, 9c, 9d, and 9e show the HUMAC data when a m-CTSIB test was completed and separated into the four different stances: eyes open stable surface (EOSS), eyes closed stable surface (ECSS), eyes open foam surface (EOFS), and eyes closed foam surface (ECFS).

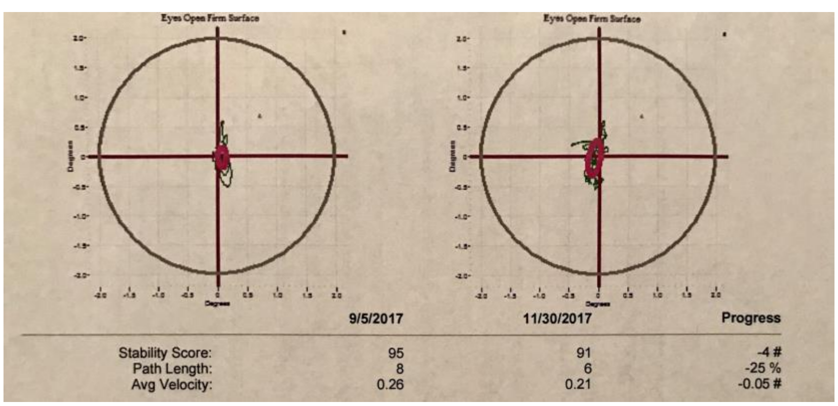

Figure 9b. Movement patterns during testing for Eyes Open Stable Surface for 9/5/17 compared to 11/30/17 (pre/post) on the m-CTSIB test on the HUMAC.

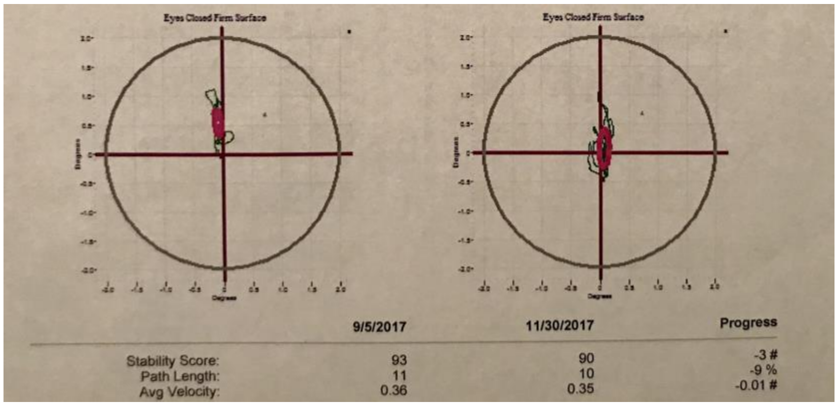

Figure 9c. Movement patterns during testing for Eyes Closed Stable Surface for 9/5/17 compared to 11/30/17 (pre/post) on the m-CTSIB test on the HUMAC.

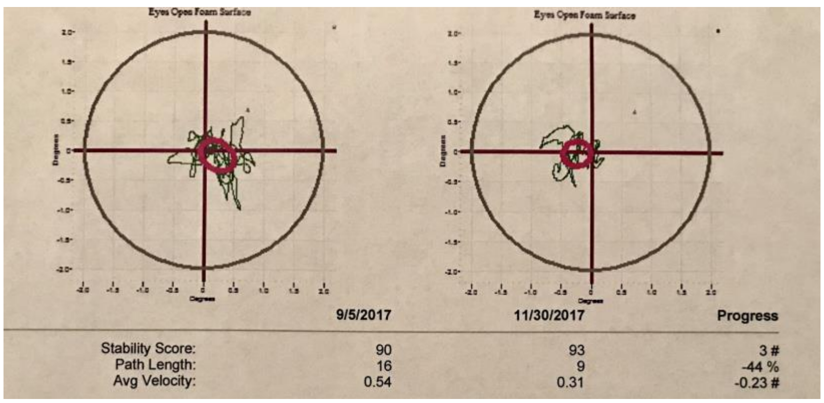

Figure 9d. Movement patterns during testing for Eyes Open Foam Surface for 9/5/17 compared to 11/30/17 (pre/post) on the m-CTSIB test on the HUMAC.

