THE EFFECT OF CAMBER ON WOMEN'S RUNNING KINEMATICS

Katelyn Campbell[1], Emily Harl[1], Ben Seedorf[2], & Michael Bird[1]

Health & Exercise Sciences Department, Truman State University, Kirksville, MO, USA[1]
Northeast Therapy Services, Kirksville, MO, USA[2]

The purpose of this study was to determine the effect of cambered surface on gait parameters and pelvis, hip, and knee kinematics of experienced road-runners. Thirty-one women ran at a matched, preferred pace on a 0° (flat), 3.5°, and 7° cambered treadmill with the right side raised. Step width (SW), step time (ST), and cadence and selected joint angles at footstrike (FS) and midstance (MS) were evaluated. No significant differences were found between conditions and extremity in SW, ST, cadence, and max knee flexion during stance. Pelvis frontal ROM and hip adduction at MS were greater on the right with hip adduction having an interaction effect between camber and extremity. Hip flexion at FS was greater at the 7° than 3.5° camber. This study identified significant kinematic changes while running on cambered surfaces which may potentially predispose a runner to injury.

KEYWORDS: camber, women, runner, gait, kinematics.

INTRODUCTION: Training on roads is a widespread practice among long-distance runners. Although roads are typically more accessible than alternative surfaces, the common design characteristics may influence gait kinematics. Roads are engineered to facilitate the drainage of water laterally through its cross-slope structure, or camber. Because runners are advised to face traffic, the cambered surface forces the right foot to land slightly uphill from the left foot for most strides. The difference in footstrike (FS) elevation may lead to compensation by the runner and contribute to injury risk, especially if a large volume of their training is on this terrain.

Biomechanical predictors of lower extremity running injuries on level surfaces have been well researched. Increased peak hip adduction and knee internal rotation have been linked to injury risk (Aderem & Louw, 2015). Excessive lower extremity length inequality may also influence risk, although there is limited evidence and further research is necessary (Messier & Pittala, 1988; Van Gent, et. al, 2006). The role of cambered surfaces on running mechanics is potentially valuable, because the lateral incline could reduce or amplify these intrinsic injury factors. However, there is limited research on this topic and only a few studies have been conducted with a focus on lower limb joint angles and gait parameters. Gehlsen, et al. (1989) identified a decreased knee joint range of motion on the high side and hypothesized the uphill knee joint to be compensated with increased valgus when the subtalar joint cannot adjust to the magnitude of camber. In addition, O'Connor & Hamill (2002) reported significantly greater maximum pronation and pronation velocity of the uphill side and lower values of the downhill side. These ankle motions are associated with increased strain on the iliotibial (IT) band and peroneals of the left leg and on the pes anserine and posterior tibialis tendons of the right leg when running against traffic. Similarly, Meissner & Pittala (1988) found that the IT band friction syndrome injury group ran on cambered roads more often than the non-injured group which suggests that training surface may have an impact on injury risk. None of these previous studies specifically examined hip and pelvis joint angles and kinematics in the frontal plane.

Although injuries are multifactorial in nature, understanding the relationship between camber and a runner's mechanics could provide insight into injury development while running on cambered surfaces. Therefore, the purpose of this study was to determine the effects of varying degrees of camber on gait parameters and pelvis, hip, and knee kinematics during the stance phase of running. Variables chosen represent possible changes in frontal plane characteristics or extremity asymmetry that may change due to camber and influence injury risk.

METHODS: Thirty-one experienced women road runners (22.8 ± 5.4 years, 59.9 ± 7.7 kg, 166.6 ± 6.3 cm, and 28.0 ± 11.2 miles per week) recruited from local road races participated in this study. They had no history of lower extremity injuries in the past six months and were familiar with running on treadmills. To simulate running against traffic, a wood framework was constructed to raise the right side of the treadmill 3.5° or 7°. The 7° camber is higher than the recommended camber for high-speed roadways (2.3°-3.4°), but runners often train on secondary roads which may have a larger degree of camber. Additionally, these values are in the range of previous cambered running studies (Dixon, et al., 2011: 10°; Gehlsen, 1989: 5° and 10°; O'Connor and Hamill, 2002: 3°; Sussman, et al., 2001: 2.5° and 5°; & Unfried, et al., 2013: 5-7°).

Prior to running, single reflective markers were attached to the lower extremity placed bilaterally at the ASIS, PSIS, thigh, knee, shank, ankle, heel, and toe. The participants ran at a comfortable pace typical of training on the treadmill at 0° (flat), 3.5°, and 7° of camber. They were given a one-minute familiarization period on each condition before data were collected and a one-minute rest period between conditions. A Vicon Nexus 3D motion analysis system with 10 cameras was used to collect and process data. Variables included basic gait kinematics such as step width (SW), step time (ST), and cadence, as well as pelvis, hip, and knee joint angles at FS or midstance (MS). Values for each variable were averages of eight consecutive strides and the contralateral and ipsilateral data was compared across the three conditions. The data were analyzed using a 2x3 repeated-measures ANOVA with SPSS software which also provided partial-eta squared effect sizes. If a significant main effect for condition was found (alpha =0.05), the post-hoc analysis used a Bonferroni correction.

