DOI:10.2478/v10237-011-0057-0

Comparative Analysis of Barefoot and Shod Running

Colin UTZ-MEAGHER[1] • John NULTY[1]
Lisa HOLT[2]

This study investigated the biomechanical difference between running barefoot and shod before and after a barefoot training program (BTP). Foot angles at contact (FA), contact time (CT), stride length (SL), initial contact force (ICF), and total peak force (TPF) in shod and unshod runners was analyzed. Fourteen collegiate runners attended 12 total sessions over a two week period. Subjects performed a baseline trial, running eight (10-20 meter) repetitions, four barefoot and four shod, at three different stations; running over a force plate, running in front of a SONY DCR-HC52 video camera (30fps) and running in front of a Casio Exilim Pro EX-F1 camera (300fps). A Post-Test (PT) was conducted at the end of the BTP. A repeated measure ANOVA showed significance ($p<.05$) in the Test factor, BTP; lowering participants FA mean from 18.8deg+/-.9deg to 5.6deg+/-15.1deg, CT mean from .221m+/-.02m to .2m+/-.03m, and TPF mean from 1427.4N+/-312.9N to 1348.2N+/-269.4N. A repeated measure ANOVA showed significance ($p<.05$) in the Condition factor (shod vs. unshod); lowering participants FA mean from 23.1deg+/-12.6deg to 1.3deg+/-14.4deg, SL mean from .9m+/-.1m to .8m+/-.1m, and ICF mean from 1465.3N+/-369.6N to 1324.7N+/-379.4N. Running barefoot and following a BTP alters running biomechanics in ways that may decrease running related injuries.

Keywords: biomechanics, shod, barefoot, running

Running shoes have been developed to serve multiple purposes, which makes it common for a runner to own many pairs of shoes. Each type of shoe falls into a category: motion control, stability control, cushioned, lightweight, trail, and racing (http://www.about.com). According to Cavanagh (1990), the purpose of these different types of shoes is to reduce force, provide comfort

[1] SUNY Cortland, State University of New York College
[2] Ithaca College, Ithaca, New York

and stability, as well as improve form. People believe that shoes will prevent their running injuries; however, wearing shoes all the time weakens the foot because of a block in plantar sensory information (Dufek, Freedman, & Mercer, 2000). Running shoes also limit the function of the longitudinal arch, which is crucial during weight bearing activities (Kadambande, Khurana, Debnath, Bansal, & Hariharan, 2006).

The foot is one of the most important weight-bearing and shock absorbing structures in the human body during ambulation (Chen, Tang & Ju, 2001). The foot and ankle serves as the foundation of structural support, balance, and propulsion. According to Weyand and Davis (2005), the foot is flexible and resilient when encountering several tons of pressure during the course of a one mile run.

Barefoot running produces minimal external protection and shock reduction (De Wit, De Clercq, & Aerts, 2000). Therefore, alterations in running style are expected to be more pronounced in barefoot conditions compared to shod conditions.

Ground reaction forces and kinematic variables have been found to vary between barefoot and shod running (De Wit et al., 2000). Kinematically in the sagittal plane, barefoot running required a more extended body position and smaller touchdown velocity from the foot than shod running (De Koning & Nigg, 1993). This is consistent with the research by De Wit, B., De Clercq D. D., & Aerts P. (1996) which found barefoot running had a significantly larger step frequency, smaller step length, and less contact time versus the shod condition.

Miller (1990) defined ground reaction as the force that reacts to the push transmitted to the ground by the foot of the runner. The components of ground reaction force are equal in magnitude and opposite in direction from the force applied to the ground. The amount of force on the body fluctuates depending on how fast the individual is running.

Running at a slow jog requires producing a force of around 1.5 times bodyweight. As running speed increases, ground support forces increase also, reaching as high as 2.5 times bodyweight while running all out on level ground and even more when running downhill (Weyand & Davis, 2005, p. 1).

Dickinson, Cook, and Leinhardt (1985) found differences in ground reaction forces between barefoot and shod running. Results from their study indicated that a running shoe without a shock absorber increases the forces on the body. This is consistent with the findings by De Wit et al. (2000), who found that loading rates and impact peaks significantly increase with barefoot running in comparison to shod. Logan, Hunter, Feland, Hopkins, and Parcell (2007) found that with minimum or no cushioning, runners adjust to the increased loading rate and impact peak by increasing vertical stiffness. The increase in stiffness subsequently causes a greater negative vertical acceleration at ground contact.

