Analysis of the Human Gait: The Effect of Footwear

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ABSTRACT

High heel shoes are prevalent in society today, with many individuals wearing them frequently, however this footwear is known to cause pain. In this project, the ankle, knee, and back along with joints and muscles related to these parts of the body, such as the ankle joint, Achilles tendon (AT), the patella tendon (PT), and the rectus femoris (RF), were analyzed. Two females, both approximately 130 lbs that wear U.S size 8.5 shoes, were used as subjects. There were three types of footwear: flat foot (FF), high heel 1 (HH 1) which was 3 inches tall, and high heel 2 (HH 2) which was 4.5 inches tall. Kinematic data showed that as heel height increased, step width, and gait speed decreased while cadence increased. It can be concluded that heel height within footwear alters gait characteristics. Kinovea software was used to measure ankle, knee, and back angles which consists of thoracic, thoracolumbar, and lumbar angles. A free body diagram of the ankle and knee was created to calculate the force applied on the PT, ankle joint, and AT. The calculations showed that there was a greater force applied on both tendons and the ankle joint when increasing heel height. The increased force limits the range of motion (ROM) of the tendons and joints, which alters dorsiflexion in the ankle, and, in a study by Hunt et al. 2015, found that this leads to an increased risk of plantar fasciitis. Kinematic angle analysis showed that the ankle angle from FF to HH 1 to HH 2 increased. These greater angles at all phases of gait while wearing HH 2 shows the change in dorsiflexion during the entire cycle. The larger force exerted on the AT from FF to HH 2 leads to stiffness of the AT making walking more difficult and painful. The limited ROM of the knee was reflected in angle measurements during gait that measured smaller angles during the loading response, terminal stance, swing phase of the gait cycle. It was concluded that wearing high heel shoes leads to stiff-knee gait, which can be seen in cerebral palsy (CP) patients. In a study by Delp and Piazza 1996, this stiff-knee gait is attributed to an increased use and force on the RF which is connected to knee pain due to the change in RF stimulation. Analyzing the back, there was a decrease in the thoracic angle from FF to HH 2 reflecting a greater chest thrust. The Mayo Clinic has found this to alter back stability and weaken back muscles making walking harder and increasing back pain. The thoracolumbar and lumbar angle increased demonstrating increased lordosis. The larger curvature of the spine is caused by the pelvis tipping forward which Araújo et al. 2017 found to increase back pain due a smaller ROM from the increased muscle tension related to the alteration in the pelvis position. The changes in angles and forces felt on the body along with alterations on posture cause a greater chance of discomfort and of injury.

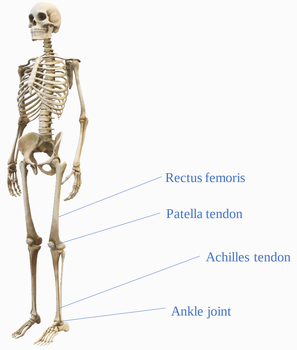
BACKGROUND

Gait

Gait is the study of how individuals walk. The angles measured were observed during three phases of gait; heel strike, toe off and midstance. The heel strike phase is when the foot, normally the heel, initially contacts the ground. Toe off is when the contralateral foot of interest is in its final moment of contact with the ground. The last stage is the midstance where the contralateral foot is above the one of interest placing all the force onto one leg. The back is crucial in terms of walking as it provides support to the body and helps keep it upright. Over time wearing heels can impact a person’s posture and center of gravity which will allow for back pain to arise.

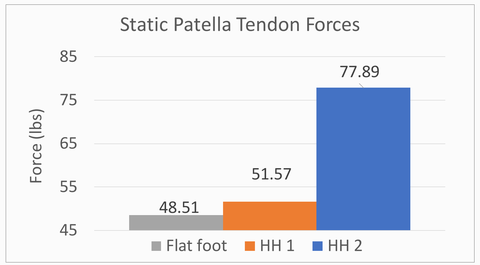
Muscles, Tendons, and Joints

The knee, ankle, and back were all examined to quantify the forces and angles put on the body while walking in heels as compared to walking barefoot. These places all play a crucial role in allowing for gait, how a person walks, to occur. If any of them were not working correctly, it can lead to a disorder within an individual's gait (McCrory et al., 1999)(Kim et al., 2015). The knee is an important joint utilized for walking. It acts like a hinge joint but can withstand some rotation. The patellar tendon is one of the main tendons in the knee used for walking. It specifically plays a role in the straightening of the knee during gait. Injuries to this tendon can lead to trouble extending an individual's leg during gait. The ankle connects the tibia and fibula to the foot. It is important as the ankle is used in human gait to adapt to the surface that an individual is on. One of the most important tendons in the ankle for walking is the Achilles tendon as it transfers the power from the calf to the foot (Pabon et al., 2021). Individuals who tend to wear high heels over time saw injuries in these specific tendons of these joints caused from increased forces exerted on the leg. Ultimately, over time this extra stress can produce an overall effect on their gait (Lee et al., 2014).