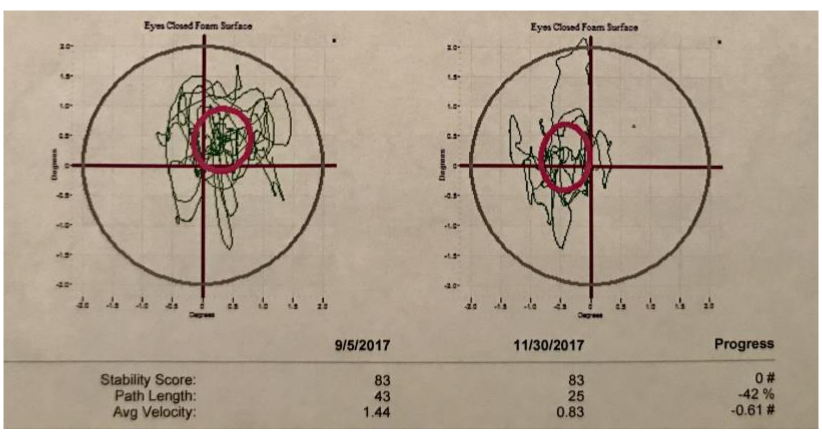

Figure 9e. Movement patterns during testing for Eyes Closed Foam Surface for 9/5/17 compared to 11/30/17 (pre/post) on the m-CTSIB test on the HUMAC.

The patient became more centered and stable with a decreased path length and velocity for ALL stances compared to the first week (Table 2).

Table 2. Path Length and Average Velocity of movements during the four stances of the m-CTSIB test, comparing the first day to the last day of testing.

	EOSS	EOSS	ECSS	ECSS	EOFS	EOFS	ECFS	ECFS
	Path Length	Avg. Velocity	Path Length	Avg. Velocity	Path Length	Avg. Velocity	Path Length	Avg. Velocity
9/5/17	8	0.26	11	0.36	16	0.54	43	1.44
11/30/17	6	0.21	10	0.35	9	0.31	25	0.83
Difference	-2	-0.04	-1	-0.01	-7	-0.23	-18	-0.61

When removing an outlier (the first week), statistical significance was found for this test ($p = 0.040$), while the full results of the testing (including the first week outlier) shows no statistical significance ($p = 0.153$).

BESS Results

From start to finish, there was a statistically significant drop in errors ($p < 0.046$) as the number of total errors decreased from 13 to 6 (shown in Table 3 and Figure 10).

Table 3. Number of errors for the BESS test pre and post intervention.

BESS Results							
	Double Leg Stance Firm Surface	Single Leg Stance Firm Surface	Tandem Stance Firm Surface	Double Leg Stance Foam Surface	Single Leg Stance Foam Surface	Tandem Stance Foam Surface	Total Errors
Pre	0	2	1	0	6	4	13
Post	0	2	0	0	4	0	6