There is little to no research incorporating a barefoot training program into a participant's workout. Research does examine the different kinematic variables in a runner, but does not differentiate which method of running, barefoot or shod, an individual should participate in. The differences between barefoot versus shod running has shown mixed results in the research [(Dickinson et al. (1985); Logan et al. (2007)]. Some studies show that there is a higher ground reaction force in barefoot running compared to shod running (Dickinson et al., 1985), while others have shown lower ground reaction forces in barefoot running than shod running (Logan et al., 2007). This may have resulted from volunteers not adapting to the lack of support on their feet. When participating in a barefoot training program, individuals will adapt to the changes in foot support and inevitably change the way they run. Such adaptations will significantly change certain kinematic variables which will later become beneficial to a runner's workouts and overall physical fitness.

The purpose of this study was to investigate the differences between barefoot and shod running and to see how effective a barefoot training program could be on an individual's body mechanics. Weyand & David, 2000; Defek, Freedman & Mercer; among others, has examined the differences in running technique between barefoot and shod running. Despite all of the existing research comparing the two methods of running, there is still debate whether a barefoot or shod condition is better biomechanically. In addition, there is no research on the effectiveness of a barefoot training program and its possible positive health benefits to runners. The aim of this study is to measure and compare the differences in barefoot and shod running, along with the effectiveness of a two-week barefoot training program. Measurements in the study will consist of stride length, stride rate, contact time, foot angle, initial ground reaction force, and total peak force.

Gait

Gait can be described as the pattern of movement of the limbs of animals during locomotion (Berg, 1999). Humans use a variety of gait, which are often based on speed, terrain, the need to maneuver, and energetic efficiency (Berg, 1999). Some of the ways gait may vary is by stride length, stride velocity, and stride frequency, as well as how the foot contacts the ground.

Gait Cycle. Berg (1999) explained that the gait cycle begins when one foot contacts the ground and ends when that same foot contacts the ground again. When the foot initially contacts the ground it starts the stance phase and then proceeds through a swing phase until the cycle ends with the limb's next initial contact. Stance phase accounts for approximately 60 percent, and swing phase for approximately 40 percent of the single gait cycle.

The stance phase, according to Berg (1999), is broken up into four periods: loading response, flat foot, mid stance, and pre swing. The first period of the loading response is with heel strike. The flat foot is where the front and heel of the foot comes into contact with the floor. The mid stance is the transfer of weight from the back to the front of the foot. The last period of the stance phase, the toe off, occurs when the toes push off to propel the runner forward. The swing phase begins once the foot is no longer in contact with the ground. The swing phase is broken up into three periods: acceleration, mid-swing, and deceleration. Acceleration is from toe off to maximum knee flexion. The mid-swing is from maximum knee flexion until the tibia is vertical or perpendicular to the ground. The last period of the swing phase is the terminal phase, which begins where the tibia is vertical and ends at initial contact.

In a study by Dufek et al. (2000), researchers examined the footstrikes of their subjects in various conditions. The results indicated that the impact peak, or the amount of force put on the foot during first contact, increased from two times the body weight (BW) with shoes to two and a quarter times the BW while running barefoot.

Changes in Gait between Barefoot and Shod Running. The human body tries to adjust to running barefoot in many ways. Research by De Wit et al. (1996) found that barefoot conditions result in a significantly larger step frequency, a smaller step length, and less contact time versus a shod condition. Taking smaller steps results in a larger plantar flexion of the foot at touchdown. Even though shorter contact time will decrease the time the force put on the foot, there is still a huge amount of force present. Dufek et al. (2000) also supported shorter contact time in their study concluding that the peak leg acceleration was more than twice as fast during barefoot compared to shod running.

In an attempt to prevent all of the force on the foot, the body produces more than one impact peak (De Wit et al. 2000). Results from De Wit et al. (2000) indicated that runners adapt to their running style by reducing the impact force they experience while running barefoot. Wearing shoes causes only one large impact peak, where the forces contact the foot all at once. Running barefoot allows the body to spread out the impact peaks.

