AN ABSTRACT OF THE THESIS OF

Justin Ter Har for the degree of Master of Science in Kinesiology presented on March 3, 2020.

Title: The Influence of Heel Drop on Running Biomechanics in Female Runners

Abstract approved:

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Christine D. Pollard

Background: Low drop cushioned running shoes have been popular over the past decade despite a lack of research on low drop shoes. There is some evidence that low drop cushioned shoes increase vertical ground reaction forces (VGRFs) and influence ankle kinematics but no study to date has focused on large heel drop cushioned shoes (>15mm). Therefore, it is unknown how a large drop cushioned shoe affects vertical ground reaction forces and ankle kinematics in female runners.

Purpose: To examine the effects of varying running shoe heel drop heights on running biomechanics in female runners.

Study Design: Cross-Sectional Study

Methods: 14 female participants ran in a low drop cushioned shoe, a traditional cushioned shoe, and a large drop cushioned shoe. Three-dimensional kinematics and vertical ground reaction forces were collected while participants ran over ground. Variables of interest included ankle frontal plane kinematics, ankle sagittal plane kinematics, VGRF active peak, VGRF impact peak, and VGRF loading rate.

Results: VGRF impact peak and loading rate were higher in the low drop cushioned shoes and lower in the large drop cushioned shoes. Both inversion and dorsiflexion at initial contact were significantly lower in the low drop cushioned shoe.

Conclusions: Female runners who rearfoot strike displayed decreased VGRF loading when running in a large heel drop running shoe compared to a traditional running shoe. Additionally, female rearfoot strikers who ran in a low heel drop cushioned shoe exhibited increased VGRF loading rate and impact peak which suggests an increased risk of running related injuries. Even though large heel drop shoes may benefit runners, future research is needed to examine the influence of these shoes on running biomechanics after habitual wear.

Clinical Relevance: Low drop cushioned shoes are popular among runners but may increase the risk of injury in runners who rearfoot strike. Alternatively, a large drop cushioned shoe may benefit runners that are at risk of impact related injuries.

Key Terms: Cushioned Shoes, Running, Footwear

The Influence of Heel Drop on Running Biomechanics in Female Runners

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APPROVED:

Major Professor, representing Kinesiology

Head of the School of Biological and Population Health Sciences

Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Justin Ter Har, Author

CONTRIBUTION OF AUTHORS

Dr. Christine Pollard was the primary investigator for this project and assisted with the interpretation of the data. Justin Ter Har independently wrote the manuscript and performed all the data analysis.

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The Influence of Heel Drop on Running Biomechanics in Female Runners

1. Introduction

Participation in recreational running has been on the rise over the past four decades.[16] Unfortunately, there has been an associated increase in injury incidence among recreational runners. In 2004, it was reported that 85% of runners were injured over a twenty-month period,[9] despite the increase of running shoe innovation to prevent these injuries.[5] According to Running USA,[13] female participation in running events are at an all-time high where 43% of United States (US) marathon runners in 2013 were female and more than 60% of US half-marathoners were female. In 2002, Taunton and Colleagues reported that female recreational runners were twice as likely to experience patellofemoral pain when compared to males.[14] Recently, a prospective study concluded that the female runners preparing for a 5km or 10km race were more likely to have knee and lower leg injuries when compared to males.[15] Even though female runners are more likely to experience an injury, much of the research investigating running injuries has been focused on male runners.

For decades, a standard heel drop height of 12-14mm was present across most variations of running shoes.[5] However, the emergence of minimal running shoes introduced a new trend in a reduction of heel drop height even among cushioned running shoes.[5] Today there are more heel drop variations in running shoes than ever before.[6] However, little is known about the influence of these varying heel drop heights on running biomechanics. Over the past several years, a number of cushioned running shoes with a low drop heel height have become available and popular among runners. While these shoes have a similar amount of midsole cushioning as a traditional running shoe, manufacturers have reduced the amount of heel drop to 0-6mm.[6]