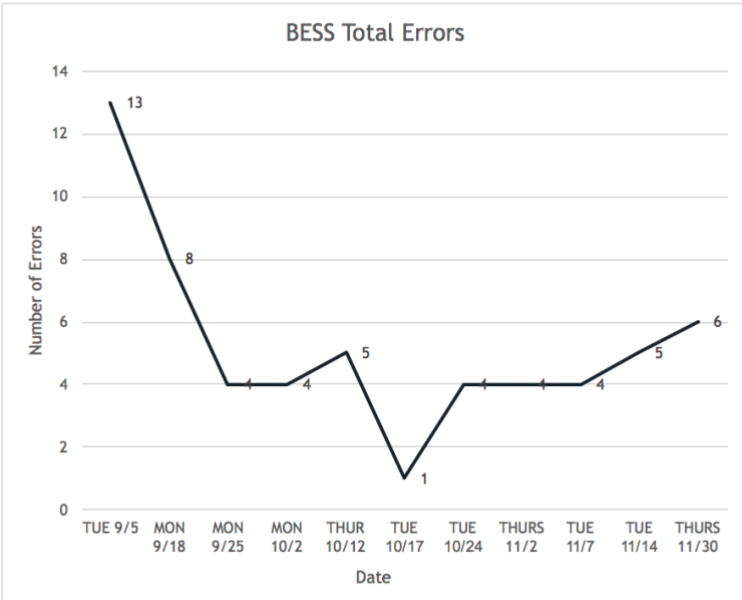

Figure 10. Total weekly errors for the BESS test (p <

Range of Motion

Range of motion (ROM) was only measured on five dates throughout the duration of the intervention. Plantarflexion ROM showed a 23.1% change, dorsiflexion exhibited a 380% change, inversion revealed a 20.0% change, and eversion showed a -8.3% change, as seen in Figure 11 and Table 4.

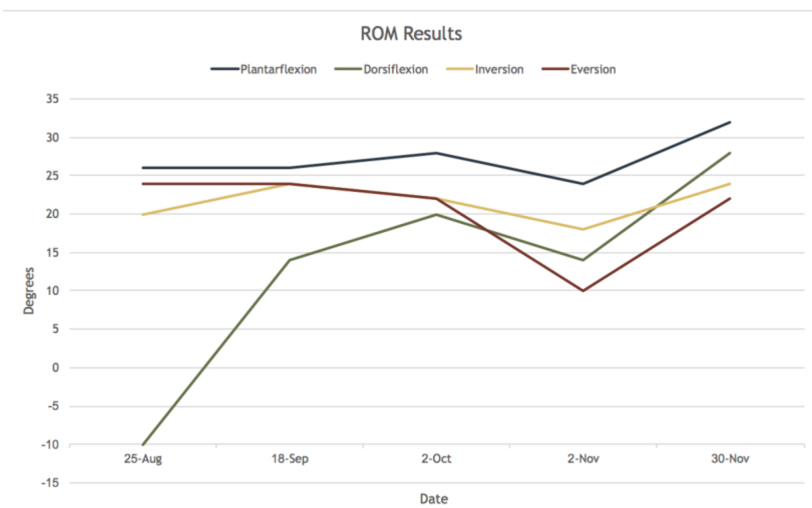

Figure 11. Range of motion measurements of the ankle throughout the intervention.

Table 4. Pre and post intervention data for ROM measurements, including percent change.

ROM Results			
	Pre	Post	Percent Change
Plantarflexion	26	32	23.10%
Dorsiflexion	-10	28	380%
Inversion	20	24	20.00%
Exersion	24	22	-8.30%

Discussion

The results of this study help in accomplishing a better understanding of the effectiveness of incorporating HUMAC therapy into a rehabilitation program for an Achilles repair patient. After an Achilles repair, a patient's level of functioning decreases. It is important to return them to their normal functional ability through exercises focusing on regaining balance, strength, and mobility.

The m-CTSIB test measures a person's ability to maintain their balance on a firm surface and a soft surface with their eyes open and closed. Although the results from pre- to post-intervention were not significant for the m-CTSIB test, comparing week 2 to the final week was ($p < 0.040$). The high scores on the first attempt could have been due to a high focus level and high rest level. The second week demonstrated scores that would be more expected for the first testing session as they were below normal for his age. Some of the later weeks where he struggled to perform well were at least partially due to the fact that he was sore and stiff from previous exercise sessions. The HUMAC-type technology has been found to detect more imbalances than traditional tests, such as the BESS, (Merchant-Borna et al., 2017). The lack of significance from pre- to post- intervention could contribute to this idea that small issues were detected that the BESS did not pick up on. It may require more than 10 weeks to return to normal functioning in the category of balance.

