# The Study of Injury Biomechanics in the Wrist/Hand and Ankle/Foot for Tumbling Using the MatScan

BME 412 – Dr. Ha Vo

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# Contents

## 1. ABSTRACT

Tumbling is a skill that puts major pressure on both the hands and feet and is utilized in both gymnastics and cheerleading. In gymnastics alone, it has one of the highest rates of injuries among girls' sports with an average of 100,000 gymnasts injured each year [1]. While not all of these injuries are tumbling related, there are a multitude of injuries that occur in the hand/wrist and lower extremities from overuse and/or landings during tumbling.

Due to high rate of injuries in both sports, there is a need for studies that oversee the injury biomechanics of tumbling to better understand a person's specific problems when tumbling and possible injuries that can incur from the way they tumble. The main purpose of this project was to analyze the landings of both the hands and feet of three different people during both a back handspring and a back tuck.

A MatScan system produced by Tekscan was used to capture pressure measurements of both the hands and feet during the tumbling. The system captured a 7 second video that had the progression of pressure changes from the start to the end of the mid-part of the back handspring and the landings. The parts of the hand and feet with the most pressure were able to be evaluated and correlated to possible injuries.

The overall study was a success as different possible injuries were able to be identified for each participant based on where they put the most pressure on their hands/feet through the progression of the different landings. There were a variety of injuries that dealt with the ankle, heel, other foots parts, hand, and wrist. There were three possible injuries that any of the participants could be affected by. The first two were sprains/strains of both the wrist and ankle due to one wrong landing can cause the injuries. The second one was a carpal fracture, which could occur at any point on the wrist.

## 2. INTRODUCTION

Tumbling is a skill that puts major pressure on both the hands and feet and is utilized in both gymnastics and cheerleading. In gymnastics alone, it has one of the highest rates of injuries among girls' sports with an average of 100,000 gymnasts injured each year [1]. While not all of these injuries are tumbling related, there are a multitude of injuries that occur in the hand/wrist and lower extremities from overuse and/or landings during tumbling.

Due to high rate of injuries in both sports, there is a need for studies that oversee the injury biomechanics of tumbling to better understand a person's specific problems when tumbling and possible injuries that can incur from the way they tumble. The main purpose of this project was to analyze the landings of both the hands and feet of three different people during both a back handspring and a back tuck.

When a tumbler lands on their hands during a back handspring, there are large compression forces, about an average of 2.37 times body weight, produced at the hands [2]. The feet also produce large amounts of pressure due to the entire body weight landing forcefully on the ground; however there are less compression forces in the foot landing of the back handspring than in the back tuck due to the landing is typically at an angle. The back handspring and back tuck were chosen due to being common tumbles and the heavy forces experienced in the hands in feet during landings could be observed as pressure.

A MatScan system produced by Tekscan was used to capture pressure measurements of both the hands and feet during the tumbling. The system captured a 7 second video that had the progression of pressure changes from the start to the end of the mid-part of the back handspring and the landings. The parts of the hand and feet with the most pressure were able to be evaluated and correlated to possible injuries.

## 3. BACKGROUND

The most common gymnastic injuries for the foot/ankle and the hand/wrist are: Achilles tendinitis, Achilles tendon rupture, ankle sprains, wrist sprains, finger fractures, wrist tendinitis, dorsal wrist impingement, and distal radial stress fracture [3] [4]. However, these are not the only injuries that can occur as there will be more injuries discussed in the analysis of the tumbling. The general description of the injury as well as the symptoms and causes will be outlined throughout this section.

### 3.1 FOOT/ANKLE INJURIES

Achilles Tendonitis & Tendon Rupture:

The Achilles tendon is both the largest and most vulnerable tendon in the human body. It joins the gastrocnemius (which crosses the ankle, the knee, and the subtalar joints) and soleus muscles of the lower leg to the heel of the foot. Due to tendons not being very flexible, they can only stretch so far before they either get inflamed and tear or rupture all together [5].

Achilles tendonitis has common symptoms of pain in the back of the ankle and just above the heel that increases when exercising. There is typically a pinpoint tenderness that is increased when it is palpated. It is also possible for the tendonitis to come on slowly and then get worse over weeks as time goes on, with the worse pain being in the morning after waking up and

easing off after the tendon is stretched. If acute Achilles tendonitis is left untreated and unable to heal properly then it can form into chronic Achilles tendonitis, which can cause small scar-like bumps to develop in the tendon.

The main cause of Achilles tendonitis is overuse as it is a chronic injury. The overuse happens by ignoring the early warning signs and the pain. Another major factor is that there is little flexibility in the calf muscles, which causes the muscle to shorten and therefore creates more tension in the tendon. Tendonitis occurs in athletes primarily due to training errors such as wearing improperly fitting shoes, but it is also related to contracture of the gastrocnemius-soleus complex as well as hyperpronation of the foot [6]. Abnormal biomechanics and friction from external or extrinsic pressure are also believed to factor into a cause for the symptoms.

One of the main indications for a rupture of the Achilles tendon is that there is often a “pop” sound when the tendon ruptures as well as the feeling of being hit in the Achilles. It is possible there will be a little pain, but the person will not be able to lift up onto their toes while weight bearing [7].

There are many contributing factors to the cause of an Achilles tendon rupture, which makes the exact cause of the rupture hard to pinpoint. The tendon can rupture without warning or it’s possible that it could rupture following Achilles tendonitis. The chance of an Achilles tendon rupture is most likely when the force on the tendon is much greater than the strength of the tendon. A rupture may occur if the foot is dorsiflexed while the lower leg moves forward and the calf muscles contract. Most ruptures tend to happen during a forceful stretch of the tendon with the calf muscles contracting.

Ankle sprains:

The most common injury of the ankle is an ankle sprain. The basic definition of an ankle sprain is when all the surrounding ligaments of the ankle joint are stretched beyond their ability to withstand a force and they end up tearing. The tear of the ligaments can be either minor or major and the recovery time depends on the degree of the sprain [8].

The two most common ankle sprains are an inversion injury and an eversion injury. An inversion injury occurs when the ankle rolls outward while the foot rolls inward in an opposite direction. This causes the ligaments outside the ankle to stretch/tear. An eversion injury has the same concept as an inversion injury, but the ankle rolls inward and the foot rolls outward [9].

The sprains are classified by different grades of severity. A Grade I sprain is a stretch and/or tear of the ligament without loosening. A Grade II sprain is a tear of the ligament along with some loosening. A Grade III sprain is a complete tear of the affected ligament with severe loosening [8].

## 3.2 Wrist/Hand Injuries

There is a great potential for a gymnast to hurt their wrist/hand due to the amounts of weight and pressure placed on the wrist/hand. For example, carrying the entire weight of the body on the wrist while it bends backwards can cause fractures, dislocations, and sprains [4].

Wrist sprains/strains:

A sprained wrist is one of the most common causes of wrist pain in athletes. A typical way for the sprain to occur is when a person falls on an outstretched hand and it tears/stretches the ligaments of the wrist. Landing on an outstretched hand also causes the muscles and tendons to take most of the impact, as well as the ligaments, which makes it possible for the gymnast to wind up with a strain [10]. In gymnastics, falling/landing hard on the hands during handsprings are a common cause of wrist sprains [3].

The sprains are classified by different grades of severity. A Grade I sprain is over-stretching and/or microtears of ligaments. A Grade II sprain is partial ligament tears and mild joint instability. A Grade III sprain is a complete tear of the affected ligament with significant joint instability [10].

Finger fractures:

A finger fracture is a minor trauma, but can cause major problems. If a bone in the finger is fractured and not treated properly then it can cause improper alignment in the hand and the finger itself can remain stiff and/or painful for a long time. Any sport has the potential for finger fractures, but in gymnastics they can be caused by a variety of things including a wrong landing [11].

Wrist tendinitis:

Wrist tendonitis occurs when there is irritation and swelling of the tissue which surrounds the tendons located at the thumb. The tendonitis often occurs from overuse, but it is also able to be caused by biomechanical problems and injury to the arm. The symptoms for tendonitis include pain in the front of the wrist, pain when bending/extending the thumb, and possible swelling [12].

Dorsal wrist impingement:

Dorsal wrist impingement is the most common injury that can occur to a gymnast’s wrist. The injury occurs from a repetitive combination of hyperextension and axial loading. More specifically, the injury occurs when the dorsal edge of the radius impinges (strikes) on the wrist bones (Figure 1). This injury is common during routines that have walkovers and handsprings. The gymnast will feel pain and tenderness on the backside of the wrist, but the pain will subside after the routine is over [13].