Investigations of the influence of heel drop on running biomechanics are limited[3,4,7,8,10,11] and only two of these studies have focused specifically on females.[3,7] Gijon-Nogueron and colleagues[7] reported that heel drop differences ranging between 4-12mm had no influence on spatiotemporal parameters (i.e. cadence, stride length, and contact time) in female runners but the study did not include vertical ground reaction forces (VGRFs). Chambon et al.[4] reported that male runners exhibited increased vertical ground reaction force (VGRF) loading rate when running in cushioned shoes with a reduced heel drop. Similarly, Horvais et al.[8] found that increased heel drop resulted in reduced leg stiffness in male runners. An increase in VGRF loading rate has been associated with tibial stress fractures in female runners[12,18] yet there is only one study to date that examines the influence of heel drop on loading rate in female runners. Besson and colleagues[3] reported that VGRF impact peak and loading rate were higher and dorsiflexion angles at contact were lower in female runners in a low heel drop (0mm) cushioned shoe as compared to a traditional heel drop (10mm) cushioned shoe. However, this study did not examine the influence of a heel drop greater than 10mm on VGRFs even though the classic amount of heel drop in a traditionally cushioned running shoe is 12-14mm.

Regarding foot kinematics, traditional heel drop (12-14mm) conditions have been associated with increased foot strike angle in male runners.[8] Similarly, a recent study found no difference in sagittal plane ankle kinematics across different running shoe heel drop amounts ranging from 0-12mm.[11] Recently, Becker and Colleagues[1,2] reported that increased eversion during running is associated with medial tibial stress syndrome in both male and females. To date, no study has examined frontal plane ankle kinematics between different heel drop conditions.

Much of the research on heel drop modifications in running shoes has focused primarily on heel drop conditions that range from 0-5mm and no study to date has included a heel drop greater than 15mm. Furthermore, there is a dearth of research on the effects of heel drop on VGRFs in female runners. Thus, it is unknown how a large heel drop condition would influence VGRFs and ankle kinematics in female runners. Therefore, the purpose of this study was to examine the effects of varying running shoe heel drop heights on running biomechanics in female recreational runners who are rearfoot strikers. We hypothesized that a large heel drop condition would decrease VGRF loading rate and impact peak while altering ankle kinematics when compared to traditional and low heel drop cushioned running shoes.

2. Methods

2.1 Participants

Participants consisted of 14 females between the ages of 18 and 45. Participants were included if they ran at least ten miles per week and were excluded if they had run in a minimal or maximal type shoe in the past six months. Participants were also excluded if they had a neurological or vascular disorder and/or an injury in the past six months that disrupted their running mileage for more than three days. Participants were included if they wore a size 8.0 (US) in running shoes and were identified as a rearfoot striker by the research team using high speed video footage. All participants were required to sign an informed consent form that was approved by the Oregon State University Institutional Review Board prior to testing.

2.2 Data Collection

Three-dimensional lower extremity kinematics were collected using a Vicon 8-camera motion capture system (Oxford Metrics LTD) at a sampling frequency of 250Hz. Ground reaction forces were collected with two force plates (Advanced Mechanical Technology, Inc) sampling at 1000Hz. The force plates were connected to an analog to digital converter and interfaced with a microcomputer to synchronize both motion capture and ground reaction force data. The low heel drop cushioned shoe condition (D4) consisted of a New Balance Fresh Foam Boracay 980 v2 with a 4mm heel drop, a heel cushion height of 22mm, and a forefoot cushion height of 18mm. The traditional heel drop shoe condition (D13) was a New Balance prototype with a 13.5mm heel drop, a heel cushion height of 31.5mm, and a forefoot cushion height of 18mm. The traditional shoe heel drop was consistent with a traditionally cushioned running shoe. The large heel drop shoe condition (D25) was another New Balance prototype with 25mm heel drop, a heel cushion height of 43mm, and a forefoot cushion height of 18mm. All shoes had identical materials and construction except for the variation in heel drop [figure 1].

Upon signing the informed consent document, participants had their height and weight measured and then donned one of four shoe conditions. The participants were also fitted to lycra running shorts prior to data collection. The order of shoe conditions was randomized to control for fatigue and learned effects. Additionally, the researchers identified the participant's dominant limb (preferred leg when kicking a soccer ball). Participants were then instructed to perform a warmup on a stationary bike for five minutes at a self-selected pace.

Before data collection, reflective markers were placed by the same experienced researcher on the following anatomical locations: between the 5th lumbar and 1st sacral spinous processes; on bilateral iliac crests, greater trochanters, anterior superior iliac spines (ASIS), medial and lateral femoral epicondyles, medial and lateral malleoli, and the heads of the 1st and 5th metatarsals. Quadrad marker clusters were attached to the lateral sides of the thighs and legs while triad marker clusters were attached to heel counters of the shoes.

