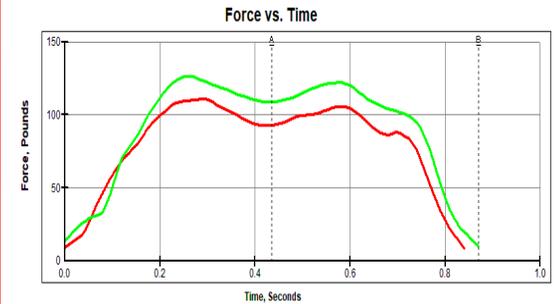
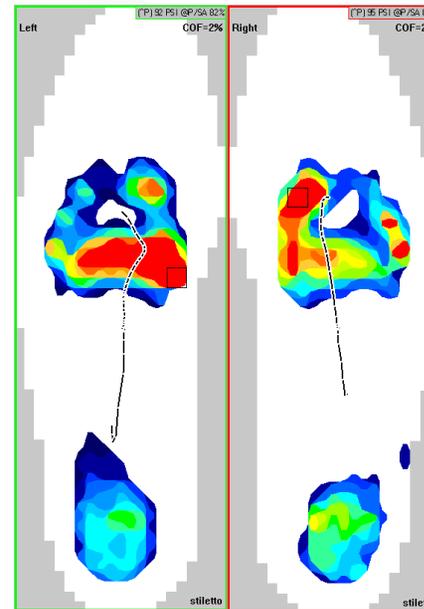


# AN EVALUATION OF IN-SHOE PRESSURE AND CENTER OF FORCE TRAJECTORIES FOR DIFFERENT HIGH-HEELED SHOES USING THE **F-SCAN™** SYSTEM



**A Study on the Effects of Heel Height on Biomechanics**

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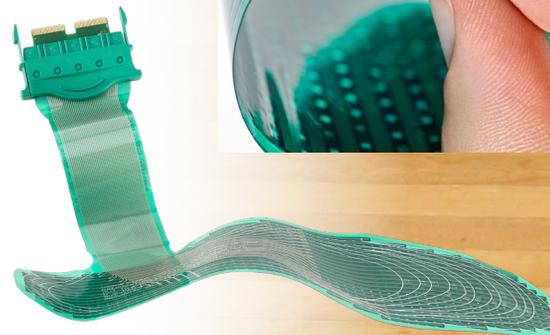
## Introduction:

Several studies have shown that high heels cause alterations in balance, and are responsible for changes in the center of pressure (CoP) and plantar pressure. Additional studies have also shown that heel rise can induce adverse biomechanical effects, which may lead to an uneven distribution of plantar pressure.<sup>1,2</sup>

Footwear researchers and designers employ visual observation to identify abnormalities in how an individual walks in their shoe designs. There are important nuances in both in-shoe pressure distribution and center of force (CoF) that may go unnoticed by visual observation alone.

The **F-Scan™ in-shoe pressure mapping system** utilizes ultra-thin and flexible pressure sensors that conform within a subject's shoe. This high-resolution pressure-sensing system captures temporal parameters in addition to pressure and force.

The goal for this study was to measure how different high-heeled shoe heights would affect in-shoe pressure distribution, CoF trajectory, total force amplitude, and asymmetries between left and right feet.



The flexible F-Scan sensor is a high-resolution array of sensing points that fits seamlessly into almost any shoe type or size.



## Experiment Summary

A healthy female subject in her 20s (52 kg weight) was instructed to walk at a comfortable pace in four different types of shoes. With F-Scan sensors inserted into both the left and right shoes, the subject was instructed to take approximately four to five steps while wearing each shoe type.

The F-Scan System which uses ultra thin sensors (0.152 mm) was inserted in the shoe data was collected at 50Hz. The high resolution sensors have a sensel density of 3.9 sensels/cm<sup>2</sup>.