RESULTS: The cambered surface had no significant effect on gait parameters (see Table 1). However, some differences were found for lower extremity angles (see Table 2 and Figure 1).

Table 1: Means (±SD) of basic gait kinematics by extremity and condition.

Variable	Right			Left		
	Flat	Low	High	Flat	Low	High
Step Width (m)	0.07±0.03	0.07±0.03	0.07±0.03	0.07±0.03	0.07±0.03	0.07±0.03
Step Time (s)	0.38±0.03	0.37±0.02	0.37±0.03	0.36±0.02	0.37±0.02	0.37±0.02
Cadence (steps/min)	166±13.5	170±15.0	171±15.7	166±12.1	165±10.8	166±15.0

Table 2: Means (±SD) of the pelvis, hip, and knee angles (°) by plane, event, extremity, and condition. ROM was FS-MS; [a] significant difference between extremities; [b] high condition different than low condition; [c] significant difference between conditions.

Joint	Plane	Event	Right			Left		
			Flat	Low	High	Flat	Low	High
Pelvis	[a] Frontal	ROM	2.8±1.9	2.9±1.7	3.1±2.1	1.6±2.4	2.2±1.4	2.2±1.3
Hip	[b] Sagittal	FS	34.8±6.6	35.1±6.3	36.1±6.4	34.9±6.2	34.3±7.0	34.9±6.7
Knee	[c] Sagittal	FS	18.9±6.5	18.1±7.6	18.8±6.6	16.5±5.9	15.4 ±6.0	15.2±5.5
		Max	43.1±5.7	43.2±5.7	42.9±6.0	42.0±5.1	42.1±4.9	41.8±5.0

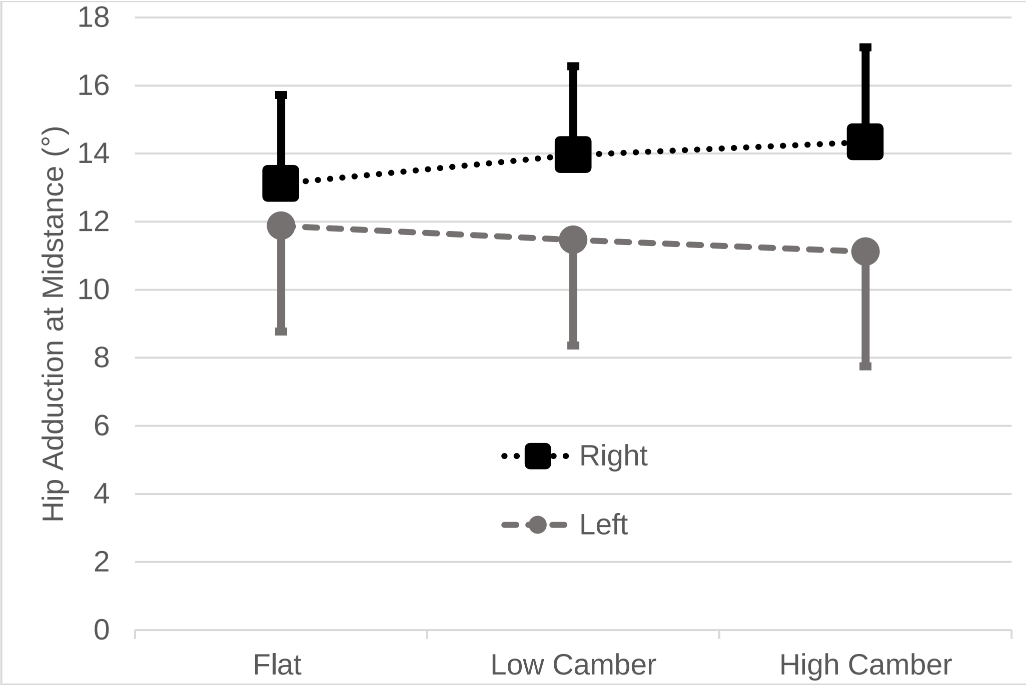

Figure 1: Hip adduction at midstance. Significant differences between extremities and a significant interaction between extremity and condition.

DISCUSSION: The goal of this study was to evaluate the effect of camber on chosen kinematic variables. No significant differences in SW, ST, or cadence between conditions and extremity were found. The consistent SW across all conditions and sides may suggest that camber has little influence on subject's balance (base of support being unchanged), yet how COM may have changed with camber was not measured. Step time and cadence not changing across conditions may indicate that subjects chose other changes in gait at consistent speed to accommodate the different conditions. Camber did not impact basic gait characteristics of the left and right extremities for these participants. Perhaps symmetry mattered for basic gait variables, but the pelvis, hip, and knee adjusted.