After marker placement, participants were directed to the center of the capture volume for a static calibration capture. All markers were then removed except for the marker clusters, 5th lumbar/1st sacral marker, iliac crest markers, and ASIS markers. For each shoe condition a new static calibration was performed prior to collecting running trials in that shoe condition. Relative angles were utilized for this study. That is, joint angles present at each static calibration were not zeroed.

For all shoe conditions, participants completed five successful running trials with their dominant limb striking a force plate. The running task was performed on a 10-meter runway over two

AMTI force plates and a successful trial consisted of a complete foot contact on one of the two force plates. The participants self-selected their running speed during the first shoe condition and speeds were held constant for all subsequent conditions within ±5% using analog timing gates.

2.3 Data Processing

Raw marker coordinate data were processed into kinematics in Visual 3D (v 5; C-Motion, Inc). Variables of interest included VGRF impact peak, VGRF loading rate, VGRF active peak, dorsiflexion at initial contact, peak dorsiflexion, inversion at initial contact, and peak eversion. All kinematic and VGRF variables were filtered using a no-lag 4th order low-pass butterworth filter with a frequency cut off of 12Hz and 50Hz, respectively. A custom LabView (v 2019; National Instruments, Inc) program was used to identify VGRF impact peak, VGRF loading rate and VGRF active peak. VGRF loading rate was calculated using the average force-time slope of the middle 60% between heel strike and impact peak.[17]

A series of one-way repeated measures ANOVAs were used to identify main effects. When significant main effects were found, dependent t-tests with a Bonferroni correction were used to identify the differences between groups. R-studio (v 1.2.5019; RStudio, Inc) was used to perform all statistical analyses with an alpha level of 0.05.

3. Results

The statistical analysis revealed main effects of shoe type for VGRF impact peak (p=0.002) and VGRF loading rate (p<0.001). Additionally, there were main effects of shoe type for dorsiflexion at initial contact (p<0.001) and inversion at initial contact (p=0.004). There were no statistically significant main effects of shoe type for peak dorsiflexion, peak eversion, and VGRF active peak.

3.1 Kinematics

Dorsiflexion at initial contact was shown to increase in the large heel drop shoe condition when compared to the low heel drop (p=0.005) and traditional heel drop (p<0.001) shoe conditions. Additionally, in the large heel drop condition, inversion at initial contact was increased when compared to the low heel drop shoe condition (p=0.006). Similarly, inversion at initial contact was higher in the traditional drop shoe condition when compared to the low heel drop shoe condition (p=0.008). These results are shown in Table 1.1.

3.2 Vertical Ground Reaction Forces

VGRF impact peak was decreased in the large drop condition when compared to the low drop condition (p=0.012) and a similar difference was found for the traditional heel drop condition (p=0.007) [figure 2]. There was also a similar decrease of VGRF loading rate in the large drop condition when compared to the traditional drop (p<0.001) and low drop (p<0.001) conditions [figure 3]. Additionally, the low drop condition had increased VGRF loading rate when compared to the traditional drop condition (p=0.011). These results are shown in Table 1.2.

4. Discussion

The purpose of this study was to examine the effects of varying running shoe heel drop heights on running biomechanics in female runners. The large heel drop shoe condition was a prototype that is not currently in production. This is the first study to investigate the influence of a large heel drop shoe that has greater than 15mm of heel drop on running biomechanics. We found that the large heel drop shoe condition decreased VGRF loading rate when compared to a traditional heel drop running shoe and a low drop cushioned running shoe. Additionally, ankle dorsiflexion at initial contact was increased in the large heel drop shoe condition, while inversion at initial contact was decreased in the low drop cushioned shoe. Thus, these findings support our hypothesis that a large heel drop shoe condition would decrease VGRFs and alter ankle kinematics in female runners when compared to traditional and low heel drop cushioned shoes.

Two studies have reported that there is no change in ankle dorsiflexion at contact between varied heel drop conditions,[4,11] Besson et al.[3] recently identified that dorsiflexion at contact was lower among low heel drop shoes as compared to traditional shoes in female runners. While we didn't find this same effect in our low heel drop cushioned shoe condition when compared to the traditional heel drop shoe, we found that the large heel drop shoe condition resulted in increased dorsiflexion at initial contact when compared to all conditions.