The following parameters were evaluated to determine the effects of the footwear on the subject's gait:

- **Plantar Pressure:** The distribution of forces over the sole of the foot; in this case, during walking. This can provide indications of foot function.
- **CoF Trajectory (CoFT):** The direction and behavior of the concentration of force as the subject completes their gait cycle. This parameter is used to identify balance control and foot function.

## Shoes Types Used in the Experiment



Sandal



Boot



Wedge



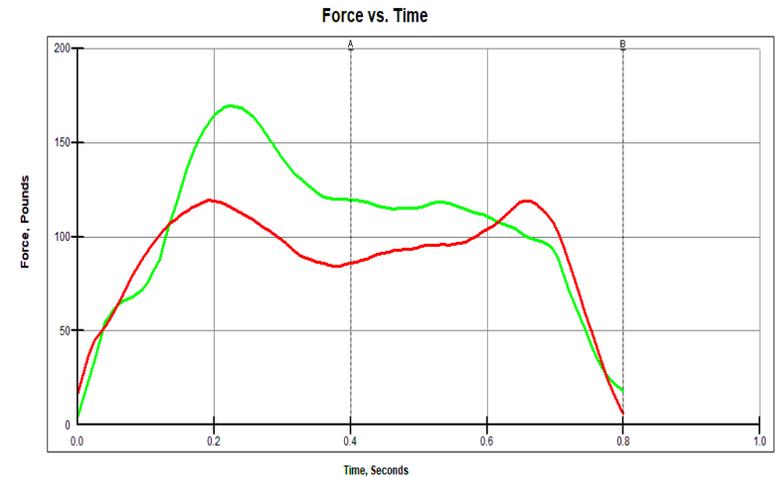
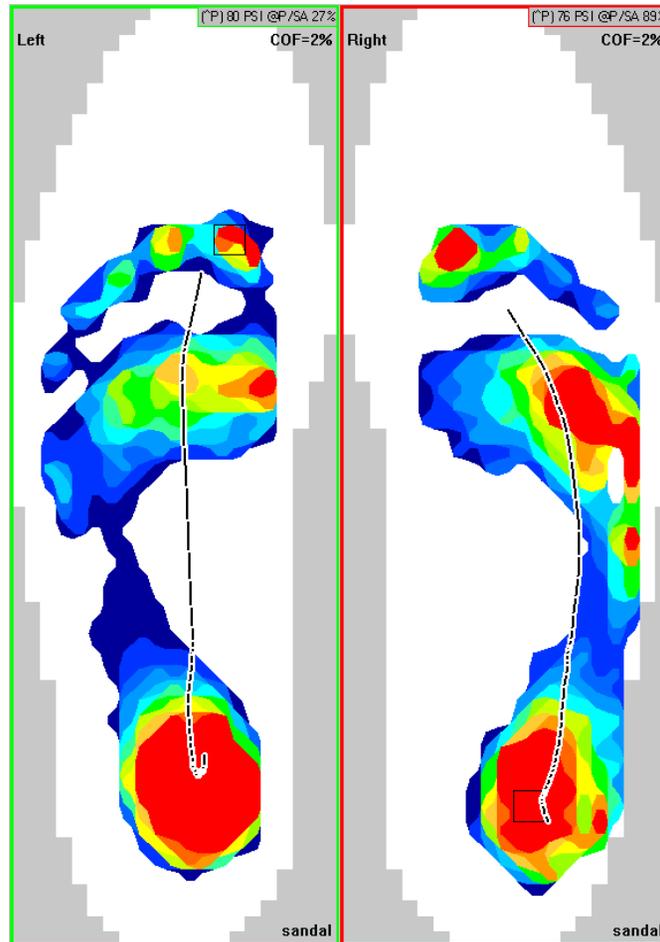
Stiletto

## AVERAGED RESULTS - SANDAL



Sandal

- There are high pressure areas in the heels of both feet, with some higher lateral pressures through the mid-foot.



- There are differences in total force amplitude between the left and right feet. The left is consistently higher than the right.
- There is not a significant difference in stance duration.

