Barefoot and Shod Running: Force on the Knee

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Abstract

While running is a very popular means of exercise, it is known for causing injuries due to the stress running places on the body. This paper defines the biomechanics of running and outlines the different styles of running and their impact on the body. An Arduino 101 board was used to measure changes in acceleration and the shock difference in running with and without shoes. The data shows that shod running (running with shoes) places more impact on the front of the leg (i.e. the knee) and promotes a rear foot strike style while barefoot running places more impact on the back of the leg (i.e. the calf) and promotes a forefoot strike style.

Introduction

It is no secret that running is one of the United States' most popular fitness activities. The fitness community can prove this, but the numbers also tell the same story. The total number of running events in the United States totaled 30,400, with 16,957,100 people participating in said events (US Road Race Trends, 2017). This huge number of participants also comes at a cost. The percentage of runners dealing with "running related injuries" is 30% at the low end, with other estimates as high as 79% (Running Knee Problems, 2014). These injuries not only prevent people from running, but can have serious, life-long effects. This issue of running injuries even extends to young runners, with one study showing 20% of high school cross country runners experiencing injury during the competitive season (Rauh et al., 2005). This begs the question, why do so many runners get injured?

For decades, many qualified and intelligent researchers have argued about what will solve the running injury problem (Knee pain and other running injuries, 2015; Altman and Davis, 2015). Some say that strengthening the lower kinetic chain will fix injuries, some say an increase in leg turnover is the key, and many think running is just too physically stressful for some people. No matter how they think it can be solved, one persistent issue is that of knee injuries. Knee injuries account for one third of all running related injuries and tend to be the most debilitating (Running Knee Problems, 2014). A potential solution to these knee injuries could be barefoot running.

Barefoot running has burst onto the scene in the last five years as a new way of running injury free. Many tout it as the "natural way to run," as is the case in New York Times bestselling author and former journalist Christopher McDougall's book Born to Run. In the book, McDougall tells the story of a Mexican tribe who runs barefoot, or with old tires for shoes, and can beat some of the best marathoners in the world. He also proclaims the health benefits of running in minimalist shoes. This minimalist shoe (i.e. barefoot running) trend has also broken into the commercial market. Many shoe companies have come out with their versions of a minimalist shoe, from the extreme example of Vibram's line of no cushion shoes to Merrell's attempts at a minimalist trail shoe (Ryan, 2016). Not only does pop culture embrace barefoot running, but much scientific research has been done on the subject. For example, a study from the *Journal of Athletic Training* in 2016 examined the effects of minimalist shoe running and negative and positive force on the knee. Their study showed that there was a decrease in both negative and positive force on the knee when running barefoot (Fuller et al., 2016). With every study that comes out in support of barefoot running, there are other counterpoints to the argument. In the same study, it is shown that there is more plantar flexion during barefoot running, which stresses the ankle (Fuller et al., 2016). This seems to discredit barefoot running as a way to avoid injuries, but there may be other advantages to running barefoot such as a faster cadence and a forefoot strike. These advantages are expanded upon later.

Before examining styles of running, one has to know the basic biomechanics of running. A typical running gait goes through three phases (Nicola and Lewison, 2012). The first, the stance phase, involves the foot striking the ground and the runner being momentarily locked in this stance. This phase involves a lot of muscles (i.e., tibialis anterior, gastrocnemius, and soleus) in the lower leg (i.e., foot, ankle, and calf). This is followed by the second phase, the swing phase. During the swing phase, the leg, which is not planted, is pulled back by the hamstring, quadricep and glute. This is when a runner typically swings the opposite arm to gain momentum. These major muscle groups are typically the most worked during running (Nicola and Lewison, 2012). The third phase is the float phase, where the runner is literally floating when both feet are off the ground. No muscles are really at work in this phase, since the runner is not making contact with the ground. Almost every muscle in the body, from the toes to the upper torso, is involved when running (Nicola and Lewison, 2012).

The biomechanics involved with running and the resulting pressures on the knee differ with the styles of running. As with the cause of running-related injuries, many doctors and trainers have argued over which style is best. There are three different styles of running that all runners use (Nicola and Lewison, 2012). The most popular of which is the rear foot strike (RFS) or heel strike. This type of running involves the leg jutting out in front of the runner's center of mass and the heel making initial contact with the ground (Figure 1). From there, the runner's foot rolls on the ground and makes a second point of contact with the forefoot, where the toes meet the body of the foot. The runner then pushes off this second point of contact and propels his or her body forward and the motion is repeated. Biomechanically, the movements of RFS tend to place force on the front of the leg (Lindsey, 2018). This includes the shin, quadricep and knee (Nicola and Lewison, 2012) proving that RFS places force on the knee.