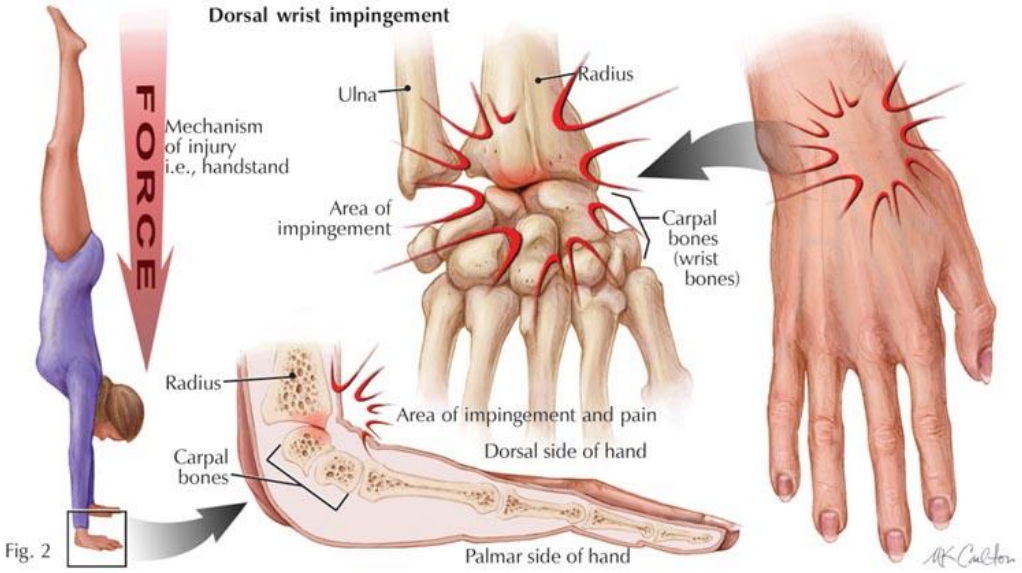


Figure 1: Dorsal wrist impingement visualization [13]

Distal radial stress fracture:

Distal radial stress fractures (Figure 2) often are associated with floor exercises. The high impact forces can cause compression on the wrist, which can cause small fractures in the radius. This injury is often caused by repeated minor trauma due to axial loading and the dorsiflexion of the wrist. The gymnast will pain and tenderness around the circumference of the radius slightly above the wrist. The pain begins during participation of an activity and will progress throughout the entirety of the activity [13].

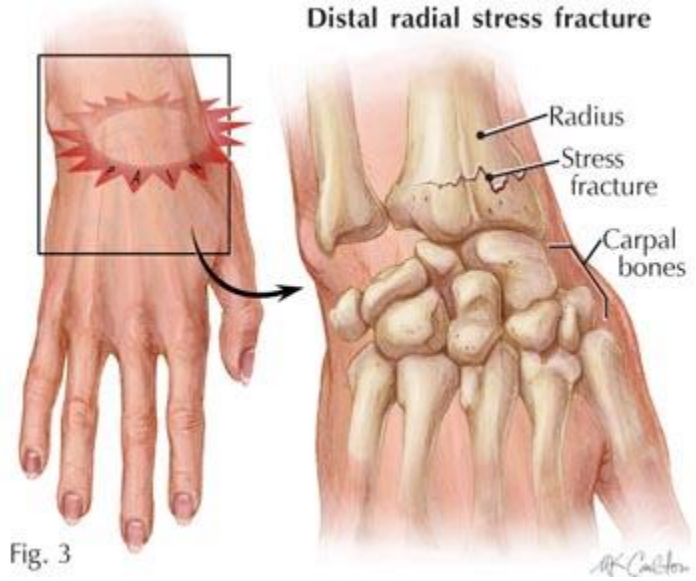


Figure 2: Distal radial stress fracture visualization [13]

## 4. METHODOLOGY

The methods used in this experiment can be broken up into three different parts. The first part was setting up the study which included setting up the MatScan and calibration. The second part was conducting the study which included taking the measurements of the tumblers during the back handsprings and back tucks. The third part was analyzing the data using the Tekscan software.

### 4.1 SETTING UP THE STUDY

Before being able to participate in the study, each participant has to sign an IRB (Institutional Review Board) form, which can be found in Appendix A, informing the participant that they were aware of the dangers of tumbling and they were not being force to do any task they do not wish.

A foam floor mat was unrolled to cover the area the participants would be conducting the tumbles. The MatScan was secured to the center of the floor mat using heavy duty duct tape so that it would not slide when landed upon.

The TekScan Research 6.70 program was previously installed onto a laptop and the settings for new patients were selected under MatScan. After the participant's information was entered, their weight was set by step calibration. The participants stepped to the side of the MatScan and conducted practice tumbles, then marked off how far back they would need to be to land in the necessary way. A video was taken for each landing, with four landings recorded per tumble, for a total of 12 videos on file per participant. The videos were recorded at 5 Hz for 7 seconds, for a total of 350 frames per video. The MatScan was set to display 17 different colors (Figure 3) according to the amount of pressure applied in the area.

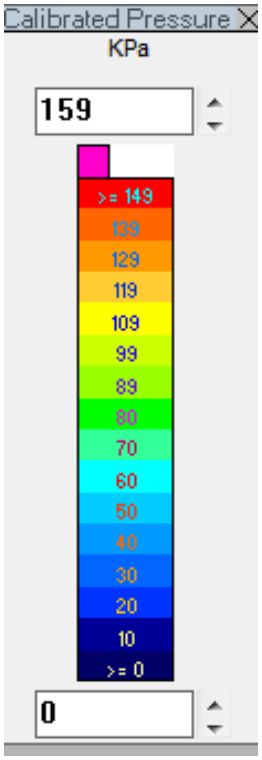


Figure 3: The calibration pressure spectrum of 17 colors.

## 4.2 CONDUCTING THE STUDY

Two different tumbles were analyzed in this study: the back handspring and the back tuck. The back handspring was analyzed for the landing of the hands and for the landing of the feet. The back tuck was analyzed for the landing of the feet. Each participant was able to do each of the tumbles.

Performance of the back tuck:
This exercise (Figure 4) required the tumbler to jump up rather than forwards or backwards, while rotating at the shoulders rather than the hip. Then, they bent their legs and pulled their knees close to their chest while in the air. The hands were not extended either, but pulled close to the body at the side or tucked in the front. The exercise consisted of one full rotation in the air, with the tumbler beginning and landing fully and only on their feet.

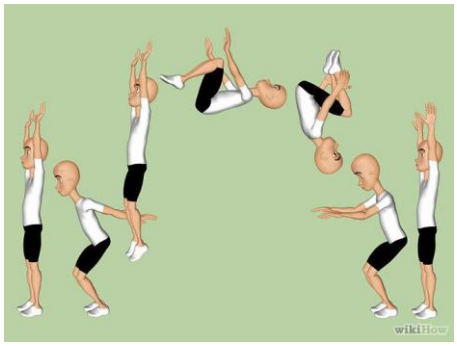

Figure 4: Performance steps of the back tuck.

Performance of the back handspring:
This exercise (Figure 5) required the tumbler to throw their weight backward and bring their legs up in the air with their head going to the ground. They then rotated at the hips so that their hands landed briefly on the ground. The person pushed off with their hands, throwing their weight forward and bringing their legs closer to the body and to the ground again, rotating at the hips to stand upright.

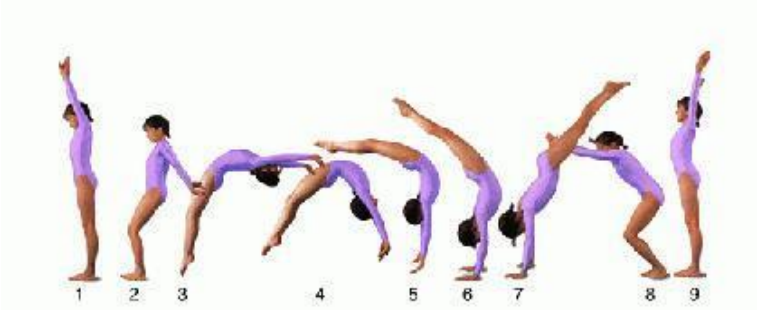

Figure 5: Performance steps of the back handspring.

## 4.3 Analyzing the Study

The videos of each landing were watched several times and the pressure changes were analyzed by location on the foot/hand and by the amount of pressure. Each set of videos was given a trend of how the pressure changed throughout the landing (see Appendix A for notes on each video) and snapshots were taken of the videos to show the different stages. Then bodily injuries were researched further based on how and where pressure is applied, and injuries were associated with each participant's type of landing.