De Wit et al. (2000) also found that the loading response at the end of the mid stance phase was reached quicker in barefoot running than shod running. During the loading response phase the initial eversion (turning the foot laterally) of the foot is slightly smaller for barefoot rather than shod running. Larger initial eversion causes a deceleration during the initial foot contact. The initial eversion is small because the foot wants to accelerate out of the impact phase as quickly as possible (De Wit et al).

When running barefoot, plantar pressure measurements reveal a flatter foot placement to correlate with lower peak heel pressures. Therefore, it is assumed that runners adopt this different touchdown geometry in barefoot running in an attempt to limit the local pressure underneath the heel. De Koning and Nigg (1993) also found there is a more extended body position and a smaller touchdown velocity of the foot during barefoot compared to shod running.

Methodology

The purpose of this study is to analyze the biomechanical difference between running barefoot and shod before and after a barefoot training program. More specifically, foot angles, contact time, stride length, initial contact force, and total peak force will be analyzed. Further investigation will compare the differences between barefoot and shod running. Many researchers have studied the difference in running technique between barefoot and shod running [(Dickinson et al. (1985); Logan et al. (2007)]. However, there is a lack of research when it comes to implementing a barefoot training program into an individual's workouts. When participating in a barefoot training program, individuals will adapt to the changes in foot support and inevitably change the way they run. Such adaptations will significantly change certain kinematic variables.

Participants. The participants included 14 males and one female collegiate level distance runners between the ages of 18 and 24. The male participants ran, on average, over 40 miles per week and the female participant ran, on average, over 30 miles per week.

Instrumentation. The instrumentation included a force plate, high speed camera, SONY video camera and Dartfish. Information recorded by the force plate and analyzed via Dartfish software.

Force Plate. Force plates measure the ground reaction forces that are the result of an individual's step. A Bertec force plate was used to collect the ground reaction force data. The Bertec force plate measures the direction of forces that are applied in addition to and the center of pressure. The force plate produces measurements of force for each of the horizontal (x and y) and vertical (z) directions, as well as the corresponding moments of force. The base of the platform is made out of rugged cast aluminum, on which four precision load transducers are mounted with a collection frequency of 600Hz.

High Speed Camera. High Speed Cameras are used to record movement or events that occur too quickly to be observed by visual or photographic means. The movement can be shot at high speeds ranging from 50 to 500 frames per second and projected at normal rates. This study recorded at 300 frames per second.

Sony Digital Video Camera. The SONY DCR-HC52, 7.2v MiniDV Handycam Camcorder with 40x Optical Zoom video camera, recording at 30Hz, was used to capture a sagittal plane view of the runners during both shod and unshod running conditions. Dartfish TeamPro v5.5 video analysis software was used to analyze the digital video of captured of runners during this study.

Procedures. Each participant signed an informed consent form prior to the start of the study.

Participants were then instructed to run five minutes at a self-selected pace for a warm up prior to testing. Participants completed a total of 24 trials, 12 shod and 12 unshod. Participants ran four trials over a force platform shod and then again barefoot. Markers were placed at the head of the femur, the meeting of the femur and tibia (hinge joint), and the talocalcaneal bone to help analyze form. Markers were put on lateral side of both their right and left leg. Participants also ran a total of eight times, four barefoot and four shod, in a hallway in front of a SONY video camera. In addition, participants ran a total of eight times, four barefoot and four shod, in front of a high speed camera. Because of schedule conflicts a day was dedicated to testing with two participants being tested per hour. The appointments made were solely based on the participant's availability.

After the initial assessment, participants then followed a ten session barefoot training program. They ran barefoot for five minutes at the end of their normal training run during the first week and ten minutes at the end of their normal training run during the second week. Participants did the barefoot runs on a 200m indoor track. When the participants completed the two week program they returned to the lab and again completed a total of 24 trials, 12 shod and 12 unshod.

Design and Statistical Analysis. A repeated measure ANOVA with an alpha of 0.05 was performed. The measurements analyzed were foot angles, contact time, stride length, initial contact force, and total peak force. A repeated measured

ANOVA was used to find significance in two different factors, Test and Condition. SPSS computed the sum of all the pre-test and tested for significance by comparing the results to the sum of all the post-test averages. The results were considered the Test factor and concluded the effectiveness of the barefoot training program. The second factor was the Condition factor which computed the level of significance between running shod and unshod. SPSS took the sum of all the unshod averages and tested for significance by comparing the results to the sum of all the shod averages.