Another style of running is the forefoot strike (FFS). The runner runs on the toes or ball of his or her foot and leans forward while doing so (Figure 1). A runner will naturally go to this style when running barefoot or when wearing minimalist shoes (Lindsey, 2018). FFS tends to place force on the back of the runner’s leg. Instead of shock being absorbed by the knee and quadricep, the calf, hamstring and ankle absorb the shock (Lindsey 2018). The shock not being absorbed on the knee is not entirely beneficial though, as FFS results in more varus and valgus movement in the knee, commonly known as knock-knees and bowleg (Morley et al., 2010). FFS is more economical to the runner, since the legs are directly underneath the runner and a higher cadence of running is used. The legs act as springs rather than propellants (Morley et al., 2010).

The third type is the midfoot strike (MFS). In this type, the runner’s foot strikes the ground flat (Figure 1). There has been a lack of research done on this type of running, and the research that has been done is inconclusive.

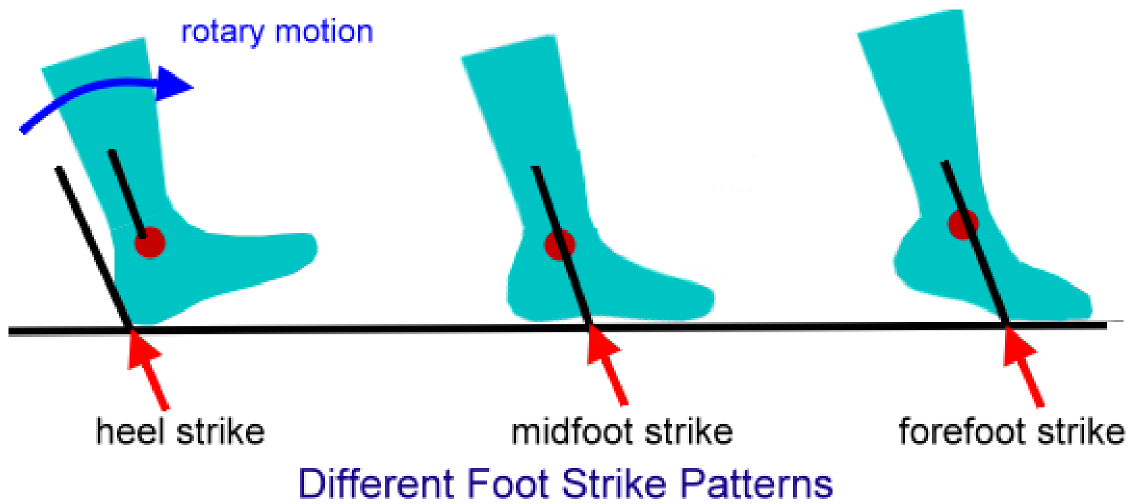

Figure 1. Three different types of foot strikes

Accelerometers in fitness trackers have been used in previous studies for various purposes. One of the most comprehensive studies comes from Zurich University, where researchers used a fitness tracker in a shoe to examine gait and balance in the elderly and motion of athletes during Olympic lifts (Adelsberger, 2013). The results showed that the accelerometer could not only accurately measure the velocity of movements, but could also provide valuable data to physicians regarding their elderly patient's gait. Another study centering around accelerometers in fitness trackers examines the computing architecture required to use tracker technology and whether it could be self-tested by the elderly to determine fall risk (Milosevic et al., 2013). The study concluded that the elderly could reliably use the fitness tracker to time and track their Timed Up and Go, or TUG, test data, which is a significant predictor of fall risk.

Though there has been research with the accelerometers, there has not been a study that collects acceleration data to determine shock, as this paper attempts to do. The accelerometer in fitness trackers have been proven to give reliable data. It can be assumed that acceleration data from a fitness tracker can be reliably used to determine shock.

