KINETICS OF LOWER EXTREMITY DURING OVERGROUND HILL RUNNING IN FOREFOOT STRIKE RUNNERS

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The aim of this study was to compare the lower extremity kinetics of forefoot strike (FFS) level ground running to those occurring during uphill and downhill running. Habitual FFS runners (n=5) completed overground trials during uphill and downhill conditions on a ramp set to 6˚ and 9˚ and during level running at a speed of 3 m/s ± 5%. Peak ground reaction forces (GRF), joint moment, and power absorption of lower limb were analyzed. GRF showed an absent impact transient in all conditions. Peak power absorptions did not change significantly during any of the hill running conditions compared to the level trial. Knee extension moment increased only during the 9˚ downhill condition. The findings suggest that running on hills with a FFS is characterized by an absent impact transient that is thought as a sign of less impact on the lower limb and may help to reduce injury risk.

KEY WORDS: moments, powers, incline, decline, slope.

INTRODUCTION: Forefoot strike (FFS) running is a landing strategy used by runners where they land with the centre of pressure located in the anterior third of their foot (Cavanagh & Lafortune, 1980). A number of studies have demonstrated that FFS running results in distinct lower extremity mechanics compared to rearfoot strike (RFS) running (Williams, Green, & Wurzinger, 2012). When running with a FFS, there is significant reduction of the impact peak of the vertical ground reaction force (GRF) and a subsequent reduction in power absorption at the knee joint. These changes can likely contribute to a reduction in the high mechanical stresses which occur during repetitive strides (Williams et al., 2012).
Slope running is common and can change GRF patterns. When running on a decline sloped treadmill there is a significant increase in GRF and knee power absorption, whereas running on an incline decreases the GRF (Gottschall & Kram, 2005). This suggests that the higher impact forces during decline running may contribute to musculoskeletal injury (Gottschall & Kram, 2005; Hreljac, Marshall, & Hume, 2000). Currently understanding to FFS running biomechanics is limited to level or sloped treadmill running, with little information in overground hill running. Biomechanics differences between level ground and treadmill running have been well documented. Differences do arise between RFS runners who run overground versus on a treadmill during level conditions. Therefore it is unknown that, so differences should exist when comparing FFS runners during hill running (Buczek & Cavanagh, 1990; Gottschall & Kram, 2005). The purpose of this study was to compare the lower extremity kinetics of level FFS running to those occurring during overground uphill and downhill conditions. The authors hypothesize that compared to the level condition: 1. Peak vertical GRF will be decreased during uphill conditions and increased during downhill conditions, 2. Peak moments and power absorptions of the lower extremity will be decreased during uphill conditions and increased during downhill conditions, 3. The knee joint will have the greatest power absorption during all conditions and 4. Total lower extremity power absorption will be decreased during uphill conditions and increased during the downhill conditions.

METHODS: Recreational runners were recruited from the Ottawa area. The study included a total of 5 male runners (age 26.8 ± 6.9 years, mass 75.8 ± 8.3 kg, height 1.80 ± 0.05 m, weekly running distance 39.0 ± 13.4 km) who had no lower extremity injuries 6 months prior to testing. All subjects ran with a FFS pattern when wearing shoes, which was confirmed with strike index measurements (Cavanagh & Lafortune, 1980). Each subject gave their written informed consent for participation in the study, which was approved by the University of Ottawa Ethics Committee.

Subjects eligible for participation completed two sessions. During the first session, dominant leg was determined using 3 tests: balance recovery, step-up, and kicking leg. The leg used for at least two of the three tests was determined to be the dominant leg. Once dominant leg was established, landing pattern was assessed using the strike index method as participants ran down an 8m runway. After confirming their landing pattern as FFS, participants were given a pair of Merrell Vapor Glove minimalist running shoes to wear during their training for a week. These are a neutral, zero drop shoe with a stack height of 6 mm.