Results

A repeated measure ANOVA indicated that a barefoot training program made a significant difference in the following kinematic variables: foot angle, contact time, and total peak force. In addition, a repeated measure ANOVA indicated that there was a significant difference in the following kinematic variables between barefoot and shod: foot angles, stride length, and initial contact force.

Foot angles had a significant difference from the barefoot training program F (1, 9) = 13.710 (p = .005). The pre-test foot angles (M= 18.8o, SD = 11.8o) were significantly higher than the post-test foot angles (M =5.6o, SD = 15.1o). For foot angles in the Condition factor there was a significant difference between barefoot and shod F (1,9) = 37.370 (p = .000). The barefoot foot angles (M = 1.3o, SD = 14.4o) were significantly lower than the shod foot angles (M = 23.1o, SD = 12.6o). Table 1 displays the mean, standard deviation and significance for foot angles.

Table 1. Foot Angles (degrees)

	Mean (M)	Standard Deviation (SD)	Significance
Test (Pre)	18.8	11.8	.005*
Test (Post)	5.6	15.1	
Condition (Barefoot)	1.3	14.4	.000*
Condition (Shod)	23.1	12.6	

* - Statistical significance

Contact time had a significant difference from the barefoot training program F (1,9) = 11.319 (p = .008). The pre-test contact time (M = .22s, SD = .02s) was significantly longer than the post-test (M = .21s, SD = .03s). For contact time in the Condition factor, the null hypothesis was accepted because there was no significant difference in time between the barefoot and shod condition. Table 2 displays the mean, standard deviation, and significance for contact time.

Table 2. Contact Time (seconds)

	Mean (M)	Standard Deviation (SD)	Significance
Test (Pre)	.221	.023	.008*
Test (Post)	.214	.025	
Condition (Barefoot)	.215	.026	.125
Condition (Shod)	.220	.022	

* - Statistical significance

Stride length was not a significant factor from the barefoot training program. For stride length in the Condition factor there was a significant difference in how long the participant stepped F (1,9) = 21.998 (p = .001). In the barefoot condition, stride length (M = .8m, SD = .1m) was significantly shorter than the shod condition (M = .9m, SD = .1m). Table 3 displays the mean, standard deviation, and significance for stride length.

Table 3. Stride Length (meters)

	Mean (M)	Standard Deviation (SD)	Significance
Test (Pre)	0.85	.107	.175
Test (Post)	0.87	.110	
Condition (Barefoot)	0.83	.102	.001*
Condition (Shod)	0.89	.114	

* - Statistical significance

Initial contact force was not significant from the barefoot training program. For Initial contact force in the Condition factor there was a significant difference with the degree of force the foot had with the ground F (1,9) = 6.341 (p = .033). The barefoot condition (M = 1383.7N, SD = 379.4N) produced significantly less force than the shod condition (M = 1481.0N, SD = 369.6N). Table 4 displays the mean, standard deviation, and significance for initial contact force.

Table 4. Initial Contact Force (Newtons)

	Mean (M)	Standard Deviation (SD)	Significance
Test (Pre)	1478.569	439.134	.071
Test (Post)	1386.146	309.853	
Condition (Barefoot)	1383.730	379.432	.033*
Condition (Shod)	1480.985	369.555	

* - Statistical significance

Total peak force was significant for a barefoot training program F (1, 9) = 5.246 (p = .048). The total peak force in the pre-test (M = 1433.3N, SD = 312.9N) was significantly higher than the post-test (M = 1379.6N, SD = 269.4N). For total peak force in the Condition factor, the null hypothesis was accepted because there was no significant difference between the barefoot and shod condition. Table 5 displays the mean, standard deviation, and significance for total peak force.

Table 5: Total Peak Force (Newtons)

	Mean (M)	Standard Deviation (SD)	Significance
Test (Pre)	1433.268	312.866	.048*
Test (Post)	1379.631	269.373	
Condition (Barefoot)	1389.658	290.452	.135
Condition (Shod)	1423.241	291.787	

* - Statistical significance

The hypotheses were partially supported. The first hypothesis was supported by three of five kinematic variables, which included foot angle, contact time, and total peak force. The second hypothesis was supported by two of five kinematic variables, which included foot angle and initial contact force.