The m-CTSIB provides images of the movement patterns as well as additional data for each stance. The path length and average velocity values comparing the first week to the last week showed improvements for every stance. Both values decreased overall and the images demonstrated a thinner length of travel on the grid. Therefore, the main numerical data provided by the m-CTSIB should not be the only information explored. This technology provides feedback that goes beyond what a researcher can see and allows for additional means to measure improvement.

The BESS test did show a statistically significant difference between pre- and post-intervention numbers. The results for the BESS fluctuated, with the best scores (lowest number of errors) occurring in the middle of the intervention. The means for counting errors depends solely on the amount of time it takes the participant to return to the correct position if they move out of it. There were times where he almost fell over, but was able to regain his positioning within 5 seconds, so it only counted as one error. One error was also counted when he abducted his hip slightly or removed his hands from his hips. These are very different from almost falling to the ground, needing some assistance from the spotter. For this reason, along with research, the m-CTSIB does seem to be a more accurate tool to use to measure balance capabilities.

The range of motion values improved in three out of the four movement assessed; eversion did not improve when the last week was compared to the first. Dorsiflexion improved over 300%, while plantarflexion and inversion showed improvements as well. When keeping the ankle in a neutral position in a cast for an extended amount of time, range of motion is lost. The large improvement in dorsiflexion most likely results from it being necessary for most movements that the ankle joint facilitates. The first steps out of the boot require dorsiflexion in the highest capacity compared to the other three joint movements. Inversion and eversion will not be necessary for walking. Also, the towel stretch exercise is easiest for the patient to perform when pulling the foot towards themselves, so dorsiflexion may receive the most training when these exercises are assigned to perform at home. Range of motion measurements were taken five times throughout the intervention. There was a large drop on 11/2/17, most likely due to the fact that the patient had been walking long distances on uneven surfaces two nights before which caused increased stiffness and soreness. In future studies, it would be beneficial to take weekly ROM measurements to acquire more data throughout the intervention and see when stiffness truly could have been a contributing factor to m-CTSIB or BESS results.

Although HUMAC training cannot be the sole type of exercise performed in an Achilles tendon rehabilitation program, it does possess qualities that are beneficial to the patient (and the therapist) that traditional rehabilitation exercises do not. For example, the HUMAC programs provide immediate visual feedback. When performing a set of squats or balancing on a Bosu ball for 30 seconds, the only feedback the patient gets is from what they feel in their body and what their physical therapist may say to them. Seeing their movements in front of them on the HUMAC's computer monitor helps to train balance by working the sensory input from the visual system comprehensively. The programs on the HUMAC provide percentages, scores, times, and show on the screen exactly how the patient is performing. They are able to beat high scores, challenge themselves to perform better than they did the last round, and more. This real time feedback is encouraging and creates a sense of competition with themselves similar to video games.

The HUMAC also provides reduced psychological or cognitive constraints. The HUMAC distracts the patient from emotions the patient may be feeling at the time. With this patient in particular, he was hesitant to push himself and extra cautious while performing some movements that he did not think he would be able to complete successfully at that point in his rehabilitation. While utilizing programs on the HUMAC, those fears disappeared because he was focused on making those quick movements to achieve a goal in the game. Also, the HUMAC programs hold the attention of the patient. Attention is an extremely important factor in rehabilitation, as the Kenyon, & Blackinton, (2011) study discussed when describing constraints to cognition that could affect a person's focus and performance. Compared to traditional exercise techniques where the patient may be facing the rest of the room which could be busy, the HUMAC programs require them to stare at a screen and block out any other distractions.