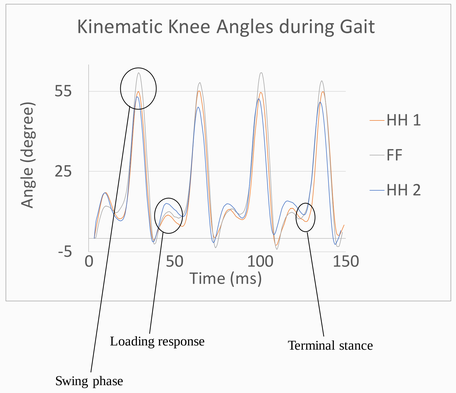
KNEE

Static Analysis



HH 2 saw a 46.5% increase in force on the PT from HH 1 and a 6.1% increase from FF. As the heel heigh increases, so did the force exert on the supporting tendons. As the force on the tendon increases, knee ROM decreases. This alteration in gait increases risk of injury since the knee will not be able to straighten when walking.

Kinematic Angle Measurements



The loading response, terminal stance, and swing phase during the gait cycle saw decreasing angles with increasing the heel height. It can be concluded that high heel walking mimics stiff-knee gait due to the loss in ROM. This gait disorder strongly resembles CP patients (Choi et al. 2017). Thus, aspects of discomfort and pain for high heel wearing and CP patients will be the same due to the similar gait trends seen in knee angle measurements. The similar gait disorder is observed mainly within the swing phase. A lower angle within the swing phase reflects an increased use of RF along with a greater force exserted on it. Delp and Piazza 1996 found that the overuse of RF is directly correlated to knee pain, which was both reported by high heel users and CP patients. As the force increases, the muscle becomes exhausted quicker, ultimately weakening it and making it more susceptible to injury (Garrett et al. 1996).

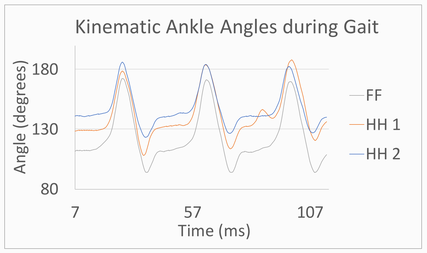
ANKLE

Static Analysis

	FF	HH 1	HH 2
Achilles tendon force (lb)	100.06	127.10	150.80
Ankle joint force (lb)	28.71	68.53	40.10

The AT force increased from by 18.65% from HH 1 to HH 2 and increased by 50.71% from FF to HH 2. Between HH 1 and HH2 there was a 18.65% increase in the force the AT endures while HH 2 was used. The AT force increased from each footwear by approximately 19%. As for the ankle joint force, it decreased by 41.49% from HH 1 to HH 2, however both high heels exhibited greater forces on the ankle joint in comparison to FF data. From FF to HH 2, the ankle joint increased by 39.67%. Generally, for the main joints and tendons within the ankle, the force applied on them increases with greater heel height.

Kinematic Angle Measurements



During the entirety of the gait cycle, HH 2 had the largest angles, followed by HH 1, then FF. The decrease in ankle angle while wearing high heel shoes is due to the alteration of dorsiflexion. Whenever the ankle is placed in a position other than its natural angle, there is a greater risk of injury such as plantar fasciitis (Hunt et al. 2015). As heel height increases, the angle of the ankle will also increase making it more likely to obtain an injury.

BACK

Static Analysis

	FF	HH 1	HH2
Thoracic angle (°)	147.5	146.9	144.4
Thoracolumbar angle (°)	173.9	179.3	180.8
Lumbar angle (°)	172.3	180.9	183.7

The decrease in thoracic angle from FF to HH 2 means an exaggerated kyphosis, which is the forward rounding of the back leading to the chest being thrusted. Mayo Clinic has found to make walking harder due to weaken back muscles. This alteration in back stability can lead to back pain due to the shift center of gravity (Fasih-Ramandi et al. 2019). This shifting along with increased pressure on muscles supporting the spine causes pain and discomfort in the back (Fasih-Ramandi et al. 2019). In addition to increasing chest thrust during high heel gait, the thoracolumbar angle and lumbar angle demonstrate a decrease from FF to HH 2 which reflects a greater curvature of the lower back while wearing high heel shoes. This is known as lordosis. Lordosis is an outcome of a greater pelvis tilt. Pelvis tilt increases muscle tension of neighboring muscles creating a change in the spine’s position (Araújo et al. 2017). This also causes a shift in back stability and center of gravity leading to a greater chance of pain.

GAIT CHARACTERISTICS

Characteristic	Shoe Type	Subject 1	Subject 2
Step Width (inch)	HH 2	2.547	2.552
Step Width (inch)	HH 1	2.587	2.636
Step Width (inch)	FF	2.642	2.654
Cadence (steps/min)	HH 2	66	66
Cadence (steps/min)	HH 1	66	66
Cadence (steps/min)	FF	60	60
Gait Speed (ft/sec)	HH 2	1.2708	1.2733
Gait Speed (ft/sec)	HH 1	1.2908	1.3150
Gait Speed (ft/sec)	FF	1.3183	1.3242

Gait speed, step width, and cadence were each examined for both individuals. It was found that as heel height increases gait speed (ft/sec) and step width (inches) decreases while cadence (steps/min) increases.

CONCLUSION

Wearing high heels over time can significantly increase an individual's chance of obtaining an injury. It is apparent as both heel heights (HH 1 & HH 2), especially at the midstance, show a significant difference in angle and force being applied on the leg, back, and ankle. An individual in heels is also taking many smaller steps to walk at approximately the same speed as they would barefoot. This is because heels change the person's center of gravity to shift forward so they are trying to offset their body position back to normal and more stable. The next steps for this project would be to test on more individuals, of varying shoe size, and see if their data will produce similar trends. Another step is to insert a pressure sensor into each shoe when a person walks to identify places of high stress while walking at different parts of the gait cycle.

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