Methods

This project involved diagraming and testing an experiment to demonstrate the different stressors running styles places on the body through measuring changes of acceleration. To measure the acceleration, an Arduino/Genuino 101 board was used because it has a built-in accelerometer (“Arduino 101”, 2018). The Arduino/Genuino 101 board requires that code be uploaded to in order to use the sensors on the board. The CurieIMU library has code to detect whether shock at a user input threshold has occurred, which is what was uploaded to the board (“Arduino - Genuino101 CurieIMU Shock Detect”, 2018). This code was then edited to collect acceleration data based on an example from the Blynk library (“Blynk Libraries”, 2017). Blynk is a mobile app that can communicate with independent boards, such as the Raspberry Pi or Arduino, using Bluetooth Low Energy, Wifi, or Bluetooth (“Blynk”, 2017). Based on the data sent from the board, the Blynk app can be configured to display the data in a variety of formats (e.g., simple value, chart).

For the actual experiment, the Arduino was placed on the distal side of a runner’s knee with a 9V battery as a power source. The Blynk app connected the Arduino with an iPhone via Bluetooth Low Energy and recorded acceleration data in the form of a graph. The x-axis displays acceleration while the y-axis displays time in the form of hh:mm. Unfortunately, the Blynk cannot display data related to shock, but Arduino 101 can detect shock given a threshold at which to detect it. Also, a higher acceleration can be directly equated to a higher shock, given the formula *Force = Acceleration*Mass*. Given this information, an educated guess can be made about the impact forces of barefoot versus shod running given a graph of acceleration and triggering of certain shock thresholds. In addition to measuring acceleration and shock, the number of steps taken during a minute was recorded. For all trials, the treadmill was placed at a

1% incline, to better simulate real world conditions, and a speed of 7.0 mph, a pace that was comfortable but was still running. The runner ran each trial for one minute and results were recorded.

Results

The purpose of measuring shock was not to give an exact measurement of force on the knee, but to test which type of running, barefoot or shod, would trigger a shock detection at a higher threshold. With the Arduino, shock detection occurred on all tests up to a threshold of 8 m/s^2 When testing shod running, shock was detected up to 9 m/s^2. When testing barefoot running, shock was detected up to 8.25 m/s^2. This means that there was a higher threshold of shock for shod running, and as such, there would be more impact on the knee when running while wearing a shoe.

For the next experiment, a clearer representation of the data can be given. Acceleration at the knee was taken for both barefoot and shod running with the data visualized in graphs.

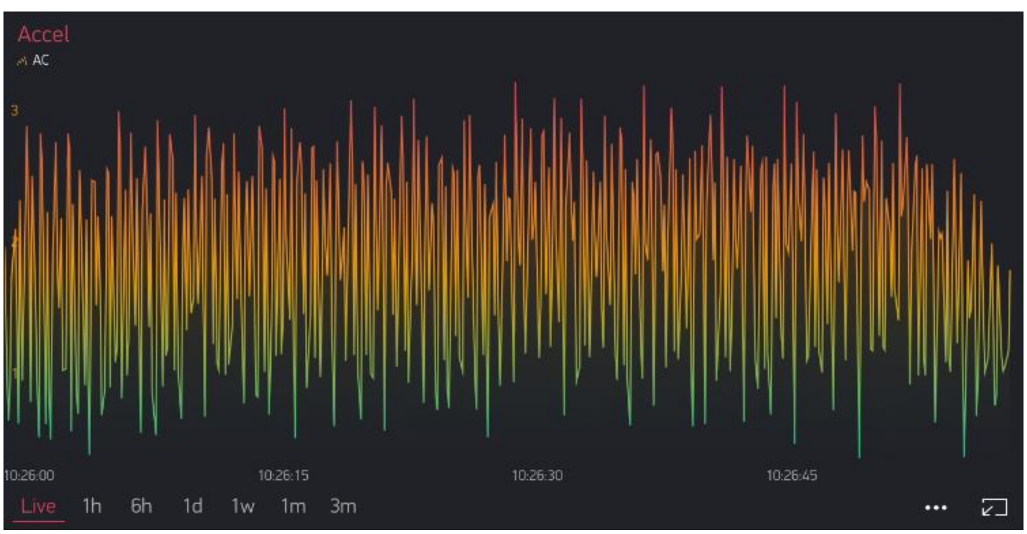

Figure 2, Acceleration Graph of Shod Running

Figure 3, Shod Running

Figure 2 illustrates the acceleration graph for shod running (Figure 3) with the Arduino attached to the knee. The acceleration of the knee in both directions is clear. Drawing a line through the horizontal middle of the graph would yield an almost mirror image of both sides. A clear pattern also emerges of a peak and a valley accompanying each other. This means that the stride length would be equal for both behind the body and in front of the body. As a result, a long stride can be assumed. Also, another point extrapolated could be that the stride is very consistent. Figure 3 captures important information as well: shod running promotes a RFS. It is clear from the picture that the heel lands, followed by a roll and a push off with the back leg becoming perpendicular to the body. From separate counting of steps, the average of five trials indicated a cadence of 79 steps-per-minute, with a full left-right-left leg motion being one step.