## 5. Results & Discussion

The foot and hand were sectioned off in order to better analyze the location changes of pressure, as seen in Figures 6 and 7. The hand was broken into four sections: callous pad, pinkie pad, thumb pad, and wrist pad. When the pinkie pad, wrist pad, and thumb pad are collectively being talked about, it is referred to as the full wrist pad. The foot was broken into six sections: big toe, big toe pad, mid pad, front pad, mid outside, and heel. The big toe pad only is in section 1; the mid pad is only in section 2; the front pad is when sections 1, 2, and 3 are collectively being talked about.

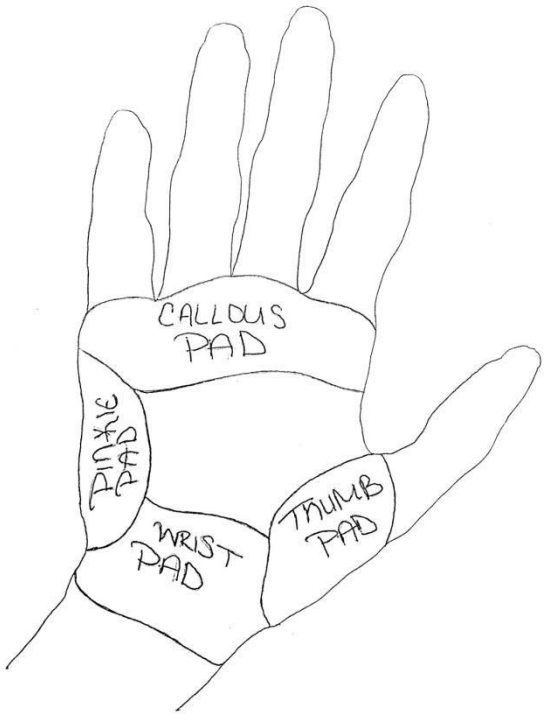


Figure 6: Labelled sections of the hand.

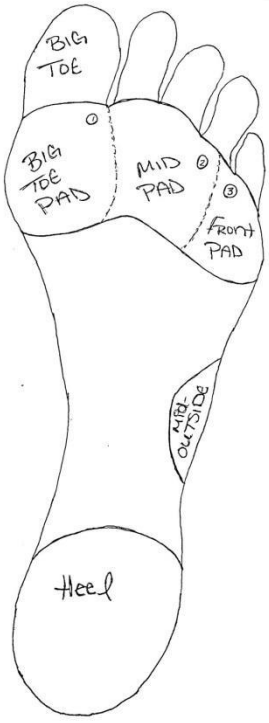


Figure 7: Labeled sections of the foot.

The 36 videos were separated by participant and landing, and the snapshots that best fit the trends for the landing are shown in Figures 8-16. They are separated by participant in this section, but can be found in Appendix C as separated by type of landing. There are different specific injuries the tumblers are prone to depending on how they land. They are mentioned here as hand/wrist and foot/ankle injuries, but explained with references in Appendices D and E respectively.

## 5.1 PARTICIPANT 1

*Back handspring:*

Both hands landed at the same time for the back handspring. When the hands landed, they landed fully on the palm and fingers, with high levels of pressure located on the wrist pads of both hands. Both hands had exceptionally high pressure at the base of the thumb. Then both hands supinated, moving the highly pressurized location to the pinkie pad of both hands, with more pressure consistently on the left hand. The right hand left after the left hand, and the fingertips pushed off last. This sequence of events is shown in Figure 8.

Due to the high pressure at the wrist pad, Participant 1 is prone to a Smith's fracture of the wrist. The supination of high pressure to the pinkie pad can lead to a triquetrum fracture or a TFCC tear.

Figure 8: Participant 1, back handspring, hand landing

Both feet landed at the same time for the back handspring. The left foot had pressure on the whole foot, with high levels of pressure located on the front pad and mid outside of the foot. The right foot also had pressure on the whole foot, with high levels of pressure located on the big toe pad and heel. The right foot also had noticeable pressure on the mid pad and mid outside of the foot. After landing, the feet quickly plantar flexed, taking all pressure off the heels of both feet. Both feet also everted, and had high levels of pressure on the front pad and the big toe. This sequence of events is shown in Figure 9.

Because of the high pressure on the mid outside of both feet, but particularly on the left foot, Participant 1 is prone to midtarsal joint sprains. The high pressure on the big toe pad of the right foot can lead to turf toe. The eversion of both feet with such high pressure introduces the risk of Pott's fractures in the feet. The right foot may also develop Policeman's Heel due to calcaneus bruising from the repeated heavy landing.

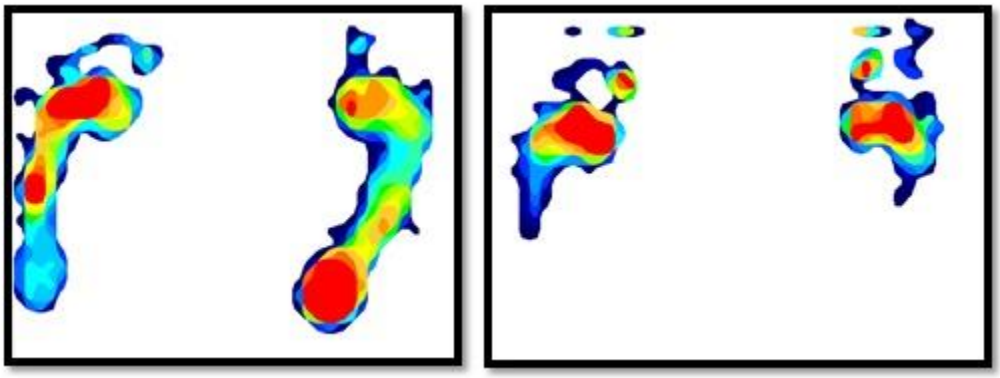

Figure 9: Participant 1, back handspring, foot landing

*Back Tuck:*
Both feet landed at the same time for the back tuck. The feet landed fully, with the heels of both feet landing with exceptionally high pressure covering the entire heel. The right foot had very high levels of pressure on the big toe pad and the mid outside of the foot. It also had noticeable pressure on the mid pad of the foot.The left foot had very high levels of pressure on the big toe pad and the mid pad of the foot, with noticeable pressure on the mid outside of the foot. After landing, the feet quickly plantar flexed, taking all pressure off the heels of both feet. Both feet also everted, and had high levels of pressure on the big toe, big toe pad, and mid pad of the foot. This sequence of events is shown in Figure 10.

Because of the high pressure on the mid outside of the right foot, Participant 1 is prone to midtarsal joint sprains. The high pressure on the big toe pad of both feet can lead to Turf Toe. The exceptionally high pressure on the heels may lead to the development of Policeman's Heel or even calcaneal fractures. Turning the foot inward after the initial landing impact can lead to peroneal tendonitis.

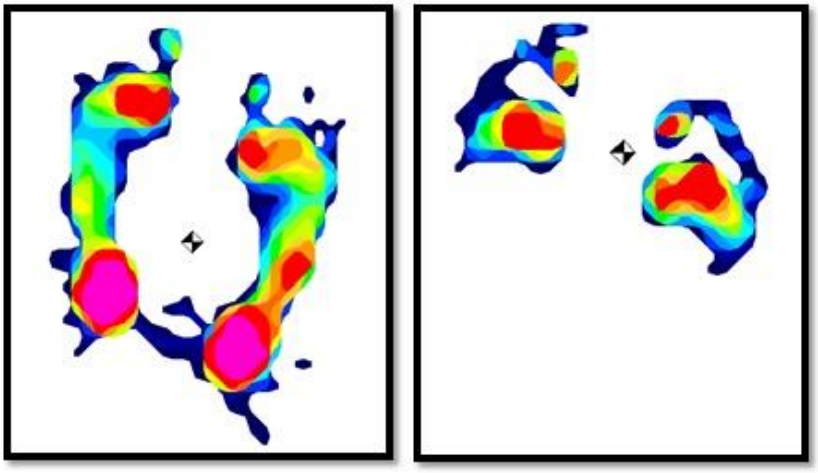

Figure 10: Participant 1, back tuck, foot landing

*Participant 1 medical history*
There have been no significant injuries to the joints of the upper body (shoulder, elbow, wrist, fingers); however, there have been many significant injuries to the joints of the lower body, specifically on the left side. Injuries to the left knee include: tibial plateau fracture, two ACL tears, MCL tear, bone graft and 3 screws, patella dislocation. Other injuries to the left lower joints include: 2 breaks of left lateral ankle, left ankle tibia bone chips/fracture, left foot talus break.

## 5.2 PARTICIPANT 2

*Back handspring:*
Both hands landed at the same time for the back handspring. When the hands landed, they landed only on the tips of the fingers. Then the palm of the hands landed, with high levels of pressure located on the thumb pads of both hands. The right hand had noticeable pressure on the wrist pad as well. Then both hands supinated, moving the highly pressurized location to the pinkie pad of both hands. Both hands left at the same time and the fingertips pushed off last. This sequence of events is shown in Figure 11.