While running is primarily a sagittal plane activity, some frontal plane motions were considered because camber changes are in that plane. There were several adjustments at the pelvis and hip in the frontal plane. The right pelvis frontal ROM was significantly greater than the left across all conditions ($p=0.030$, $ES=0.08$). Because there was no interaction effect and the ROM was still larger when the subjects ran on a flat surface, this difference could be attributed to leg dominance or pre-existing movement pattern rather than an effect of the camber. Additionally, the hip adduction angle at MS of the right extremity was significantly greater than the left ($p=0.003$, $ES=0.14$). As the degree of camber increased, the right and left hip adduction angles diverged as shown by the significant interaction effect ($p=0.001$, $ES=0.3$). While the effect sizes were small, the influence of these changes over many miles and days may lead to a greater risk of injury given the known association between increased peak hip adduction angle and injury on flat surfaces (Aderem & Louw, 2015).

The pattern of changes in hip adduction and pelvic frontal angles coupled with a consistent SW may have potential clinical implications for knee, hip, and low back. The average SW was 13 cm which relates to roughly an 8 mm and 16 mm difference of landing height between the limbs at 3.5° and 7°, respectively. Perhaps runners adapt to this difference in a variety of ways through the pelvis, hip, knee, and foot. These adaptations may affect the level of stress and strain on these joints. Changes in foot mechanics were not specifically assessed in this study, but compensatory pronation on the high side has been identified (O'Connor & Hamill, 2002). Knee flexion angle at foot strike has been shown to increase with camber (Gehlsen, 1989) which would put the IT band closer to a position to come in contact with the lateral epicondyle. An adjustment of increased hip adduction on the high side relative to the low side may have clinical relevance. Increased hip adduction during running has been implicated in runners with patellofemoral pain syndrome and ITBFS. Factors affecting running mechanics including hip and trunk strength and movement pattern training have been an area of increased research over the past several years. Based on these results, the extrinsic factor of running on a camber may affect running mechanics and, therefore, may predispose runners to injury.

The cambered surface also influenced adjustments in the sagittal plane. At FS, there was significantly greater hip flexion during the high camber condition than low camber condition ($p=0.035$, ES=0.06). There was a significant main effect for knee flexion at FS ($p=0.05$, ES=0.05), but no differences were found in the post-hoc analysis. Because some subjects seemed to alter hip flexion and others knee flexion, it is possible that at submaximal speeds, subjects may address camber at FS by changing any combination of hip and knee flexion to accommodate the differences in foot height between the right and left sides. While these adjustments are clear at FS, the maximum knee angles achieved during the stance phase may reflect the need to use a ROM similar to flat running due to the need to absorb forces of impact and provide adequate ROM for propulsion.

CONCLUSION: Women running on a cambered surface did not change basic mechanics such as SW, ST, or cadence when running speed remained constant. Adjustments were primarily made to the frontal plane mechanics of the pelvis and hip; sagittal plane mechanics were less clear as subjects were able to use different adjustments depending on her preference. It is possible that acute changes when running on a cambered surface for a long time or distance will require subjects to modify these characteristics more often than on a flat surface. Further, with this methodology other important factors, such as fatigue, were not accounted for. When runners are fatigued from running on previous days or taxed by a current long run, their ability to maintain similar form may be more influenced by camber. Future research may examine cambered gait changes when fatigued acutely or cumulatively over time, especially at the pelvis. Independent of fatigue, how these small changes influence injury risk over time will need to be determined but understanding the kinematic adjustments on camber is a valuable step toward injury prevention and treatment.

REFERENCES

Aderem, J., & Louw, Q. A. (2015). Biomechanical risk factors associated with iliotibial band syndrome in runners: a systematic review. *BMC Musculoskeletal Disorders*, *16*(1), 356.

Dixon, P. C., Tisseyre, M., Damavandi, M., & Pearsall, D. J. (2011). Inter-segment foot kinematics during cross-slope running. *Gait & Posture*, *33*(4), 640-644.

Gehlsen, G. M., Stewart, L. B., Van, C. N., & Bratz, J. S. (1989). Knee kinematics: the effects of running on cambers. *Medicine and Science in Sports and Exercise*, *21*(4), 463-466.

Messier, S. P., & Pittala, K. A. (1988). Etiologic factors associated with selected running injuries. *Medicine and Science in Sports and Exercise*, *20*(5), 501-505.

O'Connor, K. M., & Hamill, J. (2002). Does running on a cambered road predispose a runner to injury? *Journal of Applied Biomechanics*, *18*(1), 3-14.

Sussman, D., Walker, M., Tamburello, M., VanLunen, B., Dowling, E., Atkinson, R., ... & VanSchoyck, K. (2001). The effect of road camber on running kinematics. In J. Blackwell (Ed.) *ISBS-Conference Proceedings Archive* (pp. 109-112).

Unfried, B., Aguinaldo, A., & Cipriani, D. (2013). What is the influence of cambered running surface on lower extremity muscle activity? *Journal of Applied Biomechanics*, *29*(4), 421-427.

ACKNOWLEDGEMENTS: Katelyn Campbell and Emily Harl equally share first author credit.