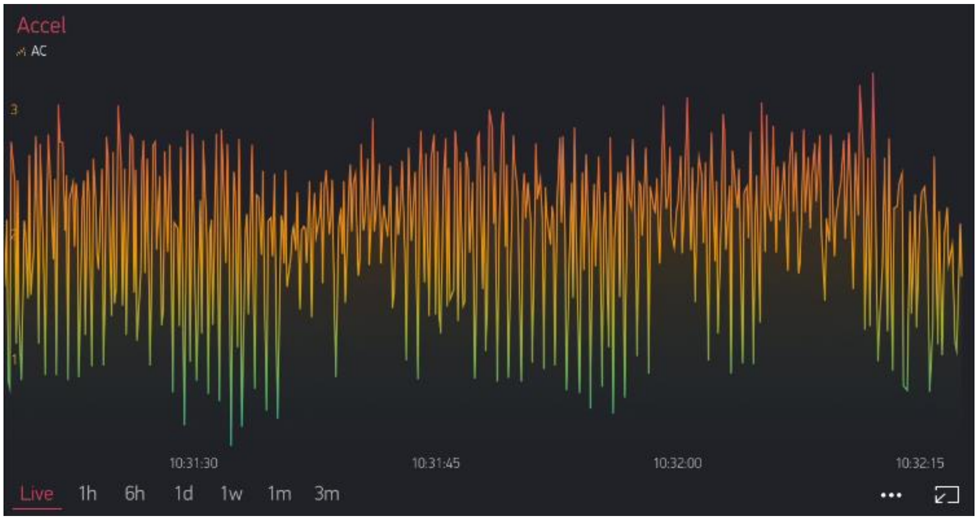

Figure 4, Acceleration Graph for Barefoot Running

Figure 5, Barefoot Running

The acceleration graph for barefoot running (Figure 4) is interesting in the fact that there is not a clear pattern. The most important point that can be extrapolated from it is that the deceleration of the knee is much less extreme than that of shod running, indicating a shorter stride length. This distinction can be made because the “down swings” of the graph are much lower in most areas than those of the shod running graph. This indicates a higher cadence, which can be confirmed through result of manual counting, which came out to be 85 steps-per-minute. One can confirm from the Figure 5 that barefoot running promotes FFS or MFS running. It is clear that the heel of the foot is not striking first, and that the trailing leg is not as perpendicular as shod running.

In addition to testing the knee, the Arduino was used to test whether there would be more force on the calf when barefoot running, as current scientific research would suggest. The calf was tested for shock in the same way as the knee was tested in the earlier explanation. When barefoot running, the shock detection threshold was set to 6 m/s^2 and triggered a positive result. Higher thresholds were tested but received no results; therefore, a shock of 6 m/s^2 is the ceiling. For shod running, the shock detection was set at 5 m/s^2 and triggered a positive result. These results mean that there is a higher shock, or force, on the calf when barefoot running than shod running, which aligns with current scientific research (Perkins et al., 2014).

Conclusion

The purpose of this study was to test the differences in the force impact on the knee using an Arduino board. It was hypothesized that there would be less force on the knee when running with a shoe on, shod running, than when barefoot. The opposite turned out to be true. Shod running promotes RFS, which puts more force on the knee and a longer stride length with fewer steps per minute. Barefoot running promotes FFS, which puts less force on the knee, more on the ankle and a shorter stride length with greater steps per minute. That being said, two important points were proved through this experiment. The first is that the barefoot running community and the shod running community, which both believe strongly in their ways and do not find benefits in the other technique, should realize that each style has their advantages and disadvantages. Runners should choose the style that puts less stress on the runner's more sensitive joints or muscles (i.e., knee versus calf). Another point proven is that technological applications in fitness are not just for elite athletes or scientists. The average runner can take a rather inexpensive device and with a little learning can replicate data being recorded in labs. This gives athletes the opportunity to test their own theories and experiment with themselves. This could lead to not only more educated athletes, but more technologically literate citizens.

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