Due to the high pressure at the base of the thumb, Participant 2 is prone to a Volar Barton fracture or a scaphoid fracture. This continuous concentration of pressure on the thumb pad can lead to a dorsal wrist impingement. The hand does supinate and the highly pressurized location moves to the pinkie pad, which can lead to a Bennett fracture.

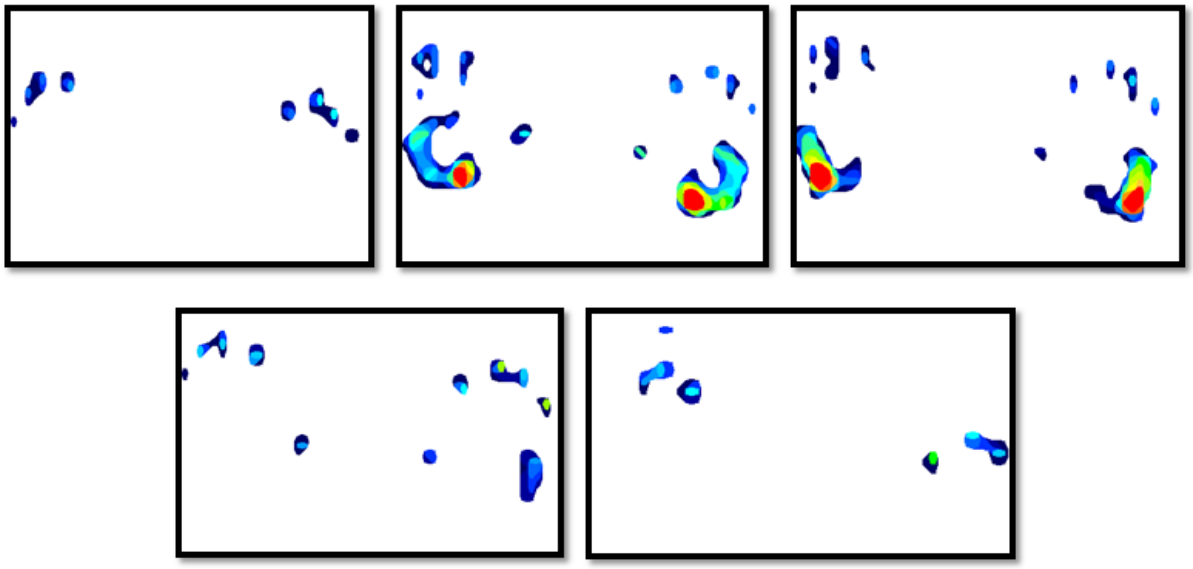

Figure 11: Participant 2, back handspring, hand landing

Both feet landed at the same time for the back handspring. Both feet landed only on the front part of the foot, with high levels of pressure located on the mid pad of the foot, and noticeable pressure on the big toe. After landing, the feet quickly dorsiflexed, putting pressure on the entirety of both feet. The mid outside of both feet had high pressure, and noticeable pressure remained on the mid pad of the foot. The right foot had higher pressure in the heel, and the left foot had lower pressure in the big toe pad. Both feet then plantar flex, taking all pressure off the heels, and creating high levels of pressure in the mid pad and big toe. The right foot had noticeable pressure on the big toe pad. This sequence of events is shown in Figure 12.

Because of the high pressure on the mid outside of both feet, but particularly on the left foot, Participant 2 is prone to midtarsal joint sprains. Because the initial landing is on the front pad of the foot, and then immediate dorsiflexion creates pressure over the entire foot, the achilles tendon and the bursae of the ankle are greatly affected. This can lead to Haglund's Syndrome, because it is a combination of retrocalcaneal bursitis and achilles tendonitis.

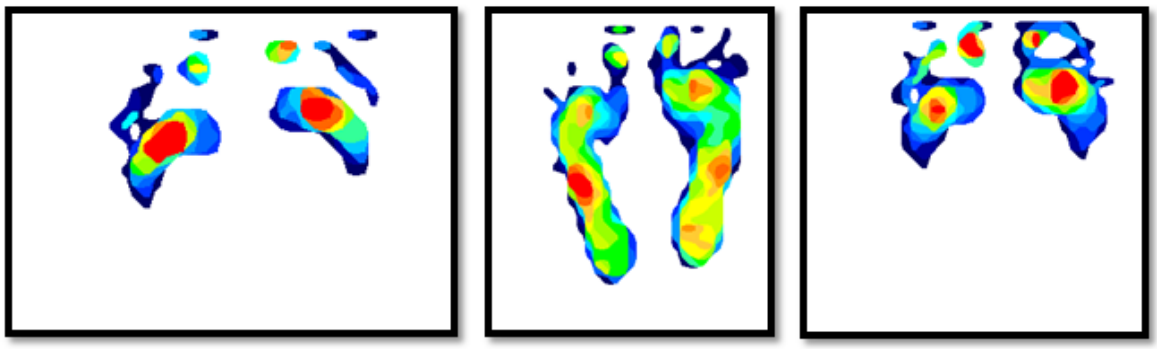

Figure 12: Participant 2, back handspring, foot landing

*Back tuck:*
Both feet landed at the same time for the back tuck. Both feet landed only on the front part of the foot, with high levels of pressure located on the mid pad and big toe of of the left foot and the front pad and big toe of the right foot. After landing, the feet slightly dorsiflexed, putting pressure on all but the heels of both feet. Both feet had high pressure located on the front pad and big toe, with the right foot having exceptionally high pressure on the mid pad. Then, the feet plantar flexed while everting, moving the highly pressurized locations to the big toe, big toe pad, and mid pad of both feet. The right foot had exceptional pressure at the base on the big toe pad. This sequence of events is shown in Figure 13.

Because the initial landing is on the front pad of the foot, and then dorsiflexion creates pressure over more of the foot, the achilles tendon and the bursae of the ankle are greatly affected because they have to suspend the heel in the air. This can lead to Haglund's Syndrome, because it is a combination of retrocalcaneal bursitis and achilles tendonitis. The eversion of the feet can create a Pott's fracture or peroneal tendonitis. This puts great pressure on the big toe pad of the foot, which can lead to Turf Toe.

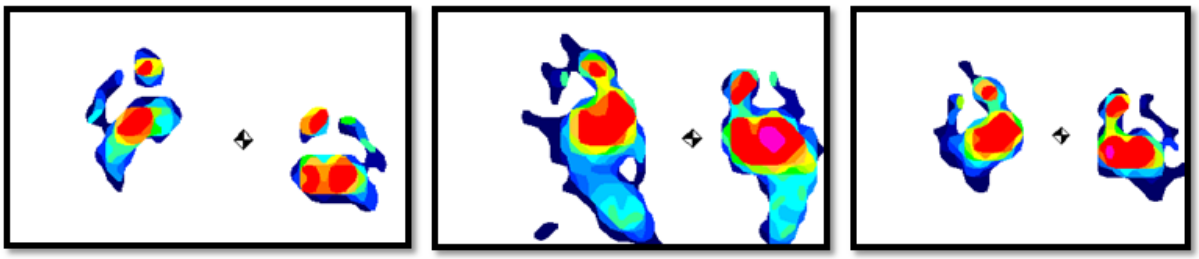

Figure 13: Participant 2, back tuck, foot landing

*Participant 2 medical history:*
There have been no significant injuries to the joints of the upper or lower body (shoulder/hip, elbow/knee, wrist/ankle, fingers/toes); however the right ankle and right wrist do develop sensitivity after constant pressure is applied.

## 5.3 PARTICIPANT 3

*Back handspring:*
Both hands landed at the same time for the back handspring. When the hands landed, they landed only on the tips of the fingers. Then the full fingers and callous pad of the hands landed, with higher levels of pressure located on the right hand, and noticeable pressure on the thumbs of both hands. Then both hands landed. The left hand had high pressure on the full wrist pad, with exceptional pressure on the thumb pad. The right hand had high pressure on the callous pad, thumb pad, and pinkie pad, but not the wrist pad. Then both hands supinated, moving the exceptionally pressurized location to the pinkie pad of both hands. Noticeable pressure was located at the thumb pad of both hands, with more pressure located on the left hand. Both hands left at the same time and the fingertips pushed off last. This sequence of events is shown in Figure 14.

Due to the high pressure at the wrist pad, Participant 3 is prone to a Smith's fracture or a scaphoid fracture of the wrist. The supination of high pressure to the pinkie pad can lead to a

triquetrum fracture or a TFCC tear. The continuous concentration of pressure on the wrist during dorsiflexion of the hand can lead to a distal radial stress fracture. Because the fingers take the initial impact, as well as push off for this landing, metacarpal fractures are possible. There is noticeable pressure exerted onto the thumb itself, which can lead to a scaphoid fracture.