This study did have limitations. First, the patient was unable to attend some appointments that they had scheduled. The patient needed approval for more appointments throughout those 10 weeks, which reduced attendance. With the small sample, the results may not be applicable to other Achilles repair patients at different therapy clinics, limiting external validity. There were a total of 13 sessions where HUMAC training was able to be incorporated into the rehabilitation session. The goal was to complete at least two 15-minute training sessions per week, as the number of weekly sessions decreased from three to two shortly after the start of the intervention. This goal was not reached due to missed sessions because of Hurricane Irma, Thanksgiving, and waiting for authorization from the insurance company to schedule more appointments. The patient returned to work part-time at week 3, then full-time at week 4. This caused him to be on his feet much more, with limited time to rest his injured leg. He also fueled differently prior to at least one session, missing breakfast due to waking up late. There were also days where variables other than balance were the focus of therapy, or various types of balance training was used instead of using the HUMAC. It was difficult to control for internal validity because it was not possible to use the HUMAC training as the only type of rehabilitation, as that would only hinder the patient's recovery. Even with these interferences with the original plan, 13 HUMAC training sessions were enough to determine that they played a factor in the recovery results.

Many outside factors could have had an effect on the results of this study, but attempts were made to protect the validity. For the majority of the weeks, the warm-up consisted of 15 minutes on the anti-gravity treadmill, where the percent body weight supported by the treadmill was decreased each session and reverse walking was included as well. For the last two weeks, a switch was made to the bicycle for warm-up, as the patient had reached 0% support from the treadmill with no issues. All of his appointments were at 7am, so testing was at approximately the same time every week.

Additionally, the m-CTSIB did not show improvements from this intervention, but it may require a longer intervention or a check in a certain number of months later to see a vast improvement in the scores. The m-CTSIB is a sensitive test, so it may take more time, focus, and/or warm-up level to attain the high scores after dipping lower. The patient achieved a high score initially. He was given the feedback that he was not improving to the level that he started at in subsequent sessions, so this could negatively impact his performance. With this in mind, it may be beneficial to take away the immediate feedback aspect during testing, only allowing it for the training programs. Even with limitations, the participant was able to attempt all of the HUMAC programs, most at least once throughout the intervention. By the eighth week of the intervention, single leg training was being performed on the HUMAC as well. This was earlier than the Mullaney et al. (2011) study where participants began single leg training at >9 weeks.

It was also earlier than the Suchak et al. (2008) study where exercises were advanced to single leg at week 12. This may indicate that the patient was progressing sooner than most Achilles tendon repair patients. Although outside factors could have affected the results of this study, many attempts were made to protect the validity.

In conclusion, a 10-week HUMAC therapy intervention helped return a patient to normal functioning in an Achilles tendon repair therapy program based on the results of the BESS, ROM measurements, as well as the path length and velocity aspects of the m-CTSIB. HUMAC training allowed the patient to push themselves and let go of the fear and world around them, while providing real-time sensory and visual feedback in a safe environment. The ability to provide this information and various levels of balance training may lead this technology to becoming a top choice in rehabilitation tools for an Achilles tendon patient.

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Appendix A: Informed Consent