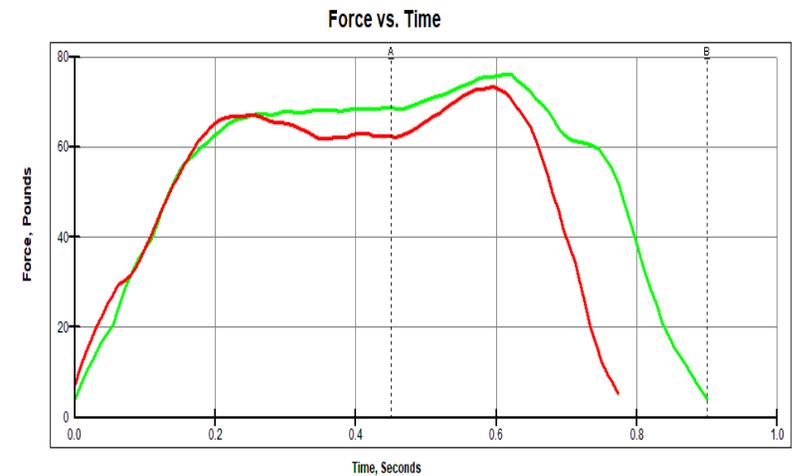
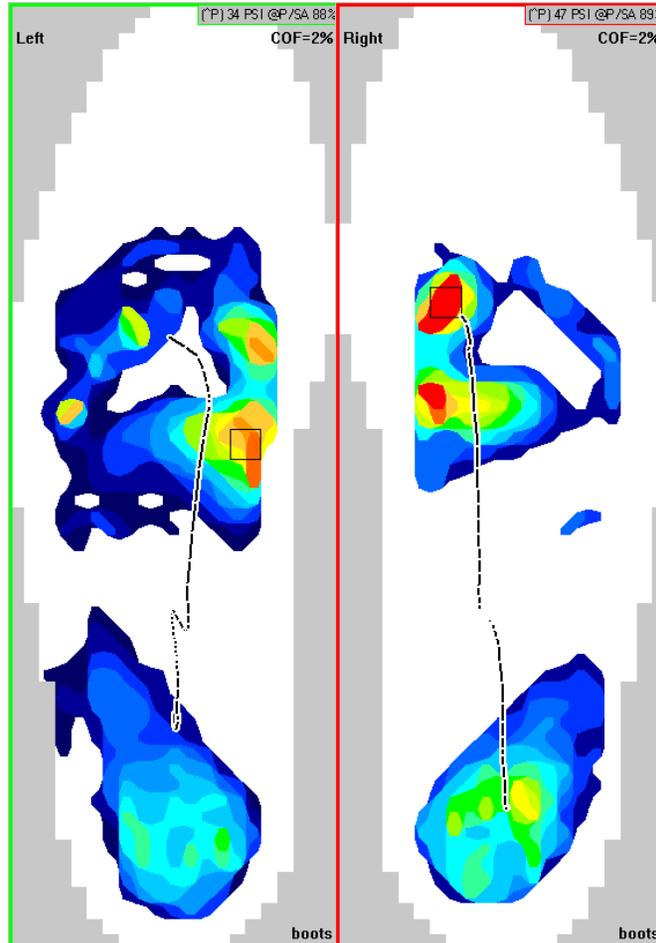
- The CoF trajectory looks similar to what you would expect in a barefoot condition.
  - CoF starts mid-heel and progresses slightly lateral to the center line of the foot. It moves laterally as it approaches the forefoot region.
  - Notice that the CoF line trajectory moves consistently in a forward progression, without noticeable changes in the mid-foot region.

## AVERAGED RESULTS - BOOT



Boot

- There are higher pressures in the forefoot regions, specifically in the medial areas of the forefeet.
- There is a little lateral pressure through the mid-foot areas, but still less pressure than the sandal condition.