Discussion

The findings of this study were similar to the findings with much of the review of literature [(DeWit et al., 2000); (Dufek et al., 2000); (Logan et al., 2007)]. Dufek et al. (2000) supported shorter contact time; DeWit et al. (2000) supported lower foot angles, shorter contact time, and a shorter amount of distance between each step; Logan et al. (2007) supported lower ground reaction forces in barefoot running than shod running. Statistical significance was achieved in every variable tested, whether it was in the Test factor or the Condition factor. Out findings were supported by other studies, however there is no research consisting of a barefoot training program. Taking into considerations our results, along with results found by other studies, it is thought that there is a benefit to the biomechanical alterations produced by barefoot running. It is the belief of the researchers that a barefoot training program, if implemented, could produce the same, if not better, biomechanical alterations for the benefit of the runner.

Foot angles decreased significantly when the participants ran barefoot. A lower foot angle allowed the participants to heel strike less and enabled them to change to a midfoot or forefoot striker. These results are supported by DeWit et al. (2000). The barefoot training program showed similar results when the participants were retested and their foot angles were lower than the original test two weeks prior.

The barefoot training program was significant because the average contact time decreased significantly with an alpha level set at .05. The Condition factor was not significant because both the barefoot and shod trials decreased equally from the barefoot training program. Dufek et al. (2000) and De Wit et al. (1996) supported the finding by stating that there is a shorter contact time when running barefoot to shod.

There was a significantly lower stride length when running barefoot compared to shod which is consistent with the findings of De Wit et al. (1996). The researchers found that running barefoot resulted in a smaller step length.

Initial contact force is the highest peak in the first 25% of the graph. It was shown to be significant in the condition factor, proving that there was a difference between barefoot and shod. There was, on average, ~100 Newtons less force during barefoot compared to running with shoes on first impact. The total peak force is the highest peak in the last 75% of the graph. That force was found to be significant because of our barefoot training program, lowering their total peak force by an average of ~80 Newtons. De Wit et al. (2000) found that loading rates and impact peaks significantly increase with barefoot running in comparison to shod. Logan et al. (2007) found that runners adjust to the increased loading rate and impact peak. The body adapts by having lower foot angles, shorter contact time and a shorter amount of distance between each step. This is similar to the results of DeWitt et al. (2000) and Dufek et al. (2000).

Summary

Running barefoot will change a person's body mechanics and is better for an individual as a whole.

1. In each variable tests, there was a significant difference, whether it was from the barefoot training program or from running with or without shoes

2. With the combination of running barefoot and the implementation of a barefoot training program, runners should start to run more efficiently and this should contribute to an overall improvement in their workouts and physical fitness.

Implications. The results of the study can be useful to coaches, along with individual runners.

1. Individuals should take the study into consideration when making a training regimen because it can help people be more biomechanically efficient

2. The study can open the door to future research because of the drastic results in such a short period of time. A longer training program could result in more significant findings

References

Aerts, P., Clercq, D. & Wit, B. (2000). Biomechanical analysis of the stance phase during barefoot and shod running. *Journal of Biomechanics, 33*, 269-278.

Asics Corporation. Retrived on Novemeber 4, 2009, from Asics America. Website: http://www.asicsamerica.com/products/category.aspx?PARENT_CATEGORY_ID=250001547

Bahram, J. (2006). Evaluation and retraining of the intrinsic foot muscles for pain syndromes related to abnormal control of pronation. Retrieved by: http://www.aptei.com/articles/pdf/IntrinsicMuscles.pdf.

Berg, B. (1999). The gait cycle. Retrieved on November 4, 2009 by: http://www.upstate.edu/cdb/grossanat/limbs6.shtml.

Brooks. Retrived on November 4, 2009, from Brooks Corporation. Website: http://www.brooksrunning.com/category/123197/Women%27s%20Shoes.

Burke, R. & Reyes, R. (2002). *Structural relationship between foot arch length and height and the relative effects on foot strength (stability) and impact loading (shock absorption) while barefoot, shod, shod with custom orthotics, and shod with a proprioceptive insole device*. Barefoot Science Technologies Inc.

Chen, W., Tang, F., & Ju, C. (2001). Stress distribution of the foot during mid-stance to push-off in barefoot gait: a 3-D finite element analysis. *Clinical Biomechanics, 16*, 614-620.

Dartfish Corporation. Retrived Novemeber 5, 2009. Website: http://www.dartfish.com/en/index.htm.