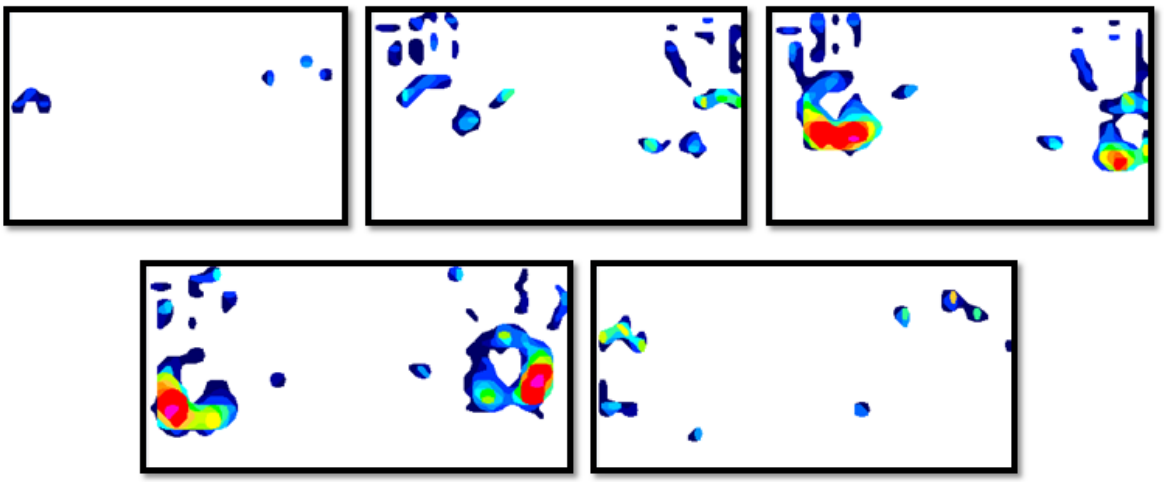

Figure 14: Participant 3, back handspring, hand landing

The right foot landed before the left foot for the back handspring. Both feet landed only on the front part of the foot, with high levels of pressure located on the mid pad of the foot, and noticeable pressure on the big toe. After landing, the feet quickly dorsiflexed, putting pressure on the entirety of both feet. The left foot had high pressure in the big toe and front pad of the foot, with the big toe pad having exceptionally high pressure. The right foot had high pressure in the big toe, big toe pad, and mid pad, with exceptionally high pressure in small areas of the big toe pad and mid pad. The right foot also had noticeable pressure on the mid outside of the foot. Noticeable pressure was on the heels of both feet. Both feet then plantar flex, taking all pressure off the heels, and creating high levels of pressure in the front pad. The right foot has high pressure on the front pad, and much of the exceptionally high pressure is removed from the left foot. This sequence of events is shown in Figure 15.

Because the initial landing is on the front pad of the foot, and then dorsiflexion creates pressure over more of the foot, the achilles tendon and the bursae of the ankle are greatly affected because they have to suspend the heel in the air. This can lead to Haglund's Syndrome, because it is a combination of retrocalcaneal bursitis and achilles tendonitis. There is also great amounts of pressure on the big toe pad of the foot, which can lead to Turf Toe.

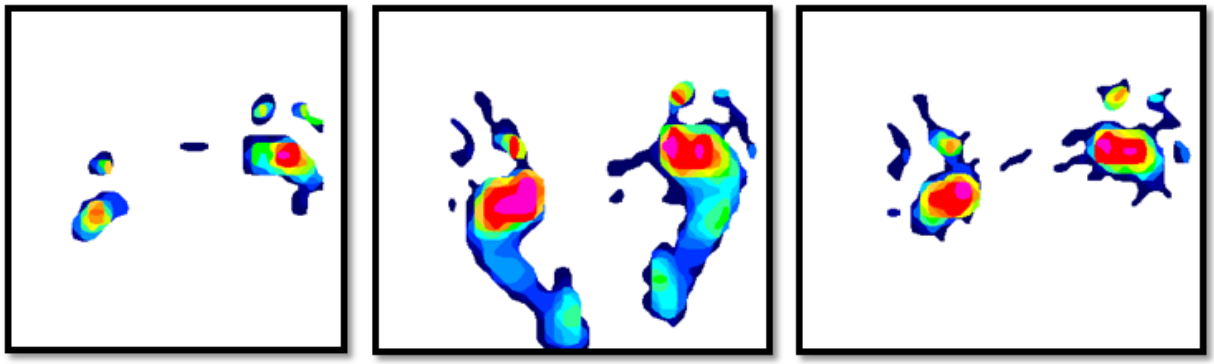

Figure 15: Participant 3, back handspring, foot landing

*Back tuck:*
Both feet landed at the same time for the back tuck. The feet landed fully, with the heels of both feet landing with exceptionally high pressure covering the entire heel. Both feet also had very high pressure on the big toe pad of the foot, and the right foot had high pressure on the big toe. Both feet also had noticeable pressure on the mid pad. After landing, the feet quickly plantar flexed, taking all pressure off the heels of both feet. Both feet also everted, and had high levels of pressure on the big toe pad of the foot. The right foot had high pressure on the mid pad, while the left foot had noticeable pressure. This sequence of events is shown in Figure 16.

The high pressure on the big toe pad of both feet can lead to Turf Toe for Participant 3. The exceptionally high pressure on the heels may lead to the development of Policeman's Heel or even calcaneal fractures.

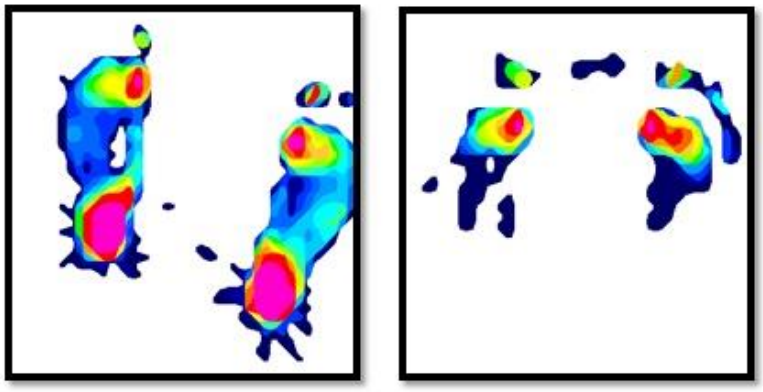

Figure 16: Participant 3, back tuck, foot landing

*Participant 3 medical history:*
There have been two significant injuries to the joints of the upper body: the left shoulder is loose and slides in and out sometimes, and the right thumb has been broken. There have been many significant injuries to the joints of the lower body, specifically to the right side: dislocated knee, patellar and quadricep tendonitis in knee, broken ankle. Both ankles have also been sprained twice.

## 6. CONCLUSION/FUTURE WORKS

The overall study was a success as different possible injuries were able to be identified for each participant based on where they put the most pressure on their hands/feet through the progression of the different landings. There were a variety of injuries that dealt with the ankle, heel, other foots parts, hand, and wrist. There were three possible injuries that any of the participants could be affected by. The first two were sprains/strains of both the wrist and ankle due to one wrong landing can cause the injuries. The second one was a carpal fracture, which could occur at any point on the wrist.

The major limitations of this study were the limited number of participants and the size of the MatScan. The limited number of participants was due to time restrictions and the ability to get in contact with participants who were practiced enough to tumble without hurting themselves. Also, the MatScan was a relatively small target for the participants to land on. All the participants had trouble with landing with both of their hands/feet on the matt for the pressure recordings.

A future study would be to continue on with the biomechanics of tumbling, except with a matt that is able to track the pressure of the entire tumble instead of just one portion. Also, with video recording and measuring the distance of the tumble, more analysis can be done on the actual angles of landings and how distance could possibly affect those angles. The angles were not able to be analyzed in this study due to time constrictions and lack of equipment.

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## 8. APPENDIX A : IRB FORM

### *Injury Mechanics of Gymnastic Tumbling*

I understand that people from Mercer University are trying to figure out the injury mechanics of tumbling in gymnastics. I am willing to help with the study. I understand that I can help by doing either a back handspring and/or back tuck. This study will take place at Mercer University and should take about 20-30 minutes of my time.

I am taking part because I want to. I have been told that I can stop at any time, and I do not have to answer any questions or do anything if I do not want to. No one will know my answers except the biomechanics professor, Dr. Vo, and the people I tell my answers to.