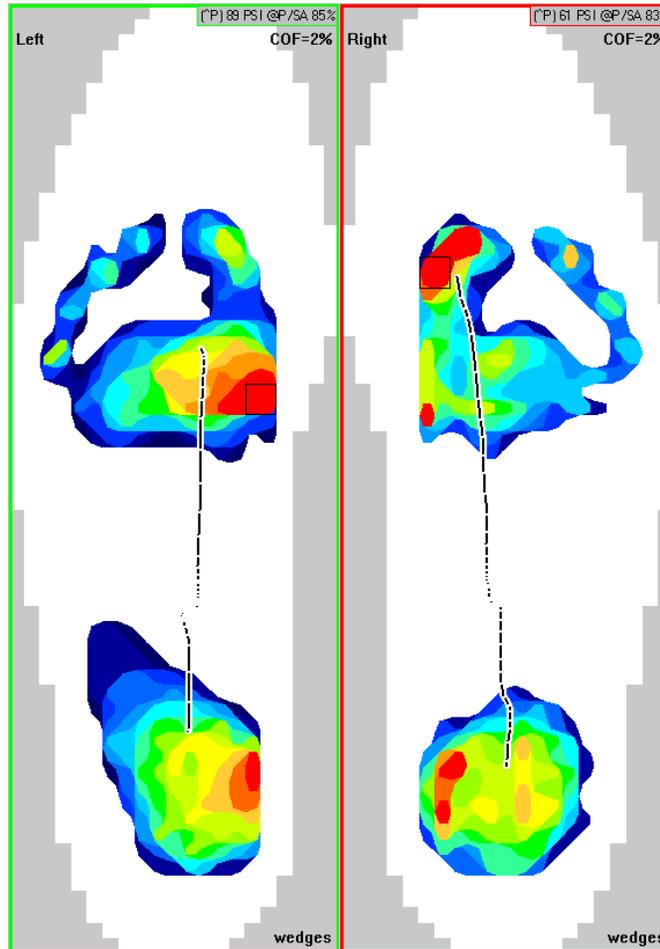
- The amplitude of force is symmetric between the left and right feet.
  - There is a significant difference in stance time, where the left foot spends more time in stance versus the right.
- The CoF trajectory has a slight interruption at the mid-foot region. This could be related to instability during the gait cycle, as there is a medial shift from the trajectory of the CoF from the center line of the feet, to the medial portion of the forefeet.

## AVERAGED RESULTS - WEDGE

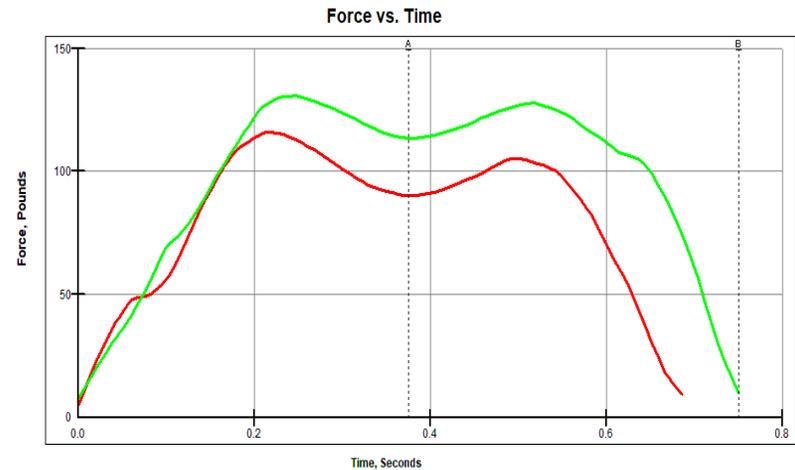


Wedge

- There is more even distribution of pressure between heel and forefoot.
- Like the boot condition, there is no pressure in the mid-foot, and a concentration of pressure on medial portions of the heels and forefeet.



- The CoF trajectory presents a slight delay occurring in the mid-foot portion of the stance phase. This could be due to instability or a function of the material in the shoe.