De Koning, J., & Nigg, B. (1993). Kinematic factors affecting initial peak vertical ground reaction forces in running. In *Abstracts of the XIVth Congress of the International Symposium of Biomechanics*, Paris, France.

De Wit, B., De Clercq D. D., & Aerts P. (1996). *Ground reaction forces and spatio-temporal variables during barefoot and shod running*. International Society of Biomechanics in Sports. The XIV Symposium on biomechanics in sports. 252-255.

De Wit, D. B., Clercq, D. D., & Aerts, P. (2000). Biomechanical analysis of the stance phase during barefoot and shod running. *Journal of Biomechanics, 33*, 269-278.

Dickinson, J.A., Cook, S.D., & Leinhardt T.M. (1985). The measurement of shock waves following heel strike while running. *Journal of Biomechanics, 18*(6), 415-422.

Dufek, J., Freedman, J. & Mercer, J. (2008). *Kinetic characteristics of barefoot running*. Presented at the Annual Conference of American Society of biomechanics, Ann Arbor, MI, USA.

Kadambande, S., Khurana, A., Debnath, U., Bansal, M., & Hariharan, K. (2006). Comparative anthropometric analysis of shod and unshod feet. *The Foot, 16*, 188-191.

Logan, S., Hunter, I., Feland, B., Hopkins, T., & Parcell, A. (2007). *Ground reaction forces between running shoes, racing flats and distance spikes in runners*.

Miller D I., (1990). Ground reaction forces in distance. In P. Cavanagh (Ed), *Biomechanics of distance running* (pp. 203-223) Champaign, IL: Human Kinetics Books.

Running shoes. Retrieved on November 4, 2009, from ePodiatry.com. Website: http://www.epodiatry.com/running-shoes.htm.

Running shoes & gear: Running shoe basics: Orthotics & pronation. Retrieved on November 4, 2009, from Runners World. Website: http://www.runnersworld.com/article/0,7120,s6-240-319-327-7000-0,00.html.

Patients guide to foot anatomy. (2002). Retrieved on November 4, 2009, from Eorthopod. Website: http://www.eorthopod.com/public/patient_education/6479/foot_anatomy.html

Travell, J. G., & Simons, D. G. (1992). Myofascial pain and dysfunction: The trigger point manual, the lower extremities. Vol II. Baltimore, MD; Williams & Wilkins. Quinn, E., (2009). How to Choose the best running, athletic or sports shoes. Retrieved on November 5, 2009, from About.com. Website: http://sportsmedicine.about.com/cs/beforeyoubuy/a/aabyb_shoes.htm

Weyand, G. P., & Davis, J. A. (2005). Running performance has a structural basis. *Journal of Experimental Biology, 208*, 2625-2631.