1. This is a research effort to assess the effect of a HUMAC therapy intervention on balance in an Achilles tendon repair therapy program.
2. Your participation in this research is voluntary.
3. Your participation in this research will require thirty appointments lasting 60 minutes per session.
4. Your participation in this research will require you to work with the research team at Leading Edge Physical Therapy
5. Your participation in this research will require you to receive HUMAC technology treatment for 15 minutes per session, incorporating double-leg and single-leg stances.
6. Your participation in this research will require you to complete a Balance Error Scoring System balance test and M-CTSIB (Modified Clinical Test of Sensory Interaction in Balance) pre- and post-intervention as well as at the half-way point of the intervention (one trial of each test on the first day of week one, week five, and week ten). Overall there will be 11 BESS and M-CTSIB testing sessions (one at the start of each of the ten weeks, as well as one at the last therapy session of week ten).
7. Your participation in this research will require you to participate in goniometry assessments of both of your ankles pre and post intervention as well as at the half-way point to determine your joint range of motion (week one, week five, and week ten). Overall there will be 11 goniometry testing sessions (one at the start of each of the ten weeks, as well as one at the last therapy session of week ten).
8. Your participation in this research will require you to have basic anthropometric tests completed before the treatment, which include: Height, weight, body composition, and body mass index.
9. You will be asked to maintain your normal eating and exercise schedule throughout the day of the experiment.
10. You may withdraw from participating in this research at any time without negative consequences or penalties; likewise, refusal to participate will not result in any penalty to you.
11. Participation presents minimal risks to you.
12. Public dissemination will occur in academic research journals and presentations with results of the research presented in summary form only and with no individual identification in the data analysis.
13. You will not receive financial compensation for your participation in this research study.
14. Your signature at the bottom of this form indicates that you have given voluntary consent to participate in this study.
15. Please contact **Nicole Harrison at 978-866-1583 or at nharrison@mocs.flsouthern.edu** if you have any procedural questions regarding this study.
16. Please contact **Dr. Mick Lynch at 863-680-6205 or at jlynch@flsouthern.edu** if one or more of the following apply to you**:**

a. You have questions regarding your rights as a participant in this study.
b. You wish to have a copy of the results presented as a summary form.

17. You may also contact Kyle Fedler, PhD, who is the Provost and Chief Academic Officer of Florida Southern College at 863-680-4124 if you have questions regarding your rights as a participant in this study.
18. This research protocol and informed consent has been reviewed and approved by the Florida Southern College Human Subjects Review Committee (HSRC) for use from (*insert approval date here*) to (*insert date 1 calendar year from approval date here*).

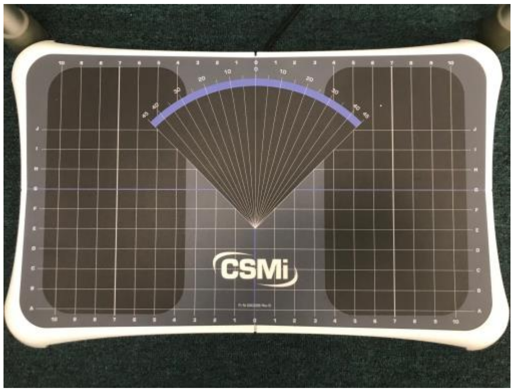
By checking this box, you acknowledge that you have read and understand the above material and that you understand what this research involves.
By signing below, you are agreeing and consenting to participate in the research.

____
Participant PRINTED Name

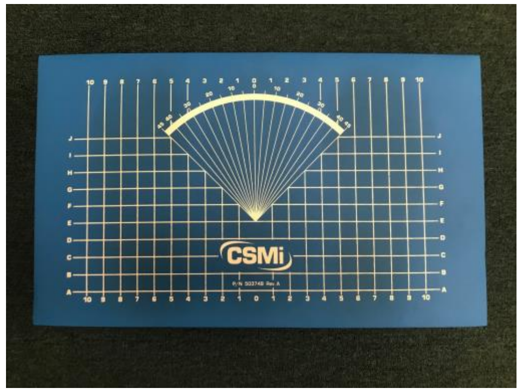
____
Participant Signature

___________________________ ________________
Date

Appendix B: HUMAC Images

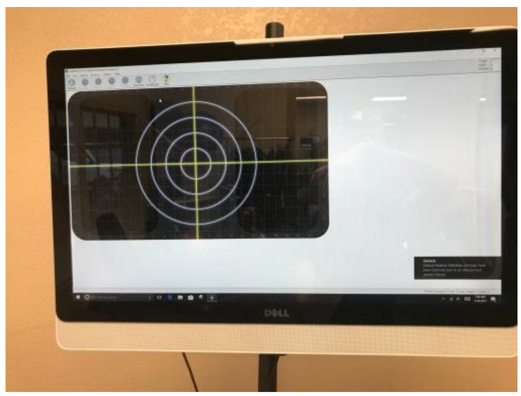


HUMAC Board



Foam Pad

Foam on Board



HUMAC Main Screen

Appendix C: BESS Test

Script for the BESS Testing Protocol

Direction to the subject: *I am now going to test your balance.*

Please take your shoes off, roll up your pant legs above ankle (if applicable), and remove any ankle taping (if applicable).