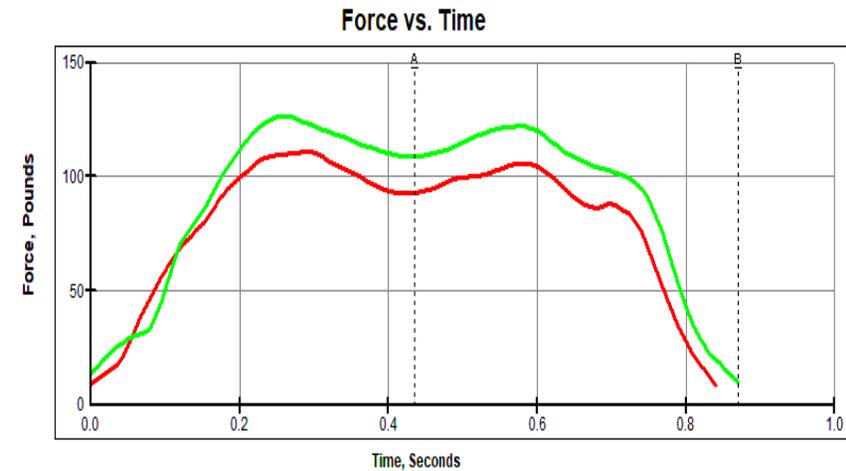
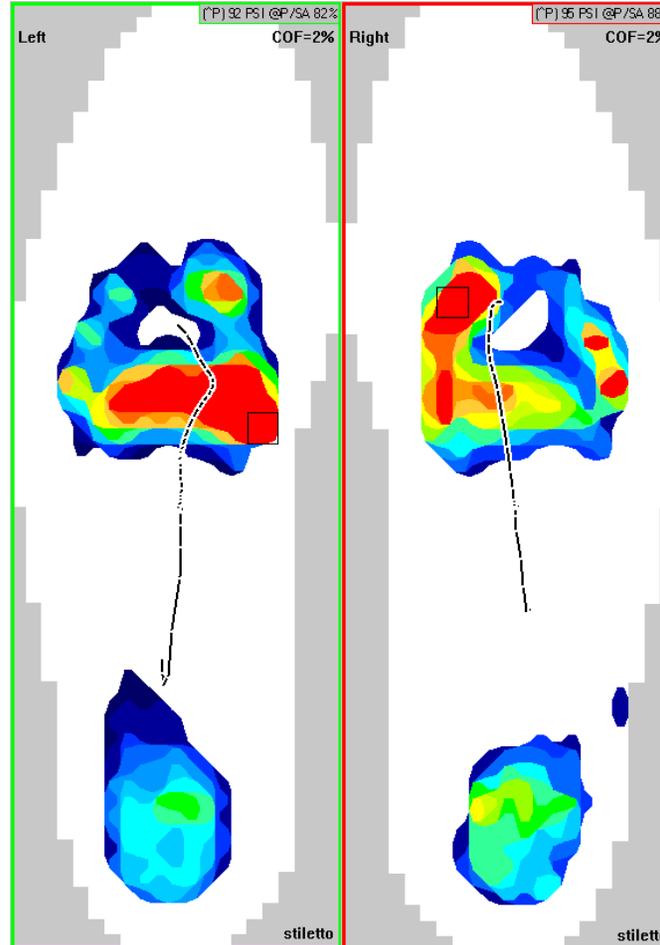
- There is similar asymmetry in the force curves between the left and right feet, where the left foot is producing more total force.
- The left foot maintains contact with the ground for a longer duration than the right.