For the second session, participants returned to the lab 1 week after the preliminary session. The participants were outfitted in 45 reflective markers which were placed according to a modified Plug in Gait Model. The participants randomly completed 5 trials of 5 different conditions: level, uphill 6˚, downhill 6˚, uphill 9˚ and downhill 9˚. Uphill and downhill trials were collected using a custom built 3 meter ramp which had a 5m deck at the top. Speed was controlled at 3.0 m/s (± 5%) and was verified using photocells 3 meters apart. Kinematic data were collected at 400 Hz with a 10-camera Vicon motion analysis system (Vicon Motion Systems, Oxford, UK). Three-dimensional coordinates for each marker were reconstructed and filtered using a Woltring 15 MSE filter. Two force plates (Kistler Instruments Corp, Winterhur, Switzerland) mounted in the floor and in the ramp recorded GRF at a sampling frequency of 1000 Hz. The GRF data was filtered at 20 Hz with a fourth-order zero lag Butterworth filter.

Trunk, pelvis, thigh, shank, and foot segments were created. All data were cropped and time normalized to 100% stance phase. Lower extremity joint moments and powers were with the inverse dynamics model using Matlab R2013a and then analyzed using SPSS Statistics 20. Kinetic values of the lower extremity were compared between the 5 conditions using a one-way mixed measures ANOVA with α set at 0.05. A Bonferroni post-hoc comparison was used to determine specific differences.

RESULTS: There were insignificant differences in peak vertical GRF for all uphill and downhill trials compared to the level trial. All conditions had an absent impact transient (Figure 1). Peak braking forces decreased 38% and 45% in the uphill 6˚ and 9˚ conditions, respectively, compared to the level condition. While peak braking forces increased by 55% and 76% in the downhill 6˚ and 9˚ conditions, respectively, compared to the level condition (Table 1). Peak propulsive forces increased by 21% and decreased by 62% in the uphill 9˚ and downhill 9˚ conditions, respectively, compared to the level condition (Table 1).

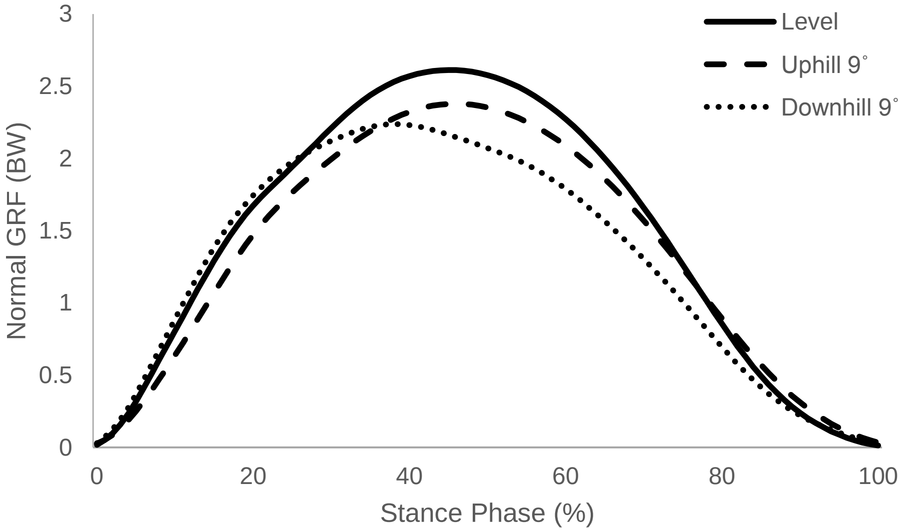

Figure 1: Normal ground reaction forces (BW) of the level, uphill 9˚ and downhill 9˚ conditions in habitual FFS (n=5) runners running overground at a speed of 3 m/s ± 5%.

Compared to level running, peak power absorptions at the hip, knee and ankle did not show significance for any of our test conditions. Power generation at the ankle joint decreased by 62% in the 9˚ downhill condition compared to the level condition (Table 1).

Peak moments at the hip and ankle joints were insignificant for all uphill and downhill trials compared to the level trial. The knee extension moment during 9˚ downhill running was significantly ($p < 0.05$) greater compared to all other conditions. Knee valgus moments were significantly ($p < 0.05$) less for both uphill conditions compared to running downhill at 9˚ (Table 1).