This test will consist of 6 - twenty second tests with three different stances on two different surfaces. I will describe the stances as we go along.

DOUBLE LEG STANCE:

Direction to the subject: *The first stance is standing with your feet together like this* [administrator demonstrates two-legged stance]

You will be standing with your hands on your hips with your eyes closed. You should try to maintain stability in that position for entire 20 seconds. I will be counting the number of times you move out of this position. For example: if you take your hands off your hips, open your eyes, take a step, lift your toes or your heels. If you do move out of the testing stance, simply open your eyes, regain your balance, get back into the testing position as quickly as possible, and close your eyes again.

There will be a person positioned by you to help you get into the testing stance and to help if you lose your balance.

Direction to the spotter: *You are to assist the subject if they fall during the test and to help them get back into the position.*

Direction to the subject: *Put your feet together, put your hands on your hips and when you close your eyes the testing time will begin* [Start timer when subject closes their eyes]

SINGLE LEG STANCE:

Direction to subject: *If you were to kick a ball, which foot would you use?* [This will be the **dominant** foot]

*Now stand on your **non-dominant** foot.*

[Before continuing the test assess the position of the dominant leg as such: the dominant leg should be held in approximately 30 degrees of hip flexion and 45 degrees of knee flexion]

Again, you should try to maintain stability for 20 seconds with your eyes closed. I will be counting the number of times you move out of this position.

Place your hands on your hips. When you close your eyes the testing time will begin. [Start timer when subject closes their eyes]

TANDEM STANCE:

Directions to the subject: *Now stand heel-to-toe with your* **non-dominant** *foot in back. Your weight should be evenly distributed across both feet.*

Again, you should try to maintain stability for 20 seconds with your eyes closed. I will be counting the number of times you move out of this position.

Place your hands on your hips. When you close your eyes the testing time will begin. [Start timer when subject closes their eyes]

Direction to the spotter: *You are to assist the subject if they fall during the test and to help them get back into the position.*

***** Repeat each set of instructions for the foam pad**

Scoring the BESS
Each of the twenty-second trials is scored by counting the errors, or deviations from the proper stance, accumulated by the subject. The examiner will begin counting errors only after the individual has assumed the proper testing position.

Errors: An error is credited to the subject when any of the following occur:

- moving the hands off of the iliac crests
- opening the eyes
- step stumble or fall
- abduction or flexion of the hip beyond 30°
- lifting the forefoot or heel off of the testing surface
- remaining out of the proper testing position for greater than 5 seconds

-**The maximum total number of errors for any single condition is 10.**

Normal Scores for Each Possible Testing Surface

	Firm Surface	Foam Surface	
Double Leg Stance	.009 ± .12	.33 ± .90	
Single Leg Stance	2.45 ± 2.33	5.06 ± 2.80	
Tandem Stance	.91 ± 1.36	3.26 ± 2.62	
Surface Total	3.37 ± 3.10	8.65 ± 5.13	
BESS Total Score			12.03 ± 7.34

Maximum Number of Errors Possible for Each Testing Surface

	Firm Surface	Foam Surface
Double Leg Stance	10	10
Single Leg Stance	10	10
Tandem Stance	10	10
Surface Total	30	30

If a subject commits multiple errors simultaneously, only one error is recorded. For example, if an individual steps or stumbles, opens their eyes, and removes their hands from their hips simultaneously, then they are credited with only one error. Subjects that are unable to maintain the testing procedure for a minimum of five seconds are assigned the highest possible score, ten, for that testing condition.