## AVERAGED RESULTS - STILETTO



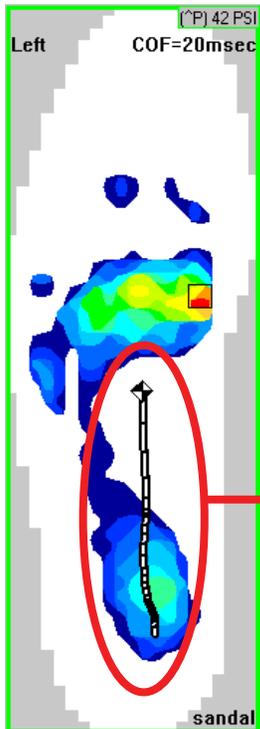
Stiletto

- Like the boot and wedge conditions, there is a significant lack of pressure in the mid-foot area.
- There is exceptionally higher pressure in the forefoot and big toe
- There is lower pressure at heel level.



- There is an asymmetry in total force generated between the left and right feet.
  - Higher forces are found in the left foot versus the right.
- The CoF trajectory shows asymmetry between the left and right foot, beginning at the mid-foot area and progressing to the forefoot.
    - The CoF appears to move backwards at the first contact point, then progresses forward.

# Center of Force Trajectory Broken Down by Phases of Gait



Center of Force trajectory as identified by the F-Scan software. The spacing between each hashmark represents CoF function.

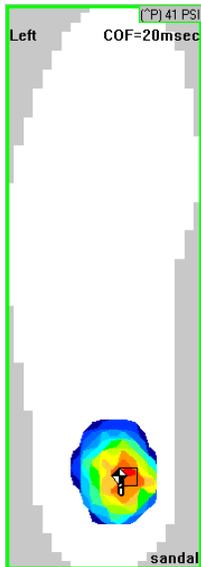
- Longer spacing = Higher velocity
- Shorter spacing = Reduced velocity, or a lack of forward movement



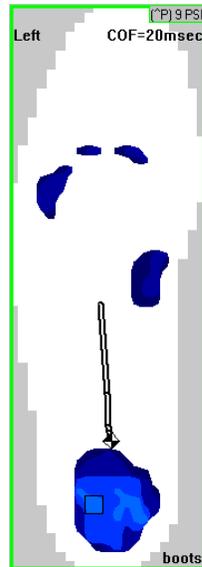
## RESULTS - TRAJECTORY COMPARISON AT 13% OF STANCE



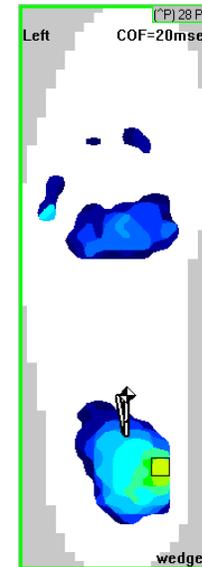
Sandal



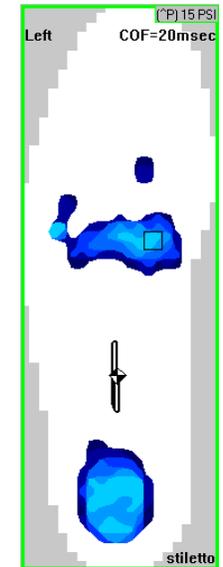
Boot



Wedge



Stiletto

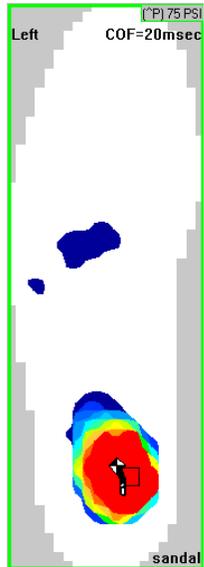


- Notice the CoF for the Stiletto and Boot conditions begins in the mid-arch region of the foot, then moves backward as the heel loads. We see the same with the Wedge condition, but to a lesser extent.
  - The initial starting point for the CoF is likely due to the higher heel on the footwear, which changes the way the foot impacts the ground.
- The Sandal condition, which is closest to a barefoot condition, shows higher pressure at the heel of the foot, while the CoF progresses forward.