Table 1

Kinetic data (mean ± SD) at the hip, knee and ankle joint during level, uphill (6˚ and 9˚) and downhill (-6˚ and -9˚) conditions.

	Level	**+6˚**	**+9˚**	**-6˚**	**-9˚**
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
GRF (BW)					
Active Peak	2.61 ± 0.28	2.26 ± 0.66	2.40 ± 0.27	2.14 ± 0.63	2.29 ± 0.31
Peak Braking Force	0.29 ± 0.05†	0.18 ± 0.10*†	0.16 ± 0.14*†	0.45 ± 0.05*	0.51 ± 0.11*
Peak Propulsion Force	0.34 ± 0.06†	0.39 ± 0.06†	0.41 ± 0.08*†	0.18 ± 0.05*	0.13 ± 0.05*
Peak Powers (W/kg)					
Hip Abs	1.00 ± 0.57	1.08 ± 1.53	1.22 ± 1.68	0.89 ± 0.68	0.97 ± 0.77
Hip Gen	3.29 ± 0.81	2.97 ± 1.77	2.78 ± 0.96	1.62 ± 0.85*	2.07 ± 2.23
Knee Abs	2.85 ± 1.11	1.97 ± 0.82	2.05 ± 0.52	2.25 ± 1.22	2.23 ± 0.67
Knee Gen	1.76 ± 0.81	1.52 ± 1.04	1.20 ± 0.71	1.16 ± 0.67	1.20 ± 0.54
Ankle Abs	2.97 ± 1.50	2.25 ± 1.32	1.88 ± 1.11	3.01 ± 1.82	3.38 ± 1.75
Ankle Gen	3.60 ± 1.86†	3.11 ± 1.99†	2.99 ± 1.92	1.87 ± 1.23	1.34 ± 0.83*
Peak Moments (Nm/kg)					
Hip Flex	0.85 ± 0.21	0.90 ± 0.74	1.56 ± 1.49	0.84 ± 0.26	0.95 ± 0.27
Hip Ext	1.63 ± 0.57	1.72 ± 0.46	1.53 ± 0.55	1.41 ± 0.49	3.03 ± 3.38
Hip Add	0.78 ± 0.73	0.67 ± 0.75	0.83 ± 0.62	0.59 ± 0.39	0.61 ± 0.42
Hip Abd	1.06 ± 0.43	1.20 ± 0.52	1.11 ± 0.62	1.22 ± 0.24	1.34 ± 0.32
Knee Ext	0.58 ± 0.09†	0.73 ± 0.13†	0.70 ± 0.09†	0.96 ± 0.92†	1.97 ± 1.88*
Knee Flex	1.71 ± 0.87	1.74 ± 1.39	2.52 ± 2.22	1.59 ± 0.80	1.72 ± 0.88
Knee Varus	0.22 ± 0.12	0.17 ± 0.12	0.29 ± 0.25	0.16 ± 0.07	0.17 ± 0.04
Knee Valgus	0.73 ± 0.25	0.58 ± 0.26†	0.63 ± 0.34†	1.04 ± 0.73	1.38 ± 1.07
Ankle DF	0.05 ± 0.01	0.04 ± 0.02	0.04 ± 0.02	0.06 ± 0.05	0.05 ± 0.01
Ankle PF	2.38 ± 1.16	2.21 ± 1.12	2.21 ± 1.13	2.19 ± 1.23	2.52 ± 1.53
Ankle Add	0.11 ± 0.09	0.13 ± 0.08	0.13 ± 0.11	0.25 ± 0.33	0.45 ± 0.69
Ankle Abd	0.15 ± 0.14	0.07 ± 0.06	0.14 ± 0.17	0.19 ± 0.28	0.11 ± 0.09

*, $p < 0.05$, vs level trial; †, $p < 0.05$ vs 9˚ downhill condition.