No previous studies on running shoe heel drop modifications have shown differences in frontal plane ankle kinematics. There is evidence that increased eversion during running could put runners at greater risk of Achilles tendinopathy and medial tibial stress syndrome.[1,2] Even though we did not see any changes in peak eversion, we did find that running in a low heel drop shoe resulted in decreased inversion at contact when compared to a traditional shoe. Since the average inversion angle at initial contact for the low heel drop cushioned shoe condition was very small, we observed that 50% of the runners landed in an everted position. This could suggest that running in a low drop cushioned shoe causes a premature “bottoming out” effect in the frontal plane at the ankle and may be related to an increase risk of injury.

According to Chambon et al.,[4] as heel drop increases in running shoes there is a reduction in VGRF loading rate while running over ground. We observed that the large heel drop shoe condition decreased VGRF loading rate and the low heel drop cushioned shoe condition increased VGRF loading rate during running. This would corroborate the findings from Chambon[4] and support the relationship whereas when heel drop is increased there will be an associated decrease in VGRF loading rate in rearfoot strike runners. This could possibly be due to the combination of decreased rearfoot cushioning in the low drop cushioned shoes paired with a lack of change in dorsiflexion at initial contact. However, the decrease of VGRF loading rate in the large heel drop cushioned shoes could be due to the opposite effect, where the runners are increasing dorsiflexion at initial contact in order to rely on the increased rearfoot cushioning which would, in turn, result in reduced impact forces. These changes in biomechanics may influence injury risk for female rearfoot strike runners. In particular, our findings suggest that running in low heel drop cushioned shoes would increase the risk of tibial stress fractures, while running in large heel drop shoes might reduce the risk of running related injuries.[12,18]

A limitation to our study is that each shoe condition was novel to the participants. Since participants had no habituation period for each shoe prior to data collection, we cannot extrapolate our results beyond the initial use of these shoes. We suggest that future studies include a habituation period to allow participants to transition to the shoe. Another limitation of the study was that all participants were female which limits our ability to generalize the findings to all runners. A final limitation is that our inclusion criteria required a minimum running mileage of 10 miles per week. This reduces our generalizability to runners who partake in higher running mileage. Future studies are needed to investigate running biomechanics in large heel drop running shoes (25mm) following a habituation period.

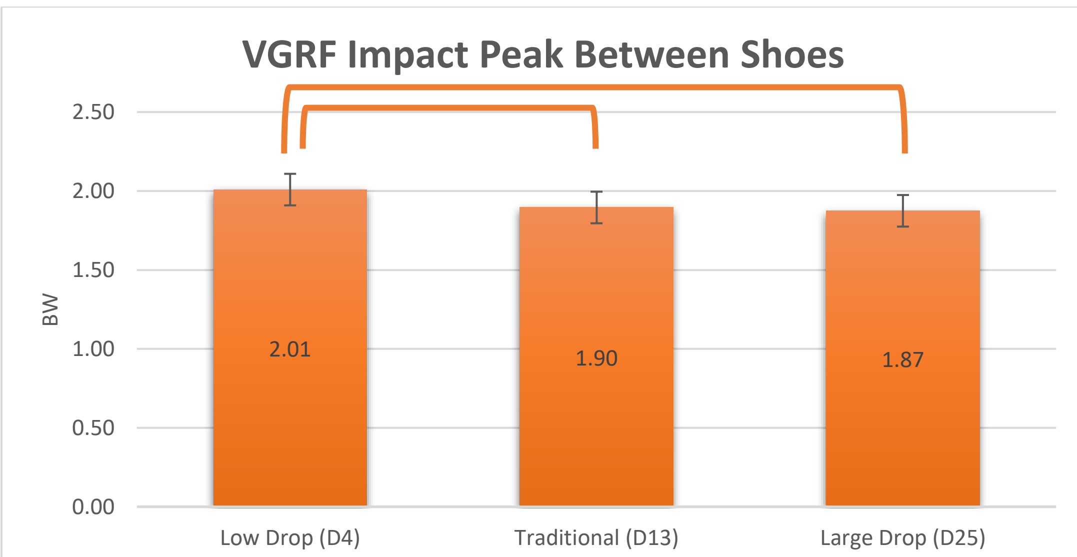
5. Conclusion

Female runners who rearfoot strike displayed decreased VGRF loading when running in a large heel drop running shoe compared to a traditional running shoe. Since these variables have been associated with running related injuries in females, a large heel drop running shoe could benefit female rearfoot strikers who are at risk of impact related injuries.[12] Additionally, female rearfoot strikers who ran in a low heel drop cushioned shoe exhibited increased VGRF loading rate and impact peak which suggests an increased risk of running related injuries.[12] Even though large heel drop shoes may reduce the risk of tibial stress fractures,[12] future research is needed to examine the influence of these shoes on running biomechanics after habitual wear.