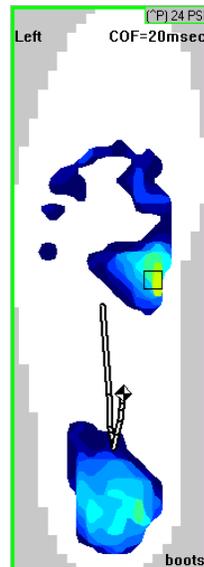
## RESULTS - TRAJECTORY COMPARISON AT 25% OF STANCE



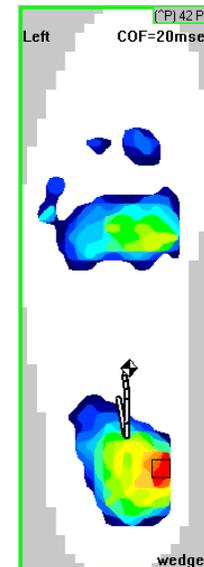
Sandal



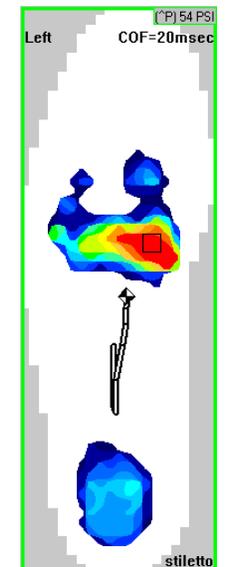
Boot



Wedge



Stiletto

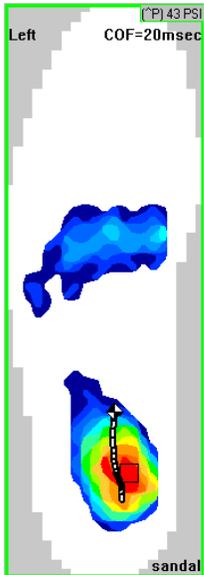


- There is a CoF in all high-heeled conditions progressing through the mid-arch region of the foot.
- The Sandal condition is just completing the heel-loading phase, and the 4th and 5th metatarsal heads begin to load.
- There is a distinct difference in the position of the CoF in the High-Heeled conditions versus the Sandal.

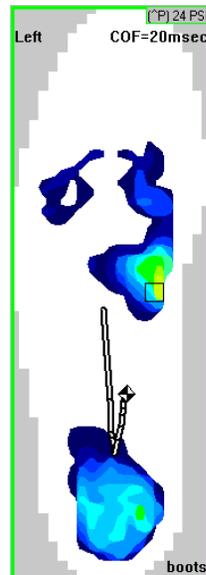
## RESULTS - TRAJECTORY COMPARISON AT 50% OF STANCE



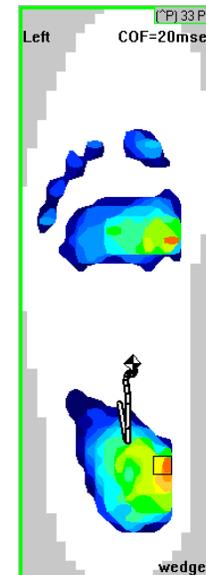
Sandal



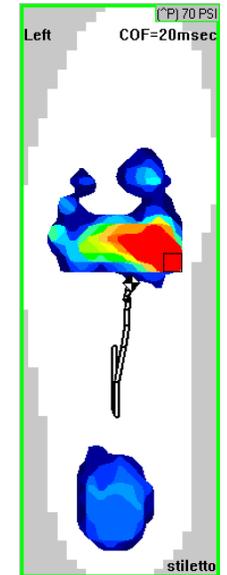
Boot



Wedge



Stiletto

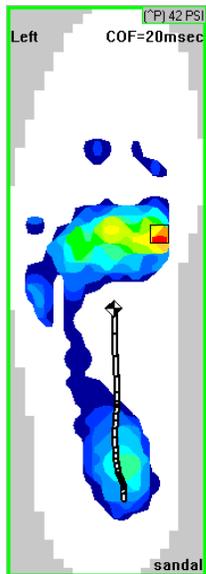


- At 50% of the stance phase, there is minimal movement of the CoF among the High-Heeled conditions. It seems as though the CoF has stalled at this point, where you can now see the CoF start to deviate to the medial aspect of the foot.
- The Sandal condition shows a fairly consistent CoF movement from the heel to the mid-foot, with the forefoot clearly loading.