By helping with this study, I will help figure out the relationship between the biomechanics of tumbling and the rate of injury. By helping, I will get possible feedback on my tumbling if something significant is found during the analysis portion. There is a risk that I might hurt myself while tumbling.

I can contact the biomechanics professor at vo_hv@mercer.edu, Jackie Harmon at 478-832-3388 or the Mercer University Institutional Review Board at irb@mercer.edu .

Name:_____
Signature: _____
Date: _____

# 9. APPENDIX B: VIDEO NOTES

Participant 1

*Back Handspring, hand*

- Video 1:
  - Fingers land first with the center of gravity in the middle
  - Extremely high pressure on the wrist pads of both hands, center of gravity in the middle
  - Both rotate to the pinkie pads with more pressure on the left hand
  - Right hand leaves last
- Video 2 and 3:
  - Center of gravity to the right
  - Full left palm, and high pressure on the wrist pad of the right hand
  - High pressure on the wrist pad of both hands
  - Center of gravity shifts to the left, with both hands rotating outward to the pinkie pad
  - Right hand leaves last
- Video 4: did not use

*Back Handspring, foot*

- Video 1:
  - Center of gravity to the left, with pressure on the mid pad of the left foot
  - Center of gravity in the middle with high pressure on the mid pad of the left foot and heel of the right foot
  - The left foot rotates upward and inward while the right foot does not move
- Video 2:
  - Center of gravity to the right, with pressure on the front pads of both feet
  - Center of gravity in the middle with the left foot having high pressure on the front pad and mid outside, and the right foot having high pressure on the big toe pad and heel
  - The both feet rotates upward and inward with more pressure on the left foot
- Video 3:
  - The right foot lands first, with the center of gravity to the right, with pressure on the front pads of both feet
  - Center of gravity in the middle with the left foot having high pressure on the front pad and mid outside, and the right foot having high pressure on the big toe pad and heel
  - The both feet rotates upward and inward with more pressure on the left foot
- Video 4: not used

*Back Tuck*

- Video 1:
  - (Land) Right foot landed first on the mid pad, center of gravity shift to the right
  - (Land) Full foot both, center of gravity on the right
  - (Land) Extreme heel pressure on both feet, center of gravity on the right
  - (Land) High pressure on the right mid outside foot, center of gravity in the middle
  - (Land) High pressure on the big toe pad for both feet, center of gravity on the right
  - Rotate to the front foot and big toe for both feet

- Video 2:
    - (Land) Front pad of both feet, center of gravity shift to the right
    - (Land) Full foot both, center of gravity on the right
    - (Land) Extreme heel pressure on both feet, center of gravity on the right
    - (Land) High pressure on the right mid outside foot, center of gravity in the middle
    - (Land) High pressure on the big toe pad for both feet, center of gravity on the right
    - Rotate to the front foot and big toe for both feet
- Video 3:
    - (Land) Right foot landed first on the mid pad, center of gravity shift to the right
    - (Land) Full foot both, center of gravity on the right
    - (Land) On the left foot high pressure throughout foot, on the right foot extremely high pressure on the heel
    - (Land) High pressure on the mid outside foot for both feet, center of gravity in the middle
    - (Land) High pressure on the big toe pad for both feet, center of gravity on the right
    - Rotate to the front foot and big toe for both feet
- Video 4:
    - (Land) Land with the front pads of both feet, higher pressure on the left foot but more pressurized area on the right foot
    - (Land) Full foot both, center of gravity on the right
    - (Land) Extreme heel pressure on both feet, higher pressure on left heel
    - (Land) High pressure on the mid outside foot for both feet, center of gravity in the middle
    - (Land) High pressure on the big toe pad for both feet, center of gravity on the right
    - Rotate to the front foot and big toe for both feet, center of gravity on the right

<u>Participant 2</u>

*Back Handspring, hand*

- Video 1:
    - Land with the fingers, center of gravity in the middle
    - Both hands land at the same time
    - Both hands equally very high pressure on thumb pad
    - Rotate out to pinkie pad
    - Push off with the right hand, center of gravity shift to the right
    - Push off with the fingers
- Video 2:
    - Land with the fingers, center of gravity shift to the left
    - Pressure on the wrist pad of the left hand, and thumb pad of the right hand
    - Both hands land at the same time
    - Both hands equally very high pressure on thumb pad
    - Rotate out to pinkie pad
    - Push off with the right hand, center of gravity shift to the left
    - Push off with the fingers
- Video 3:
    - Land with the fingers, center of gravity in the middle
    - Both hands land at the same time
    - Both hands equally very high pressure on thumb pad

    - Rotate out to pinkie pad, left hand has more pressure
    - Push off with the right hand, center of gravity in the middle
    - Push off with the fingers
- Video 4:
    - Land with the fingers, center of gravity shift to the left
    - Both hands land at the same time
    - Both hands very high pressure on thumb pad, left hand has more
    - Rotate out to pinkie pad
    - Push off with the right hand, center of gravity in the middle
    - Push off with the fingers, right hand has more pressure

*Back Handspring, foot*

- Video 1:
    - Landed with more pressure on the right foot
    - Landed with the big toe and big toe pad
    - Landed with the full left foot with the pressure on the mid outside of the foot, no change on the right foot
    - Some pressure on the big toe pad, but no right heel
    - Both have big toe and big toe pad, but no heel pressure
- Video 2:
    - Landed at same time, center of gravity shifted to the right
    - Landed with the big toe and mid pad
    - Landed with the full left foot with the pressure dispersed, no change on the right foot
    - Front pad, rotate back to heel, pad
- Video 3:
    - Landed both at the same time, with the center of gravity on the middle
    - Landed mid pad
    - Rotate back to toes and front pad
    - Left mid outside foot pressure
- Video 4: not used

*Back Tuck*

- Video 1:
    - Both feet land at the same time, with the pressure in the front pad and the big toe
    - Both land full foot without the heel
    - The right foot has more pressure
    - After landing, the pressure in both feet shifts to the big toe and big toe pad
- Video 2:
    - Both feet land at the same time, with the pressure in the big toe and big toe pad, with the center of gravity shifted to the right
    - The left foot lands full foot without the heel, and the right foot with the landing on the front pad only
    - The right foot has more pressure
    - After landing, the pressure in both feet shifts to the big toe and big toe pad
- Video 3:
    - Both feet land at the same time, with the pressure in the front pad and the big toe, with the center of gravity in the middle
    - Both land full foot without the heel, with the center of gravity shifted to the right
    - The right foot has more pressure
    - After landing, the pressure in both feet shifts to the big toe and big toe pad

- Video 4:
    - Both feet land at the same time
    - Right foot having very high pressure on the big toe and big toe pad, and the left foot landing full foot without the heel
    - The right foot has more pressure
    - After landing, the pressure in both feet shifts to the big toe and big toe pad

Participant 3

*Back Handspring, hand*

- Video 1:
    - Lands fingers first at the same time with the right having more pressure
    - The left hand has pressure in the thumb pad and the right hand has pressure in the callous pad
    - Extremely high pressure in the wrist pads of both hands with more pressure on the right hand
    - Rotate to pinkie pad
    - Fingers last
- Video 2:
    - Lands fingers first at the same time with the right having more pressure
    - The right hand has more pressure, both hands have pressure in the thumb and pinkie pad but not the wrist pad
    - Rotate to pinkie pad with the right hand having more pressure
    - Fingers last
- Video 3:
    - Lands fingers first at the same time with the right having more pressure
    - The callous pad of both hands with the center of gravity in the middle
    - High pressure in the wrist pad of the left hand and thumb pad of the right hand
    - Rotate to pinkie pad with high pressure
    - Left hand staying longer than the right hand
    - Fingers last
- Video 4:
    - Lands fingers first at the same time with the right having more pressure
    - Full hands both without palms
    - The left hand has high pressure in the wrist pad and the right hand has high pressure in the thumb pad and pinkie pad but not the wrist pad
    - Rotate to pinkie pad
    - Fingers last

*Back Handspring, foot*

- Video 1:
    - Both feet land on the mid pad with the center of gravity shifting to the right
    - The full right foot with high pressure on the big toe pad and heel with slight pressure on the mid outside of the foot
    - The full left foot without the heel, with high pressure on the front pad
    - Center of gravity on the right
    - Rotate upward to toes and inward
- Video 2:
    - Both feet land on the mid pad with the center of gravity shifting to the right
    - The full right foot with high pressure on the big toe pad and heel with slight pressure on the mid outside of the foot, no heel pressure