Score Card

Balance Error Scoring System (BESS)
(Guskiewicz)

Balance Error Scoring System – Types of Errors

1. Hands lifted off iliac crest
2. Opening eyes
3. Step, stumble, or fall
4. Moving hip into > 30 degrees abduction
5. Lifting forefoot or heel
6. Remaining out of test position >5 sec

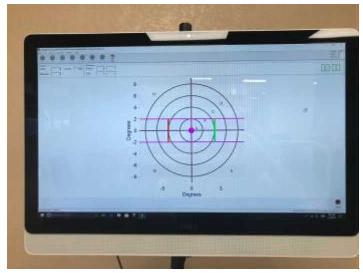
The BESS is calculated by adding one error point for each error during the 6 20-second tests.

SCORE CARD: (# errors)	FIRM Surface	FOAM Surface
Double Leg Stance (feet together)		
Single Leg Stance (non-dominant foot)		
Tandem Stance (non-dom foot in back)		
Total Scores:		
BESS TOTAL:		

Which **foot** was tested: ☐ Left ☐ Right
(i.e. which is the **non-dominant** foot)

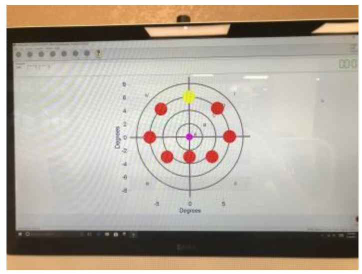
Appendix D: HUMAC Programs

Weight Shift



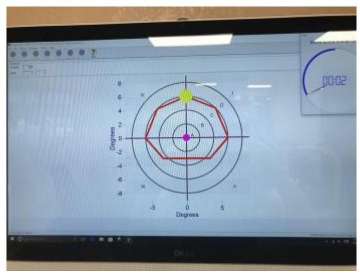
In a double leg stance, work on shifting weight forward and backward or side to side, at varying levels of difficulty.

Stability



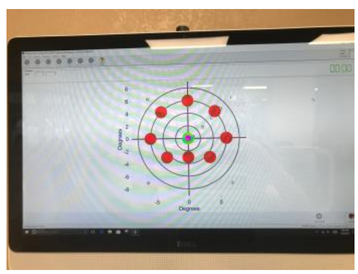
In a double leg stance, shift weight towards circles when they light up and hold balance on them for designated number of seconds; percentage correct will show up.

Mobility



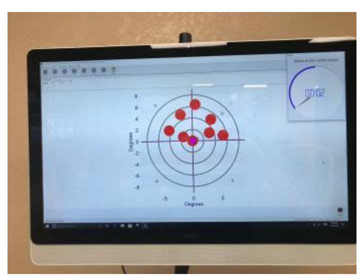
In a double leg stance, shift weight to trace along the line the dots follows, always keeping the small dot on the circle moving around the shape.

Limits of Stability



In a double leg stance, shift weight towards circles when they light up and hold balance on them for designated number of seconds.

Targets



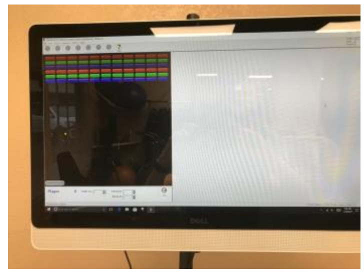
In a double leg stance, shift weight towards circles when they light up and hold balance on them for designated number of seconds - researcher will choose where circles are placed.

Roadway

In double or single leg stance, shift weight to maneuver the dot so that it stays between the lines on the road as it moves along curves and hills.

Breakout

In a double leg stance shift weight forward/backward or side to side to move paddle to bounce ball off of it and destroy blocks. Paddle size and ball speed & acceleration can be adjusted.



Skiing

In a double leg stance, shift weight from side to side to maneuver the course as if participant was skiing down a slope.

Balance

In a double leg stance, shift weight from side to side and forward and backward to move the silver ball through a maze to get to a target location.