Figure 1

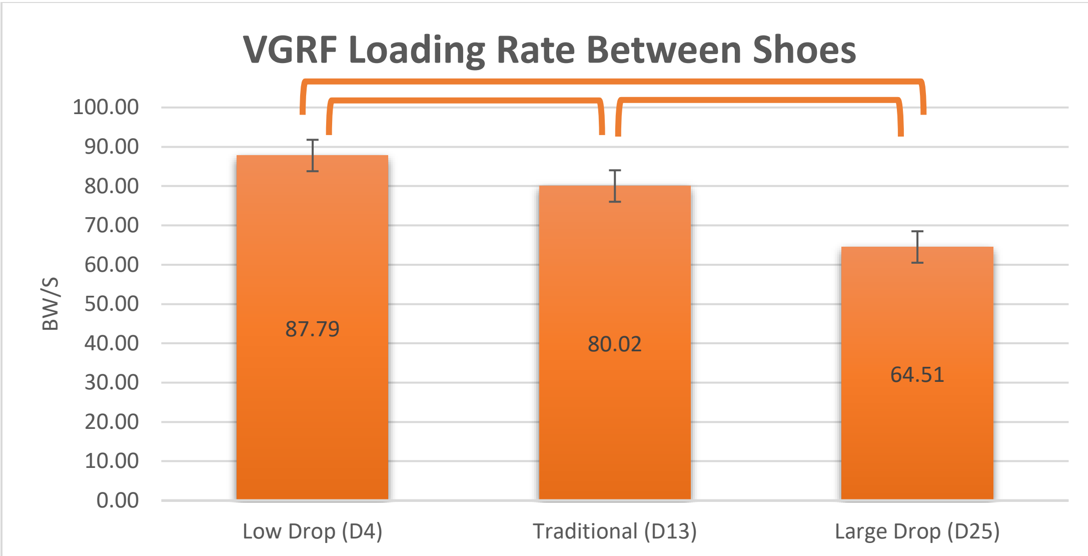
An image with each shoe condition used in the study. Starting on the left: the large drop cushioned shoe, the traditional cushioned shoe, and the low drop cushioned shoe. Brackets designate the heel to toe drop in millimeters. A heel to toe drop is the difference between the forefoot cushion height and the rearfoot cushion height.

Figure 2



As shown in the graph above, the low drop cushioned shoe (D4) had significantly increased VGRF impact peak when compared to the traditional heel drop shoe (D13) ($p=0.007$) and the large drop cushioned shoe (D25) ($p=0.012$).

Figure 3



As shown in the graph above, the low drop cushioned shoe (D4) had significantly increased VGRF loading rate when compared to the traditional heel drop shoe (D13) ($p=0.011$) and the large drop cushioned shoe (D25) ($p<0.001$). Additionally, the large drop cushioned shoe (D25) had significantly decreased VGRF loading rate when compared to the tradition heel drop shoe (D13) ($p<0.001$).

Table 1.1 - Kinematics

	Dorsiflexion @ Initial contact (˚)	sd	Inversion @ Initial contact (˚)	sd	Peak Dorsiflexion (˚)	sd	Peak Eversion (˚)	sd
Low Drop (D4)	10.70 [2]	3.53	0.19 [1,2]	1.92	23.18	3.65	11.62	3.73
Traditional Drop (D13)	11.09 [3]	3.31	1.77 [1]	2.40	22.98	2.82	12.91	4.72
Large Drop (D25)	13.25 [2,3]	3.03	1.67 [2]	2.43	22.62	3.06	12.98	4.35

$p < 0.0167$ is indicated by super script numbers listed below

D4 vs D13 [1]

D4 vs D25 [2]

D13 vs D25 [3]