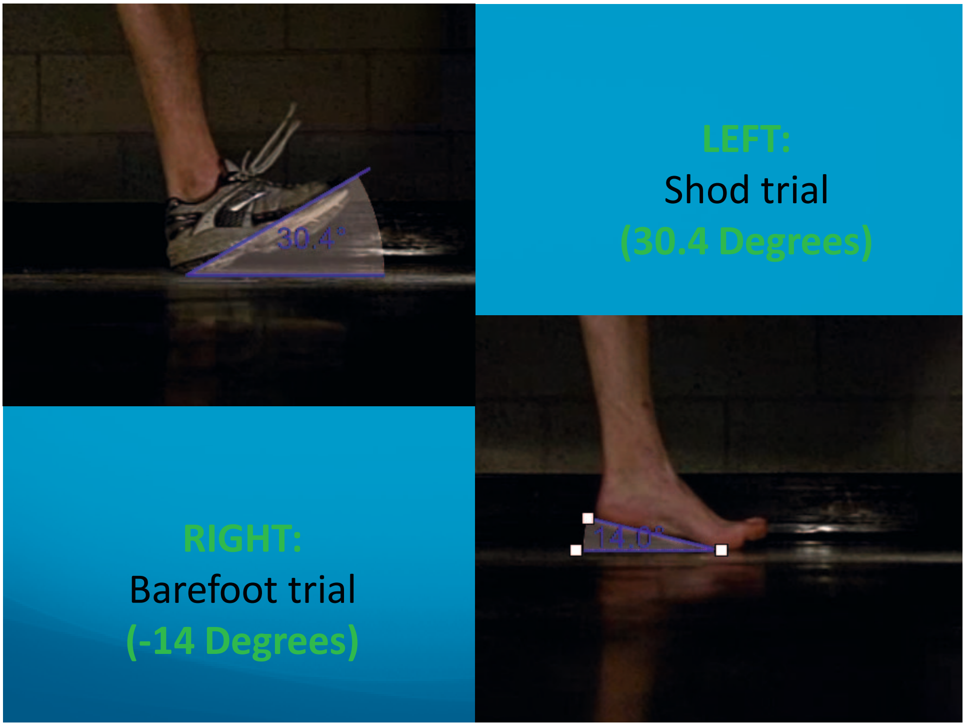

Figure 1. Foot angle measurement of forestrike (top left). Foot angle measurement of heelstrike (bottom right).

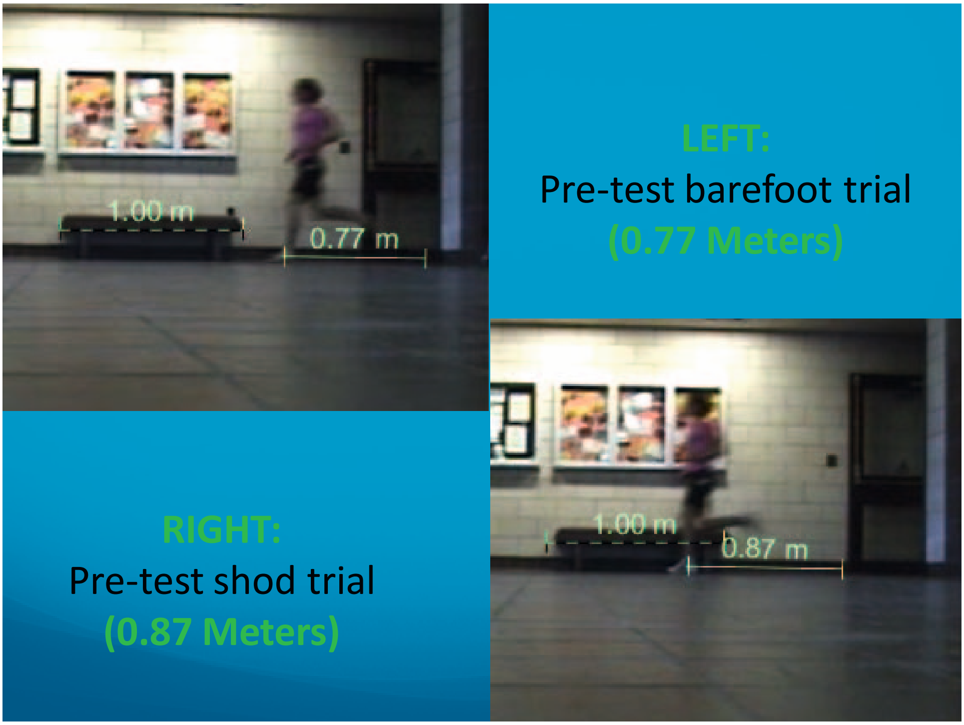

Figure 2. Point of contact for first foot (top left). Point of contact for second foot (bottom right).