DISCUSSION: The normal impact force peaks did not change significantly during downhill or uphill running compared to level running. This agrees with the findings of Gottschall & Kram who conducted a study on a wedged treadmill with same slope setting as ours (2005). Our runners had an absent impact transient in all conditions, opposite of their study which had an impact transient in all conditions. This could be due to landing pattern difference, our runners using a FFS compared to a RFS used by the runners in Gottschall & Kram's study (2005). Downhill running results in larger impact forces that are associated with greater instances of overuse injuries. Thus downhill running may lead to musculoskeletal injury (Gottschall & Kram, 2005; Hreljac et al., 2000). The absent impact transient during all hill conditions suggests that FFS running may be an effective strategy to use when approaching hills.

In this study parallel braking force peaks were greater during downhill conditions whereas propulsive force peaks were greater during uphill conditions, similar to Gottschall & Kram's findings (2005). This shows an increased metabolic cost of uphill running where the propulsive forces dominate from concentric muscle contractions. Downhill running resulted in a lower metabolic cost from the negative work of muscles contracting eccentrically (Abbott et al., 1952).

Previous studies have shown no differences in joint moments when running on incline or decline surfaces between ± 5˚ compared to level running (Buczek & Cavanagh, 1990). However our study showed that knee extension moment was significantly ($p < 0.05$) increased when running downhill at 9˚ and knee valgus moments were significantly less during both uphill conditions compared to the downhill 9˚ condition.

We did find a slight increase in ankle power absorption during downhill conditions and a slight decrease in the uphill conditions. However none of the conditions reached significance. Knee power absorption decreased for all conditions compared to the level condition, while hip power absorption increased during the uphill conditions and decreased during the downhill conditions. This goes against previous findings which showed an increase in power absorption at the knee and ankle joints during downhill running, with the largest increase occurring at the knee joint (Buczek & Cavanagh, 1990). The subjects in their study ran with a RFS, whereas ours landed with a FFS. FFS runners utilize a different landing strategy that does not involve the knees as much in absorbing the power. Power is absorbed by the triceps surae group and through the hip joint. FFS runners have also been shown to have decreased overall power absorption compared to RFS runners (Williams et al., 2012). With the decrease in knee power absorption for all hill conditions, FFS running may be a beneficial strategy for all runners to utilize when approaching hills, especially downhill running, which has been shown to have the greatest risk of injury (Hreljac et al., 2000).

This study was limited to using only a small ($n = 5$) group of FFS runners. Research is still in progress and future results will include a RFS group of runners and increase the number in each group.

CONCLUSION: Preliminary findings of this studied identified that FFS runners do not have an impact transient or increase their power absorption significantly at any of the lower extremity joints during uphill or downhill running. The findings suggest that running on hills with a FFS is characterized by an absent impact transient that is thought as a sign of less impact on the lower limb and may help to reduce injury risk. In order to have better understanding to lower limb kinetics of FFS running on hills an enlarged sample size and inclusion of RFS runners are needed in the study.

REFERENCES:

Abbot, B.C., Bigland, B., & Richie, J.M. (1952). The physiological cost of negative work. *Journal of Physiology*, 117, 280-390.

Buczek, F.L., & Cavanagh, P.R. (1990). Stance phase knee and ankle kinematics and kinetics during level and downhill running. *Medicine and Science in Sports and Exercise*, 22(5), 669-677.

Cavanagh, P.R., & Lafortune, M. (1980). Ground reaction forces in distance running. *Journal of Biomechanics*, 13(5), 397-406.

Gottschall, J.S., & Kram, R. (2005). Ground reaction forces during downhill and uphill running. *Journal of Biomechanics*, 38(3), 445-452.

Hreljac, A., Marshall, R. & Hume, P. (2000). Evaluation of lower extremity overuse injury potential in runners. *Medicine and Science in Sports and Exercise*, 32(9), 1635-1641.

Williams, D.S., Green, D.H. & Wurzinger, B. (2012). Changes in lower extremity movement and power absorption during forefoot striking and barefoot running. *International Journal of Sports Physical Therapy*, 7(5), 525-532.

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