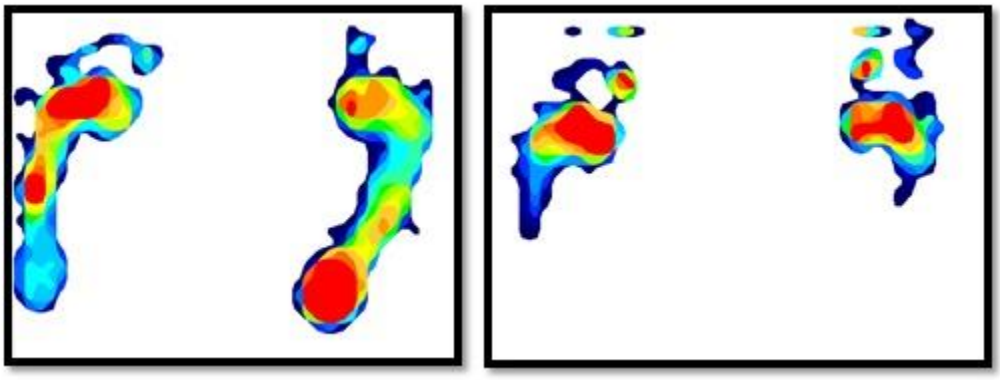
    - The front left foot without the heel, with high pressure on the front pad
    - Center of gravity on the right
    - Rotate upward to toes and inward
- Video 3:
    - Right foot has extremely high pressure in the mid pad, and no left foot
    - Landing on the front pad of both feet, center of gravity on the right
    - Both feet have full foot without the heel with extreme pressure on the front pad
    - Rotate upward to toes and inward
- Video 4:
    - Right foot lands first
    - Land on the front pad of both feet, with the center of gravity to the right
    - Full right foot pressure, and the left full foot without the heel
    - Center of gravity to the right
    - High pressure on the front pads of both feet
    - Rotate upward to toes and inward

*Back Tuck*

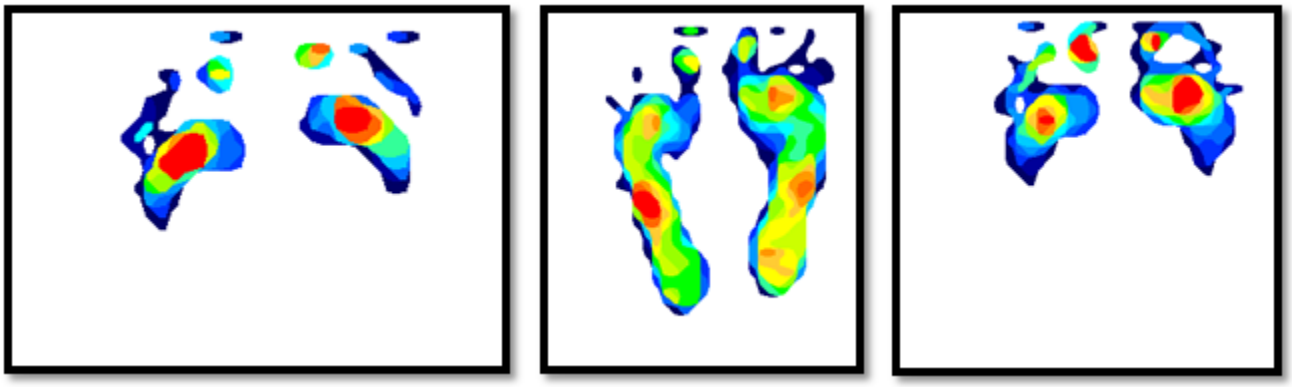
- Videos 1-4:
    - Both feet land at the same time
    - Both feet land fully
    - Extreme heel pressure on both feet
    - High pressure on the big toe pad
    - Center of gravity in the middle, slightly to the right
    - Immediately rotate to the front pad of both feet

## 10. Appendix C: Pressure Landings separated by Landing Type

Back Handspring, foot landings



Participant 1



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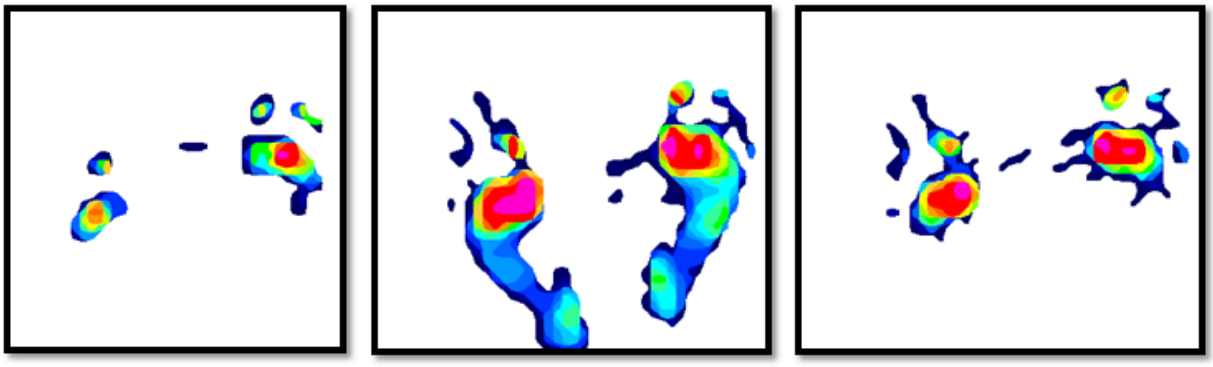
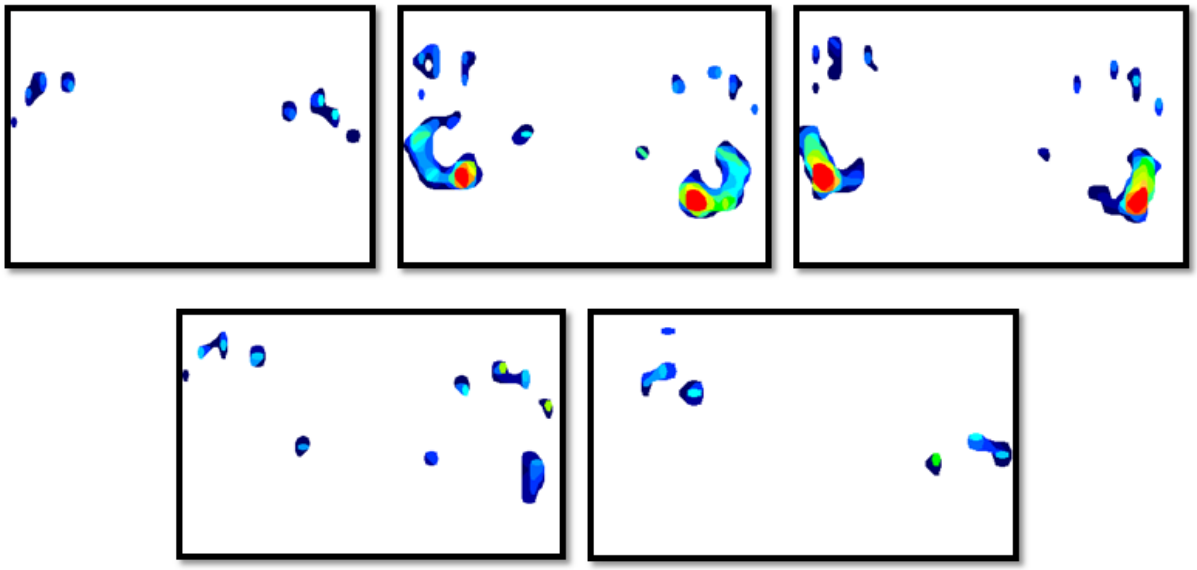