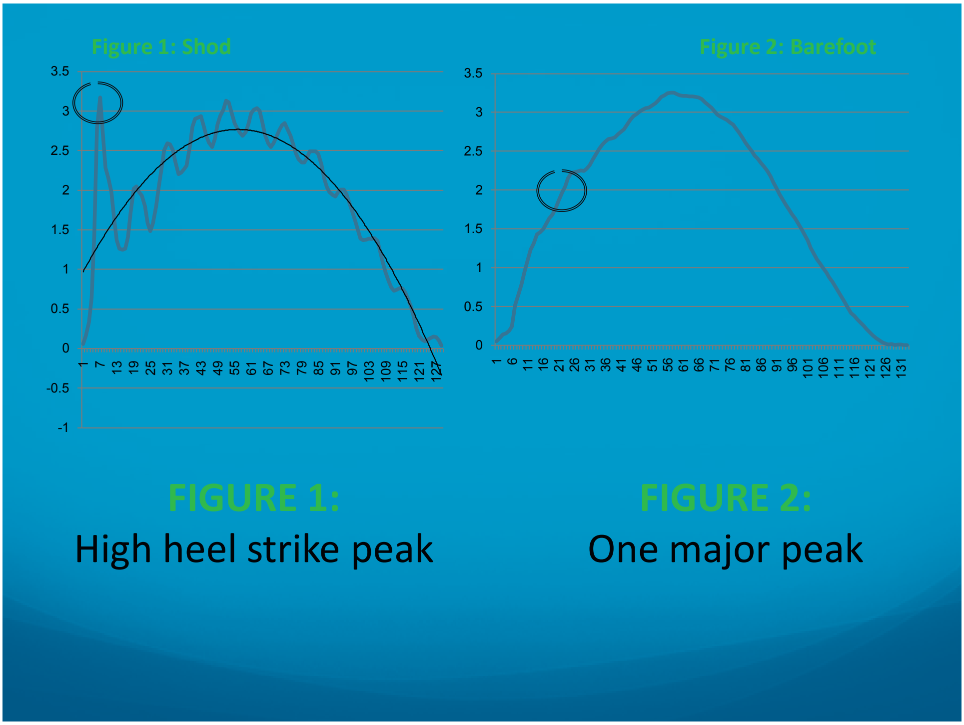

Figure 3. Initial Contact Force: Circle shows the point of highest force in the first 25% of the graph.

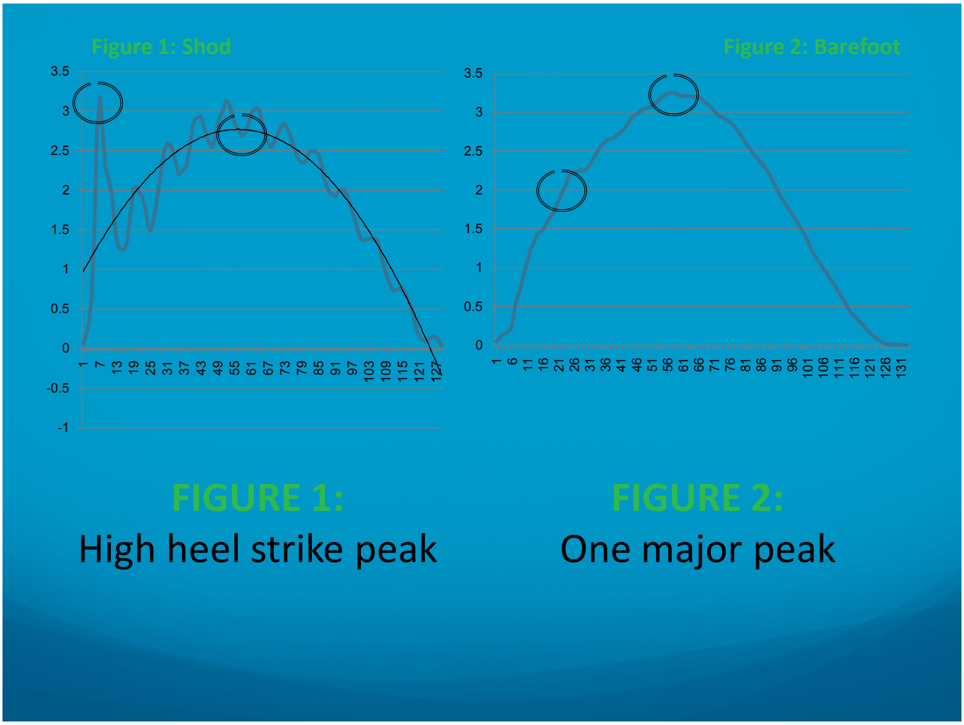

Figure 4. Total Peak Force: One circle shows the initial contact force. The other shows the highest force for the last 75% of the graph. Total Peak force was the sum of both forces.

Colin UTZ-MEAGHER, graduated from SUNY Cortland in 2010 with a B.S. in Kinesiology along with minors in both Chemistry and Biology. Currently been working at a physical therapy office as a personal trainer/medical office assistant before attending Physician Assistant School next year.

John NULTY, graduated with a B.S. at SUNY Cortland as a Kinesiology major, Exercise Science concentration, and Psychology Minor. Pursuing a M.S. in Exercise Science at SUNY Cortland while instructing Motor Behavior labs as Graduate Assistant. Email address: john.w.nulty@gmail.com;

Lisa HOLT, graduated with a B.S.in Kinesiology at SUNY Cortland. Currently pursuing a Masters in Human Performance at Ithaca College while being an Assistant Coach of the Women's Cross Country and Track and Field Programs.