Table 1.2 – Vertical Ground Reaction Forces

	Active Peak (BW)	sd	Impact Peak (BW)	sd	Loading Rate (BW/S)	sd
Low Drop (D4)	2.54	0.15	2.01 [1]	0.31	87.79 [1,2]	19.35
Traditional Drop (D13)	2.54	0.17	1.90 [1,3]	0.36	80.02 [1,3]	19.40
Large Drop (D25)	2.55	0.17	1.87 [3]	0.38	64.51 [2,3]	14.32

$p < 0.0167$ is indicated by super script numbers listed below

D4 vs D13 [1]

D4 vs D25 [2]

D13 vs D25 [3]

Bibliography

1. Becker J, James S, Wayner R, Osternig L, Chou L-SS. Biomechanical factors associated with Achilles tendinopathy and medial tibial stress syndrome in runners. *Am J Sports Med*, 2017;45(11):2614-2621.
2. Becker J, Nakajima M, Wu WFW. Factors contributing to medial tibial stress syndrome in runners. *Med Sci Sport Exerc*, 2018;50(10):2092-2100.
3. Besson T, Morio C, Millet G, Rossi J. Influence of shoe drop on running kinematics and kinetics in female runners. *Eur J Sport Sci,* 2019 *19*(10), 1320–1327.
4. Chambon N, Delattre, Guéguen, Berton, Rao. Shoe drop has opposite influence on running pattern when running overground or on a treadmill. *Eur J Appl Physiol*, 2015 *115*(5), 911–918.
5. Davis I. The re-emergence of the minimal running shoe. *J Orthop Sports Phys Ther,* 2014 44(10), 775-784.
6. Esculier J, Dubois B, Dionne C, Leblond J, Roy J. A consensus definition and rating scale for minimalist shoes. *J Foot Ankle Res*, 2015 8(1), 42.
7. Gijon-Nogueron G, Soler-Crespo F, Sanchez-Rodriguez R, Cabello-Marique D, Lopezosa-Reca E, Ortega-Avila A. Influence of speed and heel-to-toe drop in running shoes for female recreational runners: A cross-sectional study. *Medicine*, 2019 *98*(19), e15649.
8. Horvais N, Samozino P. Effect of midsole geometry on foot-strike pattern and running kinematics. *Footwear Science*, 2013 *5*(2), 81–89.

9. Lun V, Meeuwisse W, Stergiou, P, Stefanyshyn D. Relation between running injury and static lower limb alignment in recreational runners. *Br J Sports Med*, 2014 38(5), 576-580.
10. Malisoux L, Chambon N, Urhausen A, Theisen D. Influence of the Heel-to-Toe Drop of Standard Cushioned Running Shoes on Injury Risk in Leisure-Time Runners: A Randomized Controlled Trial With 6-Month Follow-up. *Am J Sports Med*, 2016 *44*(11), 2933–2940.
11. Malisoux L, Gette P, Chambon N, Urhausen A, Theisen D. Adaptation of running pattern to the drop of standard cushioned shoes: A randomised controlled trial with a 6-month follow-up. *Journal of Science and Medicine in Sport*, 2017 *20*(8), 734–739.
12. Milner C, Ferber R, Pollard C, Hamill J, Davis I. Biomechanical Factors Associated with Tibial Stress Fracture in Female Runners. *Med Sci Sports Exerc*, 2006 *38*(2), 323–328.
13. Running USA. Research Reports. http:// www.runningusa.org/RUSA/Research Published January 1, 2014. Accessed February 14, 2020.
14. Taunton J, Ryan M, Clement D, Mckenzie D, Lloyd-Smith D, Zumbo B. A retrospective case-control injuries analysis of 2002 running. *Br J Sports Med*, 2002 36(2), 95–101.
15. Van Der Worp M, de Wijer A, van Cingel R, Verbeek A, Nijhuis-van Der Sanden M, Staal J. The 5- or 10-km Marikenloop Run: A Prospective Study of the Etiology of Running-Related Injuries in Women. *J Orthop Sports Phys Ther*, 2016 46(6), 462–470.
16. Wilder B. On the run: a physician's perspective. *J Orthop Sports Phys Ther*, 2014 Oct; 44(10), 731–732.
17. Willy R, Davis I. Kinematic and Kinetic Comparison of Running in Standard and Minimalist Shoes. *Med Sci Sports Exerc*, 2014 46(2), pp.318–323.

18. Zadpoor A, Nikooyan A. The relationship between lower-extremity stress fractures and the ground reaction force: A systematic review. *Clinical Biomechanics*, 2011 *26*(1), 23–28.