Participant 3

Back handspring, hand landings

Participant 1



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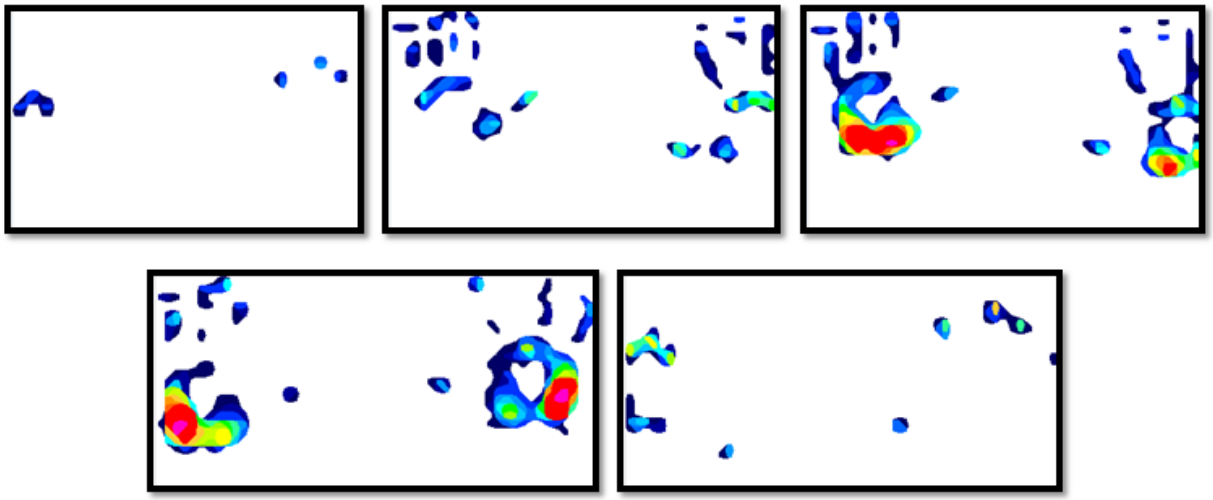
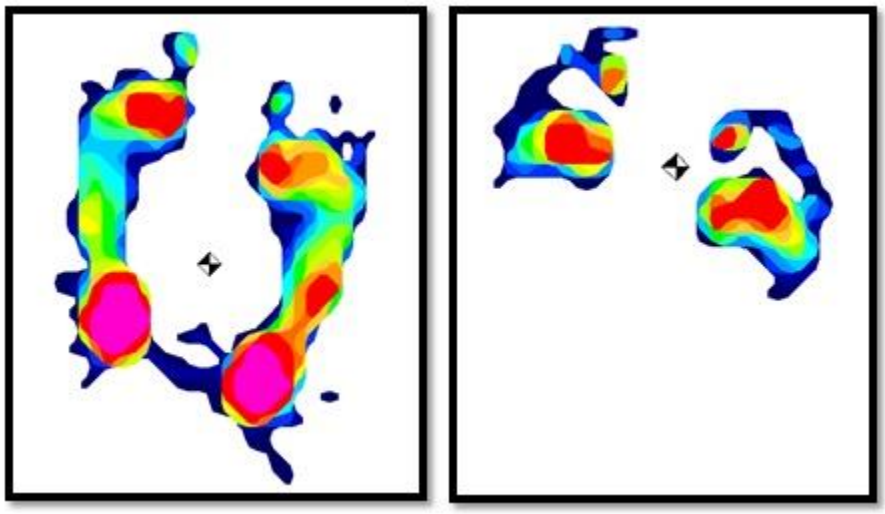
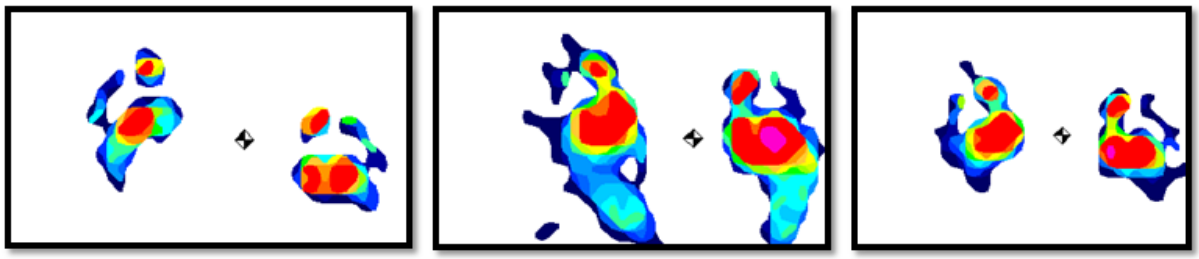


Participant 3

Back tuck, foot landings



Participant 1



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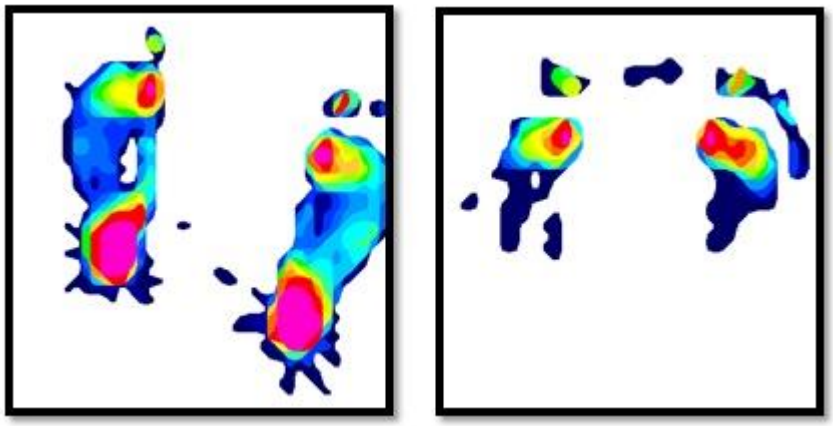

Participant 3

## 11. APPENDICES D: WRIST/HAND INJURIES

**All of the injuries were obtained from:**
**http://www.sportsinjuryclinic.net/sport-injuries/wrist-pain**

**Bennett Fracture:** A fracture and an often dislocation of the 1st carpometacarpal joint, which is at the base of the thumb where the hand metacarpal and the wrist carpal bones meet. Due to the placement of the 1st carpometacarpal joint and that there is often severe pain on the thumb pad of the wrist, high pressure on the pinkie pad and thumb pad indicate a possibility of a bennett fracture.

**Metacarpal Fracture:** Any of the five long bones (carpals) in the hand can be fractured. There is a chance any tumbler can break a metacarpal if they land wrong.

**Scaphoid Fracture:** A fracture that occurs to the scaphoid, which is a carpal bone that can be found in the wrist. The scaphoid is on the side of the hand below the thumb, so high pressure on the thumb side could indicate a possibility of a scaphoid fracture.

**Smiths Fracture:** A fracture that occurs at the end of the radius bone at the wrist. The fracture occurs for an impact with the wrists either flexed or bent with the palms down. So, high pressure on the wrist pad would indicate a possibility of a smiths fracture.

**TFCC Tear:** An injury to the triangular fibrocartilage complex (triangular fibrocartilage disk, ulna meniscus, ulnar collateral ligaments, several carpal ligaments, and extensor carpi ulnaris tendon sheath) between the end of the ulna and the carpal. This is a common tear in gymnastics due to weight bearing. Since the wrist pain would occur on the pinky side of the finger, higher pressure on the pinky side of the wrist could indicate a possibility of a TFCC tear.

**Triquetrum Fracture:** A fracture that occurs to the triquetral bone, which is one of the carpal bones in the wrist. The scaphoid is on the side of the hand below the pinky, so high pressure on the pinky pad could indicate a possibility of a scaphoid fracture.

**Volar Barton Fracture:** A barton fracture is a fracture of the distal radius at the base of the thumb. It is a volar barton fracture due to the fracture would occur on the palm side, so high pressure on the thumb pad could indicate a possibility of a volar barton fracture.

## 12. APPENDICES E: ANKLE/FOOT INJURIES

**All of the injuries were obtained from:**
http://www.sportsinjuryclinic.net/sport-injuries/ankle-achilles-shin-pain
http://www.sportsinjuryclinic.net/sport-injuries/foot-heel-pain

**Ankle Impingement:** Occurs when there is a bony growth at either the front or back of the ankle bone where it meets the shin bone. Depending on where the growth is, it could possibly restrict the normal ankle range of motion. This can develop over time due to repeated ankle sprains.

**Calcaneal Bruising:** Bruising to the tissues under the calcaneus causing pain. There is a good possibility of bruising since the heel is landed on repeatedly with high pressure during landings of tumbling.

**Calcaneal Fracture:** A fracture to the calcaneus bone. There is a good possibility of high pressure on the heel, especially during back tucks due to falling from a height straight onto the heel, which could lead to bruising of the heel/calcaneus.

**Haglund's Syndrome:** A condition where retrocalcaneal bursitis and achilles tendonitis occur at the same time in the same leg. This is possible due to immediate dorsiflexion when landing creates pressure over the entire foot, the achilles tendon and the bursae of the ankle are greatly affected.

**Midtarsal Joint Sprain:** A sprain to the ligaments holding the midtarsal joint together, which causes pain in the outside middle of the foot. This is more commonly seen in gymnastics, so high pressure on the mid-outside of the plantar aspect of the foot.

**Peroneal Tendonitis:** The inflammation of the peroneal tendons, which run behind the lateral malleolus, which causes swelling and pain on the outer ankle. Pain may occur by inverting the foot, so turning foot inwards during landings could possibly cause peroneal tendonitis.

**Potts Fracture:** A fracture that occurs to the either the lateral malleoli or medial malleoli of the ankle. This time of fracture is possible when there is high pressure on the foot rolling inward during a landing.

**Turf Toe:** Typically occurs after a very vigorous upward bending of the big toe, which causes a sprain to the ligaments under base of the big toe. So, high pressure at the base of the big tea could be an indication for possibility of turf toe.