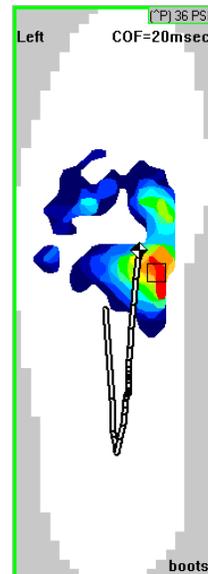
## RESULTS - TRAJECTORY COMPARISON AT 75% OF STANCE



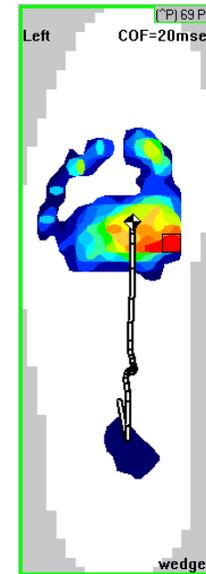
Sandal



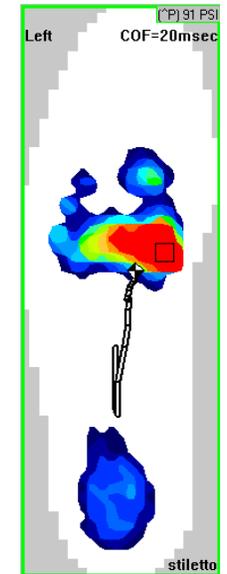
Boot



Wedge



Stiletto



- At 75% of the stance phase, the forefoot is loading clearly in all conditions.
- There is a concentration of force in the 1st metatarsal in all conditions.
- The Sandal condition still shows some heel contact and a CoF that is trailing in the High-Heel conditions.
- As for the CoF trajectory shape, all the High-Heeled shoes conditions tend to spend very little time in the heel phase. The Sandal condition spends more time loading the heel. This is obviously expected due to the pitch-forward created by a high-heeled shoe.
- It is interesting to see the CoF stalling around the mid-arch region of the High-Heeled conditions, where it moves smoothly in the same region of the Sandal condition.

## Conclusions

Based on the F-Scan data, heel height had a significant effect on the subject's gait pattern and CoF trajectory. The subject demonstrated shorter stride lengths while wearing high heels, and stepped with greater force on the front of her foot. In particular, the Wedge and Stiletto data displayed significant asymmetries. Also, the CoF trajectory would trail, and even go backward, while in some of the High-Heel conditions. Over time, this activity could prompt discomfort to the subject's ankles, hip, and spine.

Researchers are continuously seeking ways to make high-heeled shoes more comfortable and functional.<sup>3</sup> With this technology, researchers in the field of gait analysis and biomechanics can replicate and improve upon the research referenced in this article. Moreover, with the help of the F-Scan system, shoe designers and manufacturers have an effective tool to measure the impacts of their design decisions.

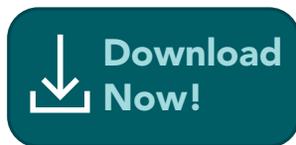
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- (2) Neil J Cronin, The effects of high heeled shoes on female gait: a review. *J Electromyogr Kinesiol.* 2014 Apr;24(2):258-63. doi: 10.1016/j.jelekin.2014.01.004. Epub 2014 Jan 24.)
- (3) Perez-Cortes, A., Silva-Moreno, A., Alvarez-Camacho, M., Hernandez-Trejo, M., Sotelo-Barroso, F. Plantar Pressure Analysis of Inserts in High Heeled Shoes. (2013) XXIV Congress of the International Society of Biomechanics/XV Brazilian Congress of Biomechanics

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