Appendix

Appendix A – R-studio Output

```
[1] "DF @ IC"

Error: Subject
          Df Sum Sq Mean Sq F value Pr(>F)
Residuals 13  361.7   27.83

Error: Subject:Shoe
          Df Sum Sq Mean Sq F value   Pr(>F)
Shoe       2  52.80  26.399   10.96 0.000353 ***
Residuals 26  62.62   2.408

"IN @ IC"

Error: Subject
          Df Sum Sq Mean Sq F value Pr(>F)
Residuals 13  158.6    12.2

Error: Subject:Shoe
          Df Sum Sq Mean Sq F value  Pr(>F)
Shoe       2  21.81  10.904   6.875 0.00401 **
Residuals 26  41.24   1.586

"Peak DF"

Error: Subject
          Df Sum Sq Mean Sq F value Pr(>F)
Residuals 13    347   26.69

Error: Subject:Shoe
          Df Sum Sq Mean Sq F value Pr(>F)
Shoe       2   2.29   1.143   0.579  0.568
Residuals 26  51.36   1.975

"Peak EV"

Error: Subject
          Df Sum Sq Mean Sq F value Pr(>F)
Residuals 13  649.7   49.97

Error: Subject:Shoe
          Df Sum Sq Mean Sq F value Pr(>F)
Shoe       2  16.35   8.175   3.214 0.0566 .
Residuals 26  66.14   2.544

"LR"

Error: Subject
          Df Sum Sq Mean Sq F value Pr(>F)
Residuals 13  11241   864.7

Error: Subject:Shoe
          Df Sum Sq Mean Sq F value   Pr(>F)
```

```
Shoe       2   3933  1966.4   43.03 5.64e-09 ***
Residuals 26   1188    45.7

"AP"

Error: Subject
          Df Sum Sq Mean Sq F value Pr(>F)
Residuals 13  0.992 0.07631

Error: Subject:Shoe
          Df  Sum Sq   Mean Sq F value Pr(>F)
Shoe       2 0.00036 0.0001792   0.098  0.907
Residuals 26 0.04776 0.0018369

"IP"

Error: Subject
          Df Sum Sq Mean Sq F value Pr(>F)
Residuals 13  4.523  0.3479

Error: Subject:Shoe
          Df Sum Sq Mean Sq F value  Pr(>F)
Shoe       2 0.1461 0.07307   7.793 0.00223 **
Residuals 26 0.2438 0.00938



"Low Drop vs Traditional Drop"

        Paired t-test

data:  INIC by Shoe
t = -3.0977, df = 13, p-value = 0.008485
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 -2.674770 -0.476801
sample estimates:
mean of the differences
              -1.575786


        Paired t-test

data:  LR by Shoe
t = 2.9698, df = 13, p-value = 0.01085
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
  2.116701 13.416299
sample estimates:
mean of the differences
                 7.7665


        Paired t-test
```

```
data:  IP by Shoe
t = 3.1902, df = 13, p-value = 0.0071
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 0.03654781 0.18988076
sample estimates:
mean of the differences
              0.1132143

"Low Drop vs Large Drop"

        Paired t-test

data:  DFIC by Shoe
t = -3.4058, df = 13, p-value = 0.00469
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 -4.1657649 -0.9320923
sample estimates:
mean of the differences
              -2.548929


        Paired t-test

data:  INIC by Shoe
t = -3.2527, df = 13, p-value = 0.006295
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 -2.4572737 -0.4958692
sample estimates:
mean of the differences
              -1.476571


        Paired t-test

data:  IP by Shoe
t = 2.9245, df = 13, p-value = 0.01184
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 0.0351050 0.2336093
sample estimates:
mean of the differences
              0.1343571


        Paired t-test

data:  LR by Shoe
t = 7.805, df = 13, p-value = 2.927e-06
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 16.83443 29.72057
sample estimates:
```

```
mean of the differences
                23.2775


"Traditional Drop vs Large Drop"

        Paired t-test

data:  DFIC by Shoe
t = -5.6372, df = 13, p-value = 8.102e-05
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 -2.987683 -1.332174
sample estimates:
mean of the differences
              -2.159929


        Paired t-test

data:  LR by Shoe
t = 7.9059, df = 13, p-value = 2.545e-06
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 11.27247 19.74953
sample estimates:
mean of the differences
                 15.511
```